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Lives Saved by Vehicle Safety Technologies and Associated Federal Motor Vehicle Safety Standards, 1960 to 2012

Passenger Cars and LTVs

With Reviews of 26 FMVSS and the Effectiveness Of Their Associated Safety Technologies in Reducing Fatalities, Injuries, and Crashes

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16. Abstract

NHTSA began in 1975 to evaluate the effectiveness of vehicle safety technologies associated with the Federal Motor Vehicle Safety Standards. By June 2014, NHTSA had evaluated the effectiveness of virtually all the life-saving technologies introduced in passenger cars, pickup trucks, SUVs, and vans from about 1960 up through about 2010. A statistical model estimates the number of lives saved from 1960 to 2012 by the combination of these life-saving technologies. Fatality Analysis Reporting System (FARS) data for 1975 to 2012 documents the actual crash fatalities in vehicles that, especially in recent years, include many safety technologies. Using NHTSA's published effectiveness estimates, the model estimates how many people would have died if the vehicles had not been equipped with any of the safety technologies. In addition to equipment compliant with specific FMVSS in effect at that time, the model tallies lives saved by installations in advance of the FMVSS, back to 1960, and by non-compulsory improvements, such as pretensioners and load limiters for seat belts. FARS data has been available since 1975, but an extension of the model allows estimates of lives saved in 1960 to 1974.

A previous NHTSA study using the same methods estimated that vehicle safety technologies had saved 328,551 lives from 1960 through 2002. The agency now estimates 613,501 lives saved from 1960 through 2012. The annual number of lives saved grew from 115 in 1960, when a small number of people used lap belts, to 27,621 in 2012, when most cars and LTVs were equipped with numerous modern safety technologies and belt use on the road achieved 86 percent.

17. Key Words

FARS; statistical analysis; evaluation; benefits; effectiveness; fatality reduction; injury reduction; crashworthiness; crash avoidance

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LIST OF ABBREVIATIONS

ABS	antilock brake system
ACIR	Automotive Crash Injury Research, a crash data file of the 1950s and 1960s
ACTS	Automotive Coalition for Traffic Safety (before 1999, American Coalition for Traffic Safety)
AIS	abbreviated injury scale; the levels of this scale are: 0 = uninjured, 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical, and 6 = maximum
AMC	American Motors Corporation
ANPRM	advance notice of proposed rulemaking
ANSI	American National Standards Institute
ATD	anthropomorphic test device (dummy)
BMW	Bayerische Motoren Werke
CATMOD	categorical models procedure in SAS
CDS	Crashworthiness Data System of NASS
CFR	Code of Federal Regulations; up-to-date text of NHTSA regulations may be downloaded from the electronic CFR, Title 49, www.ecfr.gov/cgi-bin/text-idx?c=ecfr&tpl=/ecfrbrowse/Title49/49tab_02.tpl. Regulations other than FMVSS are referenced as Part numbers (e.g., Part 563, "Event data recorders"). FMVSS are referenced as Part 571 followed by the FMVSS number (e.g., Part 571.103 = FMVSS No. 103, "Windshield defrosting and defogging systems")
CHMSL	center high-mounted stop lamp
CMVSS	Canadian motor vehicle safety standard
CPU	central processing unit
CRASH	Calspan reconstruction of accident speeds on the highway
CUV	crossover utility vehicle
CY	calendar year
DMV	department of motor vehicles

DOF	direction of force (a variable in CDS and other crash databases)
DRL	daytime running lights
ECE	Economic Commission for Europe
EMS	emergency medical services
ESC	electronic stability control
FARS	Fatality Analysis Reporting System (a census of fatal crashes in the United States since 1975)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMCSR	Federal Motor Carrier Safety Regulation
FMH	free-motion headform for testing upper interior components
FMVSS	Federal Motor Vehicle Safety Standard
GAD	general area of damage (a variable in CDS and other crash databases)
GES	General Estimates System of NASS
GM	General Motors
GSA	General Services Administration of the Federal government
GTR	global technical regulation
GVWR	gross vehicle weight rating (specified by the manufacturer, equals the vehicle's curb weight plus maximum recommended loading)
HIC	head injury criterion
HPR	high penetration resistant windshield
HSL	Highway Safety Literature, an on-line literature database that is a subfile of the automated Transportation Research Information Service (TRIS) file, accessible at trid.trb.org.
ICC	Interstate Commerce Commission
ICD-10	International Classification of Diseases, 10th revision
IIHS	Insurance Institute for Highway Safety

LATCH	lower anchors and tethers for children
LED	light-emitting diode
LTV	light trucks and vans (includes pickup trucks, SUVs, minivans and full-sized vans)
MCOD	multiple cause of death file, a supplement to FARS since 1987, listing causes of death from the occupant's death certificate
MDAI	multidisciplinary accident investigations (a file of in-depth crash investigations conducted by NHTSA and others, 1967-78)
MDB	moving deformable barrier
MVMA2D	Motor Vehicle Manufacturers' Association's 2-dimensional computer simulation of the occupant's motion in a frontal crash
MY	model year
NASS	National Automotive Sampling System (a probability sample of police-reported crashes in the United States since 1979, investigated in detail)
NCAP	New Car Assessment Program (consumer information supplied by NHTSA on the safety of new cars and LTVs, based on test results, since 1979)
NCSA	National Center for Statistics and Analysis, NHTSA
NCSS	National Crash Severity Study (a probability sample of police-reported towaway crashes in seven multicounty areas, 1977-79, investigated in detail)
NHTSA	National Highway Traffic Safety Administration
NMVCCS	National Motor Vehicle Crash Causation Study
NOPUS	National Occupant Protection Use Survey (statistics for the United States, since 1994, from a national observational survey based on a probability sample)
NPRM	notice of proposed rulemaking
NTSB	National Transportation Safety Board
RF	right front
RSEP	Restraint Systems Evaluation Project (a probability sample of police-reported towaway crashes involvements of model year 1973-75 cars in five urban or multicounty areas, 1974-75, investigated in detail)

RWAL	rear-wheel antilock brake system
SAE	Society of Automotive Engineers
SAS	statistical and database management software produced by SAS Institute, Inc.
SCI	Special Crash Investigations, NHTSA's National Center for Statistics and Analysis
SID	side impact dummy
SSF	static stability factor (half of the vehicle's track width divided by the height of its center of gravity)
SUV	sport utility vehicle
TPMS	tire pressure monitoring system
TREAD Act	Transportation Recall Enhancement, Accountability, and Documentation Act
TTI	thoracic trauma index
TTI(d)	thoracic trauma index for the dummy in a side-impact test
TTMA	Truck Trailer Manufacturers Association
UMTRI	University of Michigan Transportation Research Institute
VIN	Vehicle Identification Number
VMT	vehicle miles of travel
VW	Volkswagen

A REVOLUTION IN SAFETY AND HEALTH

For occupants of cars and LTVs (pickup trucks, SUVs, and vans), the fatality rate per vehicle mile of travel dropped by an astounding 81 percent from 1960 to 2012. In CY 1960, 28,183 drivers and passengers died in 662 billion VMT. By 2012, only 21,696 occupants died in 2,653 billion VMT. The green line and squares in Figure A track the VMT fatality rate for car/LTV occupants, indexed to 100 in 1960, as it descends to 19 by 2012.

At least four developments in technology and social science can take credit for some of the reduction:

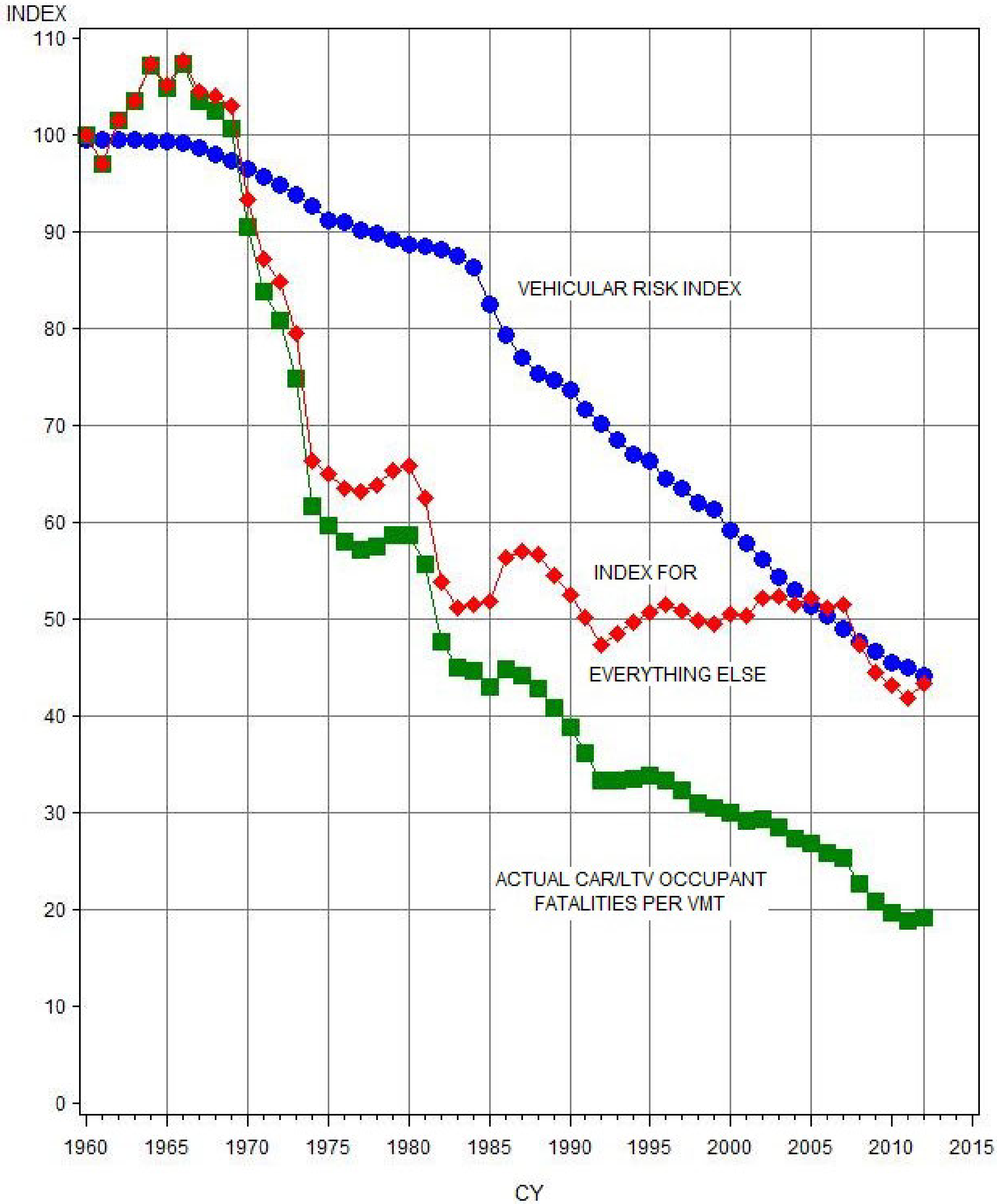
- Vehicle safety technologies such as seat belts, air bags, and electronic stability control (ESC), combined with programs to increase the use of belts and other safety equipment;
- Safer roads, including major new infrastructure such as the Interstate Highway System and gradual improvements to existing roads, such as guardrails;
- Behavioral programs to make people drive more safely; above all, laws and programs to abate drunk driving; and
- Better medicine: quicker arrival of EMS, more effective treatment in transport and at the trauma center, and any developments in surgery and medicine that made injuries more survivable than they used to be.

In addition, the past 53 years have witnessed important demographic and geographic trends that would likely have lowered the VMT fatality rate substantially even without advances in science: a shrinking population of young drivers (who have high fatality rates), a much larger share of VMT for female drivers (who have low fatality rates, specifically, a low incidence of drunk driving), and population movement from rural to metropolitan areas (where fatality risk per mile is lower). At times however, demographic and geographic trends have worked in the opposite direction, such as a growing proportion of older drivers (who have high fatality rates) and movement within metropolitan areas from central cities to more sparsely populated outer suburbs.[1]

This report focuses exclusively on the fatality reduction attributable to vehicle safety technologies introduced since 1956 (when factory-installed lap belts first became optionally available on some cars) and, from 1968 onwards, largely associated with the Federal Motor Vehicle Safety Standards and/or related programs such as safety ratings. It develops a **vehicular fatality-risk index** by calendar year, tracked by the blue circles in Figure A, that measures how much safer the average car or LTV on the road has become relative to a car or LTV on the road in 1955.

[1] The chapter titled “Car/LTV occupant fatalities per 100,000,000 VMT” in Part 2 of this report presents additional discussion, including references, of factors (other than vehicle safety technologies) that influenced fatality rates between 1960 and 2012.

FIGURE A: FATALITY-RISK INDICES BY CALENDAR YEAR (1960 = 100)
FOR CAR AND LTV OCCUPANTS



The index stayed essentially unchanged from 1955 (100) to 1960 (99.6), but it had dropped to 44 by 2012. In other words, this report estimates that the fatality risk in the average car or LTV on the road in 2012 would be 56 percent lower than in the average vehicle on the road in 1960, even given the same exposure, drivers, roadways, and medicine. The reduction includes the effects of crash avoidance technologies such as ESC, occupant protection technologies such as seat belts and air bags, and programs to increase belt use. The report estimates that vehicle safety technologies saved 613,501 lives from 1960 through 2012, including 27,621 in 2012.

The estimate of lives saved by vehicle safety technologies is not based on some kind of multivariate or time-series analysis of the VMT fatality rates over the years, but on a review of the occupant fatality cases in NHTSA's Fatality Analysis Reporting System. Since 1975, the agency has issued 82 retrospective evaluations of individual FMVSS or related vehicle technologies, based on statistical analyses of the agency's crash data files. The evaluations estimated the fatality-reducing effectiveness, if any, of each technology, relative to vehicles produced just before its introduction (i.e., incorporating every earlier technology, except the one being evaluated).

Thus, if a vehicle is equipped with multiple safety technologies, their combined fatality-reducing effectiveness is the composite of the individual effectiveness estimates. The individual (and the combined) effectiveness, of course, may depend on the type of crash (e.g., frontal air bags are most effective in directly frontal impacts), the occupant's seating position and age, and whether the occupant made correct use of the technology (e.g., buckled up). But the average composite effect of the safety technologies in cars and LTVs on the road in CY 2012 is a 56-percent reduction of fatality risk relative to what it would have been if the same vehicles had not been equipped with any of those technologies – if the vehicles had incorporated only the 1955 level of safety. This report considers every FARS fatality case in 2012 (and also in earlier years), identifies what safety technologies were in the vehicle, and estimates the hypothetical additional risk if none of those technologies had been present in the vehicle.

Figure A shows that the 56-percent reduction in the vehicular risk index from 1960 to 2012, although remarkable, does not fully explain the overall 81-percent reduction in the VMT fatality rate during those years. The red diamonds in Figure A index the effects of "everything else" – everything except the benefits of vehicle safety technologies. The "everything else" index is 43 in 2012, almost the same as the vehicular risk index (44). In other words, the net effect from 1960 to 2012 of "everything else," a 57-percent reduction, is almost identical to the 56-percent reduction attributable to vehicle safety improvement.[2] But Figure A shows the trend in the vehicular risk index differs from the trend in "everything else" in several important ways:

- The vehicular risk index tells a story of uninterrupted improvement; each year is lower than the one before it. The red diamonds zigzag up and down in response to demographic trends and transient phenomena such as an energy crisis, fuel-price increases, or economic slowdowns.

[2] The index of "everything else" is computed by dividing the VMT-rate index by the vehicular index and then multiplying by 100. For example, in 2012, the VMT-rate index is 19, the vehicular index is 44, and the index of everything else is 100 x (19/44) = 43.

- The vehicular risk index changes gradually. Even a highly effective technology such as ESC needs some years to demonstrate its efficacy, some years of lead-time before it can be built into all new vehicles, and quite a few years before vehicles with ESC replace all the older vehicles on the road that do not have it. The only abrupt change (for the better) is from 1984 to 1988, when belt-use laws in the States suddenly prompted millions of people to start buckling up the belts that had already been in their vehicles for years.

- The great reduction in the index of "everything else" is from 1965, when the large cohort of baby-boomers born just after World War II began to drive until 1975, when this cohort entered their late 20s, an age when fatal-crash involvement rates are substantially lower than in adolescence. The 1965-to-1975 decade also saw major new infrastructure such as completion of many Interstate highways, extensive urbanization, and increased numbers of women working outside the home (an influx of low-risk VMT); also, toward the end of the decade, an energy crisis and the national 55 mph speed limit. In 1975, the vehicular risk index was still above 90; even though the initial FMVSS arrived in the 1960s, there were still many pre-FMVSS vehicles on the road until the mid-1970s.

- The large, steady reduction in the vehicular risk index begins after 1984 and does not stop. By contrast, the trend in the red diamonds fluctuates in response to a range of factors affecting traffic volumes and risk. Factors reflected in the "everything else" index likely include the effects of economic slow-downs on the amount and type of highway travel as well as demographic trends such as an increase in the number of older drivers and the movement from central cities to outer suburbs where roadway travel is more frequent and speeds are higher.

In summary, from 1983 through 2012, the vehicular risk index fell from 87 to 44, while the index of "everything else" changed from 51 to 43. The effects of significant improvements in behavioral safety during this period are not clearly reflected in this analysis for several reasons. First, it is important to note that the effects of the sharp increase in seat belt use during this period, from less than 60 percent in 1984 to 86 percent in 2012, are incorporated in the vehicular risk index rather than in the "everything else" index. Second, the effects of other traffic safety behavioral improvements such as the reduction in the proportion of alcohol-impaired driving fatalities from more than 40 percent in 1984 to 31 percent in 2012 and other improvements such as safer roadways and improvements to the emergency medical system are obscured by changes in demographic and socioeconomic trends.

The reduction in car and LTV occupants' fatality risk attributable to vehicle safety technologies, totaling 56 percent from 1960 through 2012, can be put in perspective by comparing it to reductions in fatality risk from heart disease, cancer, and other diseases during those years, a time of legendary advances in pharmacology, surgery, and preventive medicine. For that purpose, it is necessary to identify a measure of risk from diseases that is intuitively comparable to the vehicular fatality-risk index and that also can be computed from available health statistics. One important characteristic of fatal crashes is that they result in **premature** death – i.e., certainly earlier than a person would have died if there had been no crash. The comparison statistic for diseases would not be all deaths, but premature deaths. To the extent that 70 years has historically been considered a full life, fatality rates from diseases among people younger than 70 might at first glance appear to be a good comparison statistic.

However, an important feature of the vehicular risk index in Figure A is that the effect of demographic and geographic trends has been filtered out; the meaning of the index is **invariant**, so to speak, from year to year. That would not be true of fatality rates from diseases for all people younger than 70. Because the birth rate generally declined after 1960, the population under 70 has included an increasing share of people over 50 and a decreasing share of young people – and that, by itself, would push fatality rates from diseases upward over time. But the fatality rates from diseases **from 60 to 70** are nearly invariant measures of risk, because the average age in that limited cohort changes little over time.[3] The rate in 1960 would be directly comparable to the rate in 2010. The fatality rates from diseases for people 60 to 70 years old make intuitively good comparison statistics with the vehicular risk index, even though the latter pertains to occupants of all ages, not just 60 to 70.

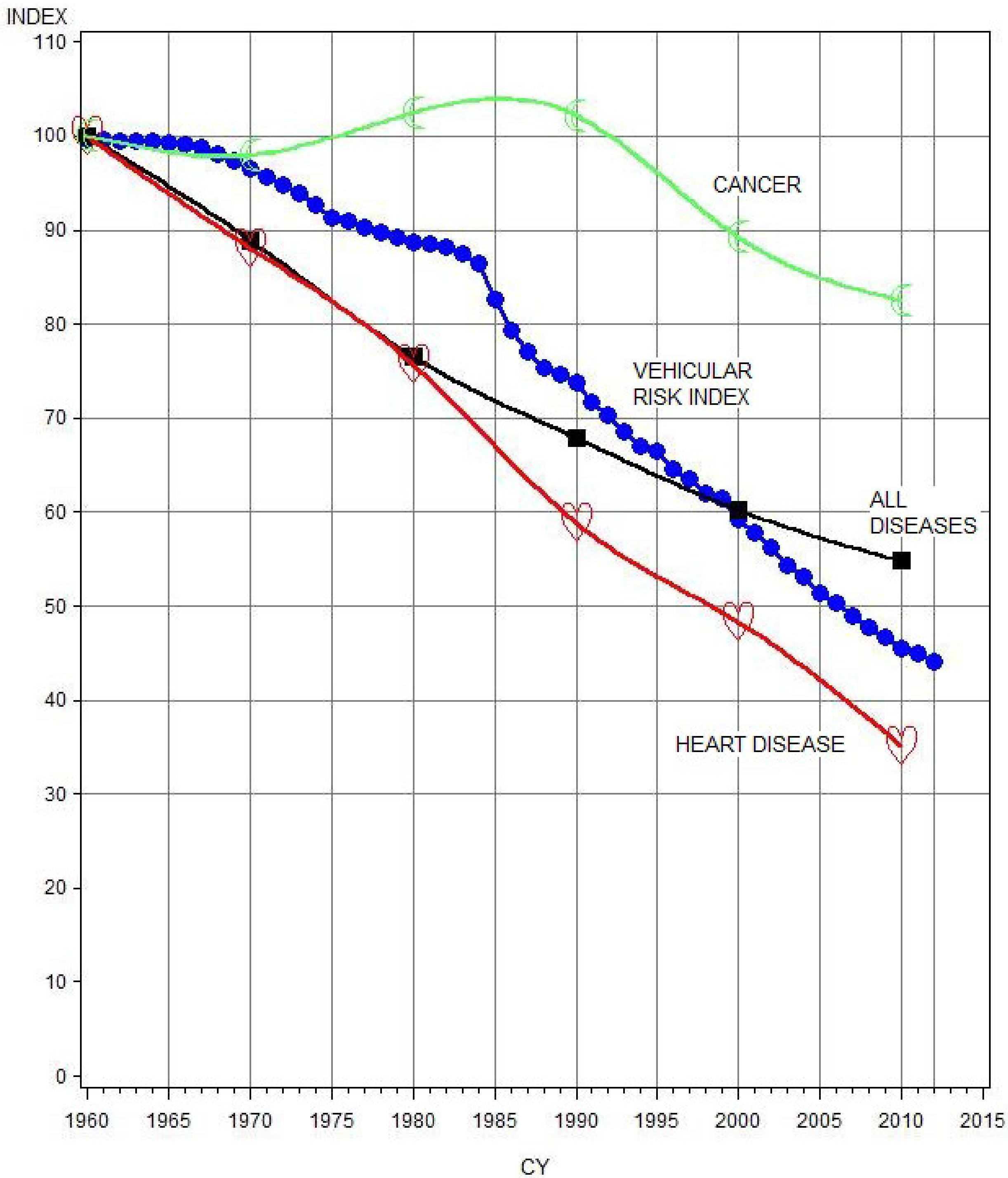
Figure B compares the vehicular fatality-risk index (unchanged from Figure A; same blue circles) to the fatality rate from all diseases for people 60 to 70 years old, indexed to 100 in 1960 (black line and squares) and specifically to the approximate rates from heart disease (red line and hearts) and cancer (green line and crescents), also indexed to 100 in 1960. The indices for diseases are estimated at 10-year intervals from 1960 to 2010 (as described in Appendix D of this report) and interpolated.

The revolution in vehicle safety compares favorably with the revolution in health over the same 50 years. The index for all diseases fell from 100 in 1960 to 55 in 2010. In other words, the likelihood of dying between 60 and 70 was 45-percent lower in 2010 than it was in 1960, a great reduction in the risk of premature death. But the vehicular fatality-risk index did even better over the whole period, dropping to 46 in 2010 and 44 by 2012. The vehicle safety technologies reduced the probability of dying in a crash by 56 percent from 1960 to 2012. Figure B shows that the risk index for all diseases initially did better than the vehicular risk index, because the first safety technologies were not widely implemented in production vehicles until the mid-to-late 1960s and then needed several years to replace the pre-FMVSS vehicles already on the road. But the vehicular index begins catching up after 1984, pulls even in about 2000, and since then has actually outpaced the reduction in fatal diseases.

Progress against heart disease has been truly extraordinary. The index was 35 in 2010, a 65-percent reduction in the risk of dying of heart disease between 60 and 70. Based on research and a deeper understanding of what causes heart disease, a remarkable combination of medicines, diet, life-style modification, and, when necessary, surgical procedures have helped prevent heart disease, while innovations in emergency care, medicine, and surgery have helped save people after heart attacks. Importantly, most of these innovations, including preventive drugs and diet, take effect relatively quickly and minimize the lag time to realize a benefit. Nevertheless, the vehicular risk index has not done badly in comparison. Since 1985, the vehicular risk index has declined in parallel to the heart disease index and mirrored the rate of decrease, year by year.

[3] The median age in the United States of all people younger than 70 was 27.2 in 1960, but a substantially older 33.6 in 2010; however the median age of people between 60 and 70 was 64.7 in 1960 and a nearly identical 64.3 in 2010 (sources: www.cdc.gov/nchs/data/statab/pop6097.pdf and www.census.gov/prod/cen2010/briefs/c2010br-03.pdf).

FIGURE B: FATALITY-RISK INDICES BY CALENDAR YEAR (1960 = 100)
VEHICULAR RISK INDEX FOR CAR AND LTV OCCUPANTS
COMPARED TO RISK INDICES OF DYING FROM DISEASES AT AGES 60 TO 70



The index for deaths from cancer between 60 and 70 has not fared nearly as well in comparison to the vehicular risk index. Cancer, of course, is a complex group of diseases and the basic research to understand it still continues. Furthermore, an important weapon in the fight against cancer is life-style modifications such as smoking cessation. But unlike heart disease, it can take many decades of not smoking or not working around hazardous substances before a payoff of lower fatality risk – longer than the lag time to install new safety technologies into most of the vehicles on the road. Figure B shows the cancer index perhaps even became slightly worse before it began to significantly improve: the index (as estimated from the data in Appendix D) went up to 102 in 1980 and 1990, possibly reflecting the long-term effects of increased numbers of new smokers in the 1940s and 1950s – people who were in their 60s by 1980 or 1990.[4] The tide turned after 1990 with a 20-point drop in the index by 2010, catching up somewhat with the index for all diseases, but still not quite keeping up with the rate of improvement in vehicle safety.

[4] Shopland, D. R., Burns, D. M., Samet, J. M., & Gritz, E. R. (eds.) (1991, October). *Strategies to Control Tobacco Use in the United States – A Blueprint for Public Health Action in the 1990s.* (Smoking and Tobacco Control Monograph No. 1, NIH Publication No. 92-3316, Chapter 3). Bethesda, MD: National Cancer Institute. Available at cancercontrol.cancer.gov/Brp/tcrb/monographs/1/m1_complete.pdf

EXECUTIVE SUMMARY

NHTSA began in 1975 to evaluate the effectiveness of vehicle safety technologies associated with the Federal Motor Vehicle Safety Standards. By 2004, NHTSA had evaluated virtually all of the life-saving technologies introduced in passenger cars and in LTVs (light trucks and vans – i.e., pickup trucks, SUVs, minivans and full-size vans) from about 1960 through the mid-1990s. These were retrospective evaluations with estimates of fatality-reducing effectiveness based on statistical analyses of the actual crash experience of production vehicles equipped with the technologies. In October 2004, the agency issued a report estimating the number of lives saved from 1960 to 2002, year-by-year, by the combination of those life-saving technologies and by each individual technology; the estimates added up to 328,551 lives saved through 2002.[5]

Since 2004, NHTSA has evaluated nine additional life-saving technologies, such as ESC and curtain air bags and has acquired 10 additional years of crash data (through 2012). Although some of these technologies, including ESC and curtains were already available in production vehicles by 2002, they could not be included in the previous report because the vehicles had not yet accumulated enough on-the-road experience for statistical analyses. This report updates the 2004 study and estimates 613,501 cumulative lives saved from CY 1960 through 2012. The update includes not only new estimates of 281,042 lives saved from CY 2003 through 2012 (the years not included in the earlier report), but also a slight upward revision from the previous report's estimate of 328,551 to 332,459 for CY 1960 through 2002 to account for the technologies that had begun to appear in production vehicles by 2002 but had not yet been evaluated by 2004.

Past evaluation reports estimated the **effectiveness** of a safety technology – a percentage reduction of fatalities – by statistically analyzing crash data. An initial evaluation is based on production vehicles produced just before versus just after a make-model received that technology. Effectiveness might subsequently change over time if vehicles and/or the crash environment changes; when feasible, NHTSA tracks effectiveness with follow-up evaluations of crash data based on later vehicles. These follow-up analyses show that effectiveness has remained quite stable for key safety technologies such as seat belts, frontal air bags, and ESC. But the **benefits** of a technology – the absolute number of lives saved in a year – readily change from year to year depending on the number of vehicles equipped with the technology, their VMT, and the crash-involvement rate of the driving population (exposure). This report will:

- Review the effectiveness estimates in past evaluations of safety technologies for cars and LTVs, describing how the technologies work and the history of the FMVSS that regulate them.

- Develop a model that uses Fatality Analysis Reporting System data and these past effectiveness estimates to calculate how many lives the following technologies have saved, individually and in combination, in each year from 1960 to 2012:

[5] Kahane, C. J. (2004, October). *Lives saved by the Federal Motor Vehicle Safety Standards and other vehicle safety technologies, 1960-2002*. (Report No. DOT HS 809 833). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809833.PDF.

FMVSS: Safety Technologies	Cars	LTVs	Heavy Trucks
105/135: Dual master cylinders & front disc brakes[6]	X	X	
108: Conspicuity tape for heavy trailers			X[7]
126: Electronic stability control[8]	X	X	
201: Voluntary mid/lower instrument panel improvements	X	X	
Head-impact upgrade	X	X	
203/204: Energy-absorbing steering assemblies	X	X	
206: Improved door locks	X	X	
208: Lap belts	X	X	
3-point belts	X	X	
2-point automatic belts[9]	X		
Voluntary NCAP-related improvements for belted occs.[10]	X		
Belt pretensioners and load limiters	X	X	
Frontal air bags (barrier-certified, sled-certified, advanced)	X	X	
212: Adhesive windshield bonding	X	X	
213: Child safety seats	X	X	
214: Side door beams	X	X	
Structure and padding to meet a dynamic side-impact test	X		
Curtain and side air bags	X	X	
216: Roof crush resistance (eliminate true hardtops)	X		
226: Ejection mitigation (rollover curtains)	X	X	
301: Fuel system integrity: rear-impact upgrade	X	X	

In addition to safety equipment compliant with a specific FMVSS in effect at that time (and perhaps even excelling the performance requirements of that FMVSS), the model tallies lives saved by installations in advance of the FMVSS and by non-compulsory improvements shown in the preceding list, such as belt pretensioners and load limiters. The model includes car/LTV occupants saved by car/LTV technologies or child safety seats (99 percent of the total) plus pedestrians/bicyclists/motorcyclists saved by car/LTV brake improvements, motorcyclists saved by ESC, and car/LTV occupants saved by conspicuity tape on heavy trailers.

The model does not include technologies so recent that NHTSA has not yet evaluated them based on statistical analysis of crash data, such as tire pressure monitoring systems (phased in during MY 2006 to 2008). The study is limited to technologies in cars and LTVs or that save lives of car/LTV occupants; for example, motorcycle helmets are not included. It is limited to vehicle technologies. It does not estimate the effects of behavioral safety programs such as the reduction of impaired driving – except to the extent that buckle-up programs have contributed greatly to the number of lives saved by belts and child safety seats. It does not include effects of

[6] Applied to cars and LTVs, but also saves pedestrians, bicyclists and motorcyclists not hit by these cars and LTVs.
[7] Applied to heavy trailers, but also saves occupants of cars and LTVs that avoid collisions with these trailers.
[8] Applied to cars and LTVs, but also saves motorcyclists not hit by these cars and LTVs.
[9] LTVs were not equipped with 2-point automatic belts.
[10] NCAP testing, the dynamic side impact test of FMVSS No. 214, and FMVSS No. 216 apply to LTVs as well as cars, but NHTSA evaluations have not identified a life-saving effectiveness for the LTVs.

roadway and traffic engineering improvements (such as rumble strips), shifts in the vehicle fleet – e.g., between large and small cars or between cars and LTVs, or improvements in EMS or follow-up medical care. The model is limited to estimating fatality reduction by the safety technologies; NHTSA does not have sufficiently complete evaluation results to develop comparable estimates for the numbers of nonfatal injuries prevented.

How the model works: Consider 1,000 cases of driver fatalities in directly frontal multivehicle crashes in cars with 1960 technology: no energy-absorbing steering columns, all drivers unbelted, and no air bags. A NHTSA evaluation estimates that energy-absorbing steering columns reduce fatalities of drivers in frontal crashes by 12.1 percent. Thus, if these cars had been equipped with them, there would have been only 879 fatalities, a saving of 121 lives. Another evaluation estimates that 3-point belts, in cars with energy-absorbing steering columns, reduce drivers' fatality risk by 42 percent in these types of crashes. If the cars had been equipped with 3-point belts in addition to energy-absorbing steering columns and the drivers had buckled up, the 879 fatalities would have diminished to 510, saving another 369 lives. A third evaluation estimates that frontal air bags reduce fatality risk by 25.3 percent for belted drivers in these types of crashes, in cars with energy-absorbing steering columns. Frontal air bags would have cut the 510 fatalities down to 381, saving another 129 lives.

The model uses 1975-to-2012 FARS data and performs the same calculations in reverse order: e.g., there might be 381 actual FARS cases of 3-point-belted driver fatalities in directly frontal multivehicle crashes in MY 1999 cars, all of which were equipped with frontal air bags and energy-absorbing steering columns. If frontal air bags, the most recent (1990s) of these three safety technologies, had been removed from the cars, fatalities would have increased to an estimated 510. In other words, we surmise there must have been 129 potentially fatal collisions of these MY 1999 cars that did not become FARS cases because frontal air bags saved the driver's life. If the 3-point belts, a 1970s technology, had also been removed from the cars and all the drivers had been unbelted, the fatalities would have increased to 879. Finally, if the energy-absorbing steering columns, a 1960s technology, had been replaced by rigid columns, downgrading these cars all the way back to a 1960 level of safety, fatalities would have increased to 1,000. The three technologies, in combination, saved an estimated 619 lives: 129 by air bags, 369 by 3-point belts and 121 by energy-absorbing columns. In summary, FARS cases of fatalities in vehicles equipped with modern safety technologies constitute evidence of an even larger hypothetical number of fatalities that would have occurred without those technologies. This approach "removes" the technologies in reverse chronological order; alternative approaches removing them in some different order would still have estimated 619 overall lives saved from 1960 to 2012, but might have allocated that total differently among the individual safety technologies.

FARS data has been available since 1975, but the FMVSS date back to January 1, 1968, and some technologies were introduced even before that. An extension of the model allows estimates of lives saved from 1960 to 1974.

Lives saved from 1960 to 2012: Safety technologies saved an estimated 613,501 lives from 1960 through 2012. Table 1 shows that the annual number of lives saved grew from 115 in 1960, when a small number of people used lap belts, to 27,621 in 2012, when most cars and LTVs were equipped with numerous modern safety technologies and belt use on the road achieved 86 percent. This is a large increase from the previous NHTSA study, which estimated 328,551 lives saved from 1960 through 2002. Table 1 shows that vehicle safety technologies had great benefits during the decade from 2003 through 2012, saving between 26,000 and 31,000 lives each year.

Figure 1 tracks the estimated benefits of vehicle safety technologies. Fewer than 1,000 lives per year were saved during 1960 to 1967. Starting in 1968, vehicles incorporating most of the safety improvements of the 1960s superseded older vehicles; lives saved reached 4,000 in 1978, but remained at that level for 6 years as belt use temporarily declined. The greatest increase, from 4,835 in 1984 to 11,265 in 1988, came with buckle-up laws in the States. From 1988 until 2007, continued increases in belt use; air bags, ESC, and other recent technologies; and an expanding "base" of more vehicles and more VMT helped the fatality reduction grow, exceeding 15,000 in 1994 and 20,000 in 1999, reaching a peak of 30,312 in 2007. From 2007 until 2011, however, even though safety technologies continued to save a growing share of the potential fatalities, a shrinking "base" of VMT, especially the high-risk VMT, contributed to a decrease in the absolute number of lives saved, down to 26,098 in 2011, but then rebounding to 27,621 in 2012.

Car/LTV occupants: actual fatalities, potential fatalities and percent saved: Among the 613,501 lives saved in 1960 to 2012, 610,566 were occupants of cars and LTVs. (The remaining 2,935 were pedestrians, bicyclists, and motorcyclists who avoided fatal impacts by cars or LTVs because dual master cylinders, front disc brakes, or ESC improved the car or LTV's braking or handling performance.) The sum of the actual fatalities and the lives saved is the number of fatalities that potentially might have happened if cars and LTVs still had 1960 safety technology and nobody used seat belts. Table 2 shows 1,712,855 actual car/LTV occupant fatalities from 1960 through 2012; without the 610,566 lives saved, there would have been 2,323,421 potential fatalities. Actual car and LTV occupant fatalities decreased from 28,183 in 1960 to 21,696 in 2012. Without the vehicle safety technologies and increases in belt use, the model estimates that fatalities would not have declined but would have substantially increased, from 28,298 in 1960 to 49,214 in 2012.

Figure 2 compares the trends in actual and potential fatalities. Up to the early 1980s, both trend lines were fairly close together. Both moved up or down in response to the large cohort of baby boomers starting to drive in the1960s; the same cohort in the 1970s turning 25, an age when fatal-crash involvement rates are already substantially lower than in adolescence; plus transient reductions in the mid-1970s and early 1980s, perhaps triggered by events such as an energy crisis, high fuel prices, or an economic slowdown. From the mid-1980s, vehicle safety made a big difference. Potential fatalities have historically continued to rise as the number of registered vehicles and VMT increased in an affluent society – with transient interruptions from 1989 to 1992 and 2006 to 2011. But increased belt use, air bags, ESC, and other vehicle safety technologies held the line on actual fatalities at about 32,000 a year during the two decades of generally rising potential fatalities and then helped bring them down to levels not seen since the 1940s, such as 21,331 in 2011 and 21,696 in 2012.[11]

[11] The chapter titled "Car/LTV occupant fatalities per 100,000,000 VMT" in Part 2 of this report presents additional discussion, including references, of factors (other than vehicle safety technologies) that influenced fatality rates between 1960 and 2012.

Table 1: Lives Saved by Vehicle Safety Technologies, 1960 to 2012
(Car and LTV Occupants Saved, Plus Non-Occupants and Motorcyclists
Saved by Car/LTV Brake Improvements or ESC)

CY	LIVES SAVED
1960	115
1961	117
1962	135
1963	160
1964	203
1965	251
1966	339
1967	509
1968	816
1969	1,179
1970	1,447
1971	1,774
1972	2,226
1973	2,576
1974	2,518
1975	3,058
1976	3,240
1977	3,671
1978	4,040
1979	4,299
1980	4,540
1981	4,455
1982	4,057
1983	4,248
1984	4,835
1985	6,389
1986	8,531
1987	9,992
1988	11,292
1989	11,522
1990	11,761
1991	12,250
1992	12,573
1993	13,902
1994	15,263
1995	16,265
1996	17,956
1997	18,751
1998	19,613
1999	20,256
2000	22,280
2001	23,364
2002	25,691
2003	27,174
2004	28,253
2005	29,936
2006	30,242
2007	30,312
2008	27,941
2009	26,770
2010	26,695
2011	26,098
2012	27,621
	===========
	613,501

FIGURE 1: LIVES SAVED PER YEAR BY VEHICLE SAFETY TECHNOLOGIES, 1960 TO 2012

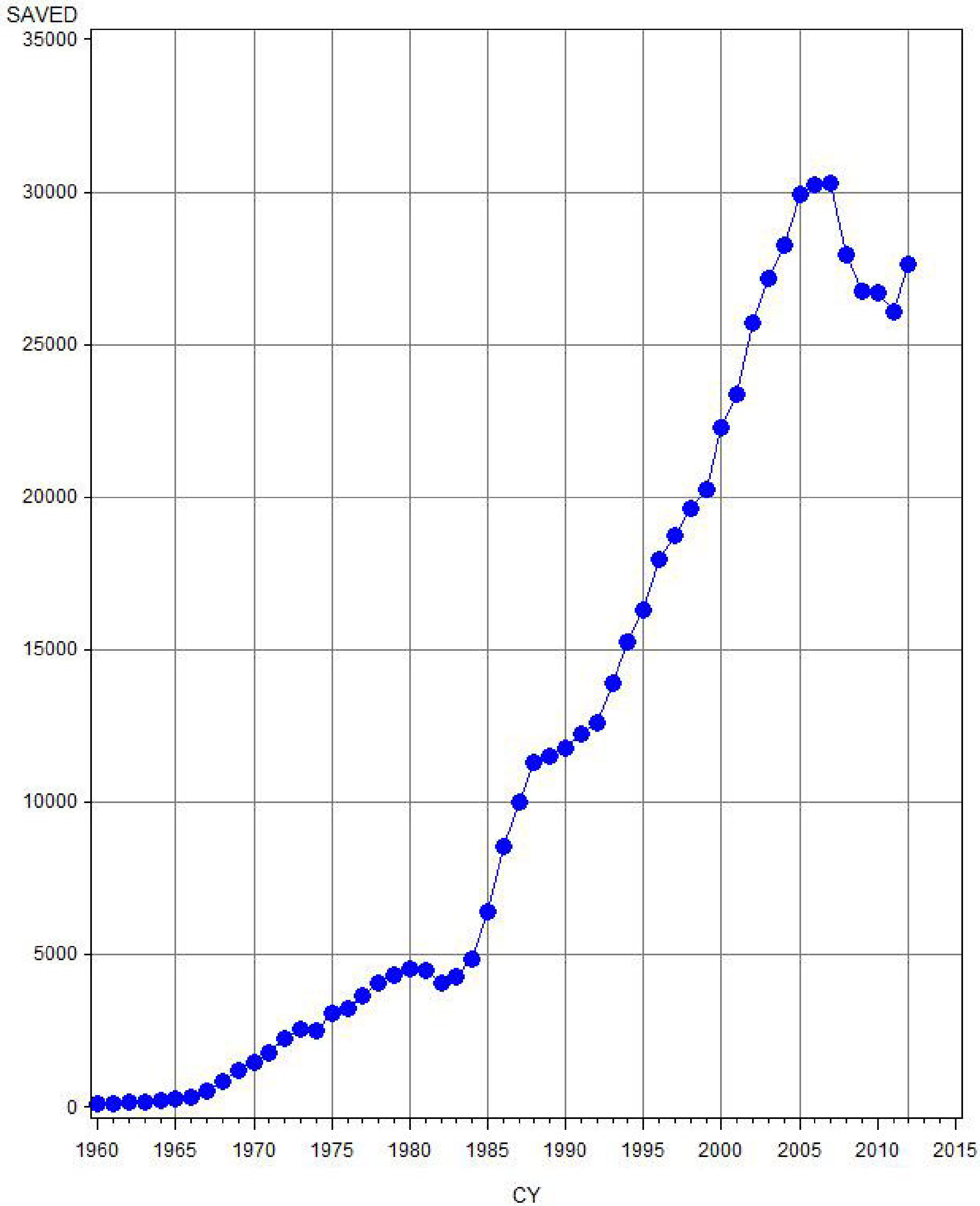
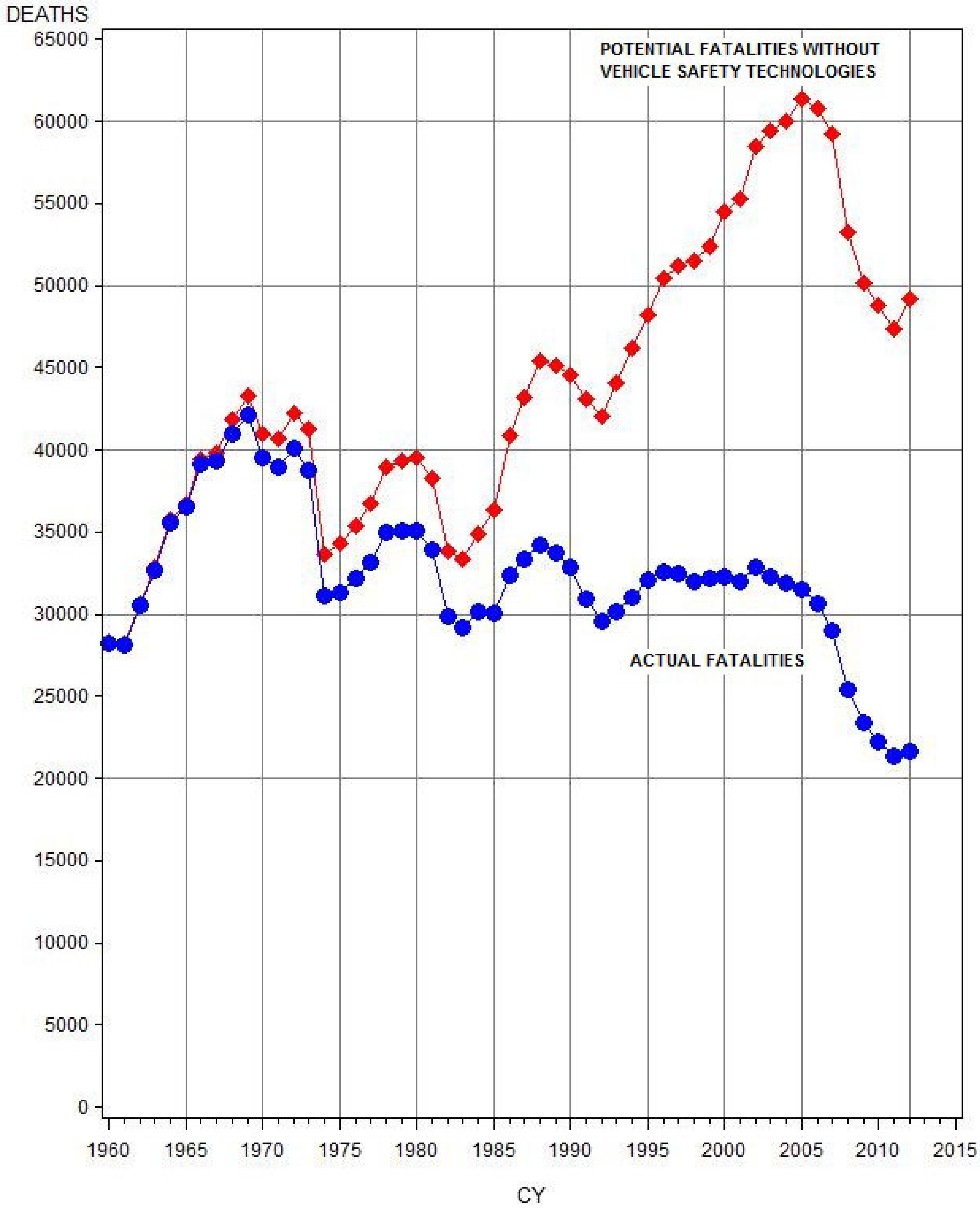


Table 2: Actual Occupant Fatalities, Potential Fatalities Without The Vehicle Safety Technologies, and Lives Saved in Cars/LTVs

CAR+LTV OCCUPANT FATALITIES

CY	ACTUAL	W/O SAFETY TECHS.	LIVES SAVED	PERCENT SAVED
1960	28,183	28,298	115	0.40
1961	28,087	28,204	117	0.41
1962	30,544	30,679	135	0.44
1963	32,664	32,823	159	0.49
1964	35,603	35,805	202	0.56
1965	36,518	36,767	249	0.68
1966	39,130	39,465	334	0.85
1967	39,327	39,826	499	1.25
1968	41,019	41,818	799	1.91
1969	42,117	43,273	1,156	2.67
1970	39,556	40,972	1,415	3.45
1971	38,916	40,651	1,735	4.27
1972	40,103	42,281	2,178	5.15
1973	38,739	41,258	2,520	6.11
1974	31,145	33,608	2,463	7.33
1975	31,361	34,355	2,995	8.72
1976	32,222	35,398	3,176	8.97
1977	33,173	36,772	3,599	9.79
1978	34,988	38,951	3,964	10.18
1979	35,108	39,325	4,217	10.72
1980	35,097	39,554	4,456	11.27
1981	33,911	38,284	4,373	11.42
1982	29,855	33,834	3,979	11.76
1983	29,209	33,384	4,176	12.51
1984	30,177	34,935	4,758	13.62
1985	30,044	36,357	6,314	17.37
1986	32,394	40,849	8,454	20.70
1987	33,334	43,251	9,916	22.93
1988	34,245	45,461	11,216	24.67
1989	33,725	45,177	11,452	25.35
1990	32,844	44,534	11,690	26.25
1991	30,939	43,126	12,187	28.26
1992	29,557	42,071	12,514	29.75
1993	30,192	44,033	13,840	31.43
1994	30,995	46,200	15,204	32.91
1995	32,067	48,271	16,204	33.57
1996	32,541	50,438	17,897	35.48
1997	32,515	51,208	18,693	36.50
1998	31,955	51,512	19,557	37.97
1999	32,171	52,373	20,202	38.57
2000	32,241	54,465	22,225	40.81
2001	32,021	55,327	23,306	42.12
2002	32,872	58,506	25,634	43.81
2003	32,297	59,411	27,114	45.64
2004	31,871	60,064	28,193	46.94
2005	31,539	61,408	29,869	48.64
2006	30,633	60,804	30,171	49.62
2007	29,009	59,246	30,236	51.04
2008	25,423	53,287	27,864	52.29
2009	23,417	50,115	26,698	53.27
2010	22,235	48,852	26,617	54.49
2011	21,331	47,342	26,011	54.94
2012	21,696	49,214	27,518	55.92
	===========	===========	===========	
	1,712,855	**2,323,421**	**610,566**	

FIGURE 2: ACTUAL VERSUS POTENTIAL CAR/LTV OCCUPANT FATALITIES, 1960 TO 2012



The overall, combined **effectiveness** of the vehicle safety technologies is the percentage of potential fatalities that were saved, as shown in the right column of Table 2. The effectiveness grew in **every** year from 1960 to 2012, from a humble 0.40 percent in 1960 to a very substantial 55.92-percent fatality reduction in 2012. Figure 3 charts the trend, showing:

- Not much effect before the FMVSS;
- Steady growth in the early-to-mid 1970s as the early FMVSS phased in;
- A slowdown in 1978 to 1982, when belt use declined prior to national buckle-up campaigns;
- The largest gains coming with the buckle-up laws in the mid-to-late 1980s; and
- Steady progress since the late 1980s thanks to continued increases in belt use, air bags, ESC, and other recent technologies.

Figure 4 tracks a **vehicular fatality-risk index** for occupants of cars or LTVs that isolates the effects of vehicle safety improvements. The index is obtained by subtracting from 100 the percentage of potential fatalities saved. The index was 100 in 1955 and had declined to 44 by 2012. In other words, given the same mileage by the same driver on the same roads, the average vehicle on the road in 2012 would have 56 percent lower fatality risk for its occupants than the average vehicle on the road in 1955.

FIGURE 3: PERCENT OF POTENTIAL FATALITIES SAVED
BY VEHICLE SAFETY TECHNOLOGIES, 1960 TO 2012

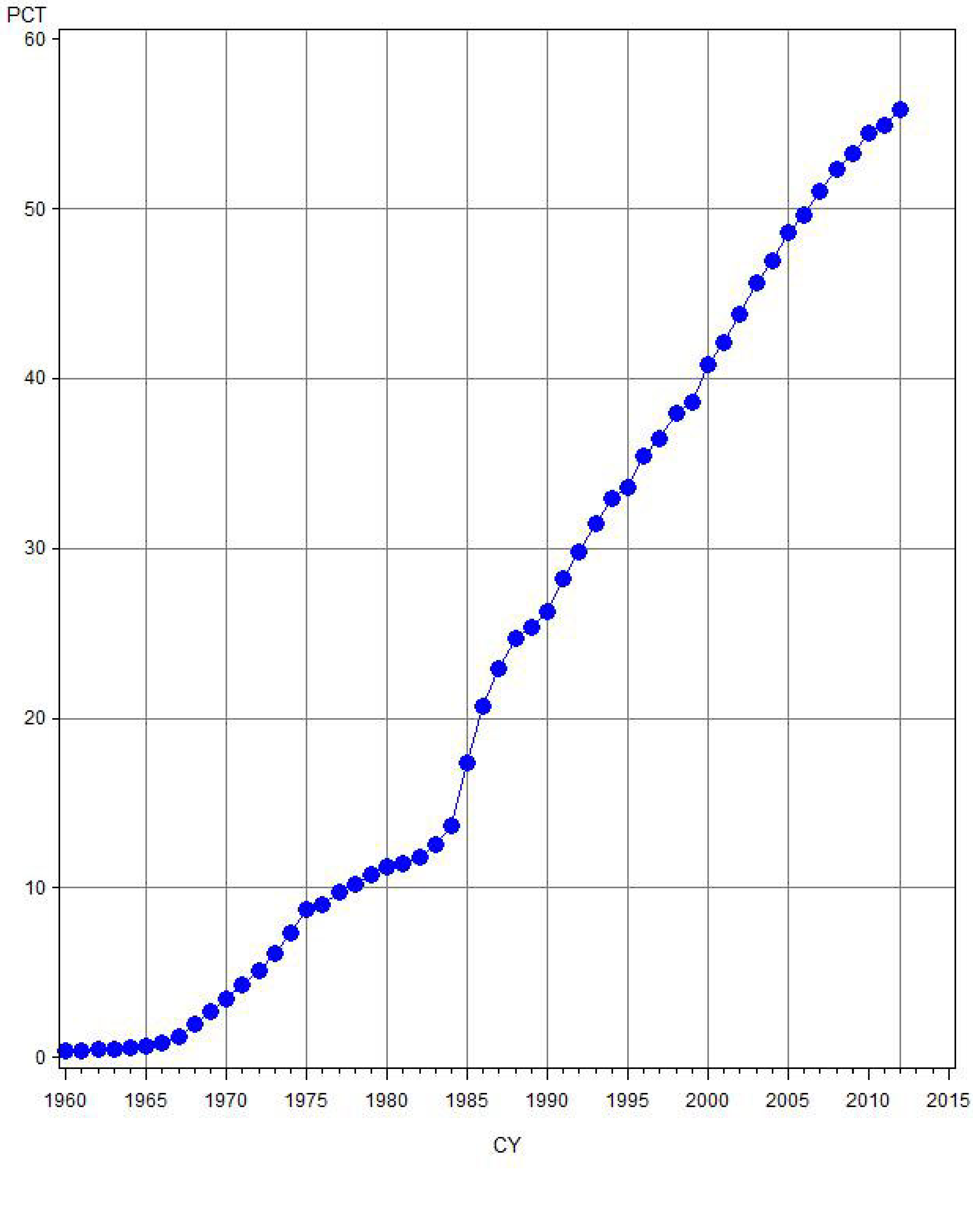
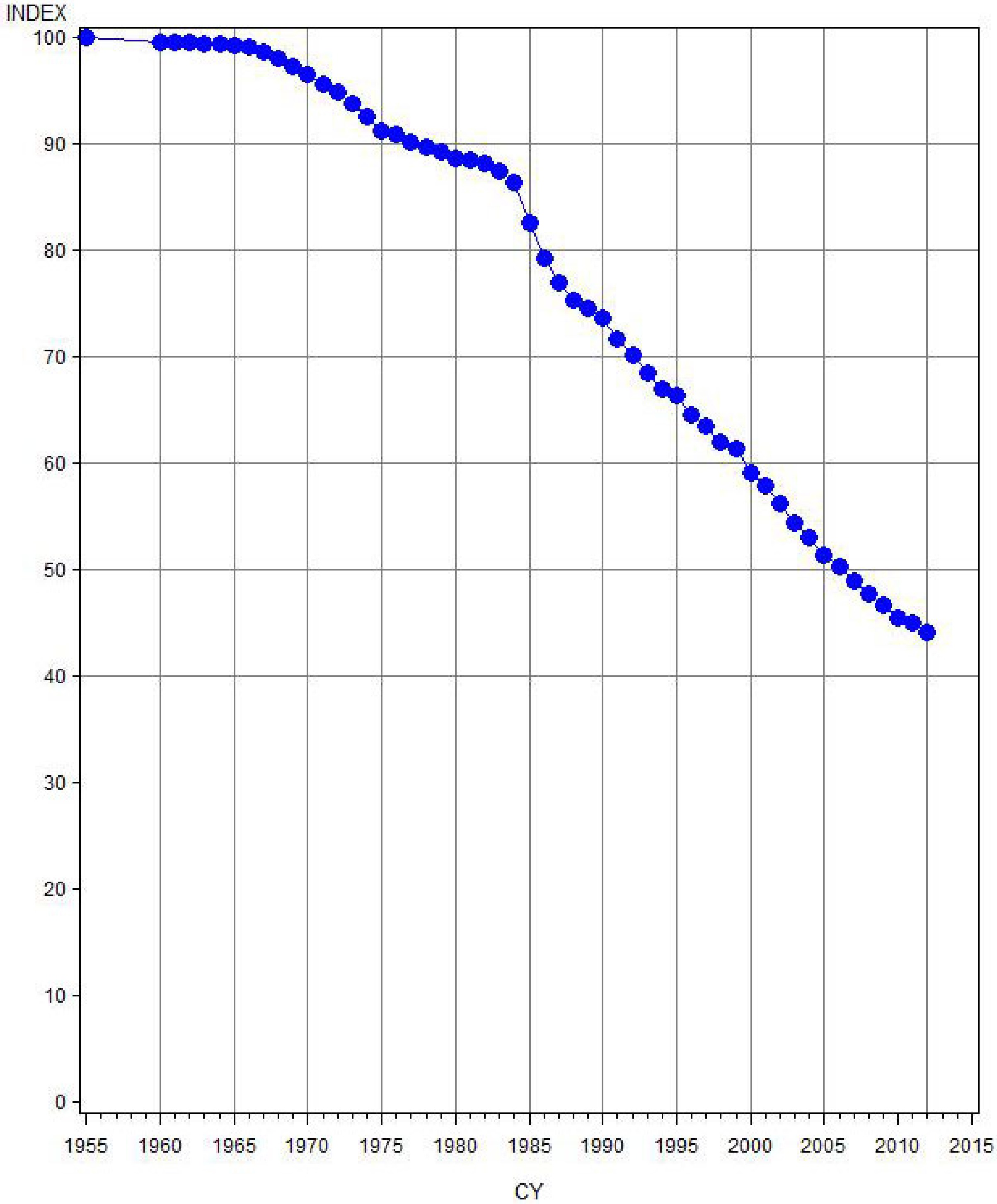


FIGURE 4: VEHICULAR FATALITY-RISK INDEX BY CALENDAR YEAR (1955 = 100)
BASED ON PERCENT OF POTENTIAL FATALITIES SAVED BY VEHICLE SAFETY TECHNOLOGIES



Estimates of lives saved by individual technologies (grouped by FMVSS): Car/LTV safety technologies saved an estimated 27,621 lives in 2012. That total includes 14,018 car occupants and 13,500 LTV occupants. It also includes 103 pedestrians, bicyclists and motorcyclists saved by car/LTV braking improvements or by ESC. Table 3 apportions how many of those lives were saved by the various individual technologies and groups those technologies according to the FMVSS with which they appear to be most closely associated:

- Seat belts are by far the most important occupant protection, saving an estimated 15,485 lives[12]: over half the total of 27,621. The estimate includes seat belts of all types (3-point, lap-only, automatic), at all designated seating positions. Seat belts are designed to keep occupants within the vehicle and close to their original seating position, provide "ride-down" by gradually decelerating the occupant as the vehicle deforms and absorbs energy, and, if possible, prevent occupants from contacting harmful interior surfaces or one another (however, NHTSA recommends correctly installed, age-appropriate safety or booster seats for child passengers until they are at least 8 years old, unless they are at least 4'9" tall). Seat belts are especially important in LTVs, where a large proportion of unrestrained fatalities are ejections and/or rollover crashes; belts saved 8,316 lives in LTVs, over 60 percent of the 13,500 LTV occupants saved.

- Frontal air bags saved 2,930 lives in 2012, when 95 percent of cars and 91 percent of LTVs on the road were equipped with dual or driver-only frontal air bags.[13] Frontal air bags have significant benefits in frontal and partially frontal impacts for nearly all occupants 13 and older, including the oldest drivers and passengers, by providing energy absorption and ride-down and by preventing head contacts with the windshield or windshield header. However, a deployed frontal air bag, especially some of the pre-2007 designs without the advanced features of current models, can present risks to child passengers 12 and younger. The risk can be eliminated if the child rides in the rear seat, correctly restrained – or by turning off the manual on-off switch in pickup trucks or other vehicles where children cannot ride in a rear seat correctly restrained.

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[12] NHTSA's **official** estimate is that belts **directly** saved 12,174 lives in 2012 – i.e., fatalities would have increased by 12,174 if nobody had buckled up, but otherwise the cars and LTVs on the road had remained unchanged. [Source: NCSA. (2014, March). *Traffic safety facts 2012 Data – Occupant Protection*. (Report No. DOT HS 811 892). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811892.pdf.] This report's estimate, 15,485 lives saved in 2012, is higher because it also includes some indirect savings: this report estimates how many additional fatalities would have occurred if **all** safety technologies had been removed, not just the belts, and it then **apportions** the total among the various individual technologies. Accounting for the lives directly saved by recent technologies such as ESC, by this report's computational method, also indirectly augments the estimates of lives saved by earlier technologies such as seat belts (as explained in Part 2 of this report). The estimates here **do not supersede** the agency's official estimates of lives directly saved by seat belts, frontal air bags, and safety seats. They are primarily meaningful within the context of this report: estimation of the overall effect of all the vehicle safety technologies and apportionment of the overall effect among the individual technologies.

[13] NHTSA's official estimate in *Traffic safety facts 2012 Data – Occupant Protection* is 2,213 lives saved directly by air bags in 2012.

Table 3: Estimates[14] of Lives Saved by Safety Technologies in 2012

FMVSS & Associated Safety Technologies	Car Occupants	LTV Occupants	Pedestrians Bicyclists Motorcyclists	TOTAL
105/135: Dual master cylinders & front disc brakes	217	201	65	482
108: Conspicuity tape for heavy trailers	90	70		161
126: Electronic stability control for cars and LTVs	500	824	38	1,362
201: Instrument panel improvements & head impact protection	778	573		1,350
203/204: Energy-absorbing steering assemblies	1,323	1,084		2,407
206: Improved door locks	486	641		1,127
208: Seat belts – all types, all seating positions[15]	7,169	8,316		15,485
208: Frontal air bags	1,738	1,193		2,930
212: Adhesive windshield bonding	177	95		271
213: Child safety seats	213	145		357
214: Side impact protection & curtain/side air bags	1,196	315		1,512
216: Roof crush resistance (eliminate true hardtops)	122			122
226: Curtains that deploy in rollovers	3	41		43
301: Fuel system integrity – rear impact upgrade	5	4		9
TOTAL	14,018	13,500	103	27,621

[14] All estimates in this table are rounded to the nearest whole number. Estimates might not add up exactly to row or column totals because of the rounding.
[15] Estimates in this table for seat belts, frontal air bags, and child safety seats do not supersede NHTSA's official annual estimates in *Traffic safety facts 2012 Data – Occupant Protection* of the lives directly saved by those technologies. The footnotes on the preceding page explain that the estimates in this table, which also include estimates of lives indirectly saved by those technologies, are meaningful primarily in this report's context of computing the overall effect of the FMVSS and the comparing the effects of various FMVSS; they also explain why the estimates on this page differ from *Traffic safety facts*.

- Energy-absorbing steering assemblies meeting FMVSS Nos. 203 and 204 are an important "built-in" safety technology that saved an estimated 2,407 lives in 2012. In the 1960s, they were the first basic protection for drivers in frontal crashes, designed to cushion their impact into the steering assembly. Today, the combination of energy-absorbing steering columns, seat belts and frontal air bags provides far better protection for the driver in frontal crashes.

- Three groups of technologies associated with FMVSS No. 214, "Side impact protection" saved an estimated 1,512 lives in 2012. The technologies are: (1) Side door beams in cars and LTVs meeting the original static crush test of FMVSS No. 214, which are primarily effective in side impacts with fixed objects, such as trees or poles; (2) Structures and padding added to passenger cars before or after FMVSS No. 214 was upgraded in the 1990s with a dynamic test requirement, which are primarily effective in near-side impacts by other vehicles; and (3) Curtain and side air bags, which further enhance protection in near-side impacts.[16]

- Electronic stability control (now required in new cars and LTVs by FMVSS No. 126) saved 1,362 lives in 2012, the first year when all new cars and LTVs had ESC – but in 2012 only 20 percent of cars and 22 percent of LTVs on the road were ESC-equipped. Benefits can be expected to grow substantially in future years as the on-road fleet approaches 100 percent ESC-equipped. ESC detects when a vehicle is about to lose traction and automatically applies the brakes to individual wheels and/or reduces engine torque to help the driver stay on course. It is a highly effective crash avoidance technology.

- Two groups of technologies associated with FMVSS No. 201, "Occupant protection in interior impact" saved an estimated 1,350 lives in 2012. The technologies are: (1) Improvements to the materials and contours of middle and lower instrument panels in the late 1960s and 1970s, not specifically required by FMVSS No. 201 but historically and functionally associated with that standard to some extent; instrument panels were redesigned, using energy-absorbing materials, to decelerate occupants at a safe rate and keep them in an upright position during frontal crashes. (2) The head-impact upgrade of FMVSS No. 201, phased in during MY 1999 to 2003, which added energy-absorbing padding to pillars, roof headers, roof side rails, and other components that were sources of life-threatening head injuries.

- Improvements to door locks, latches, and hinges, generally implemented by manufacturers in the 1960s and regulated by industry standards subsequently incorporated into FMVSS No. 206, saved 1,127 lives in 2012. They reduce the risk of occupant ejection by keeping doors closed in rollover crashes.

- Car/LTV braking improvements directly or indirectly associated with FMVSS Nos. 105 and 135 include dual master cylinders and front disc brakes. By eliminating brake failure or helping cars and LTVs stop more effectively, they saved 482 lives in 2012, including 65 pedestrians, bicyclists or motorcyclists.

[16] A "near-side" impact is a left-side impact for the driver and a right-side impact for the RF passenger.

- Child safety seats or booster seats meeting FMVSS No. 213 saved an estimated 357 young passengers in 2012.[17] Child safety seats and booster seats are the basic protection system for passengers who are too small to obtain full benefits from seat belts. Newborns should start with rear-facing seats and stay in them until their weight or height reaches a point where they should graduate to forward-facing seats, subsequently to booster seats and, finally, when they are at least 9 years old or 4’9” tall, to adult seat belts.

- Adhesive windshield bonding saved 271 lives in 2012 by keeping the windshield attached to the vehicle in severe impacts and preventing occupant ejection via the windshield portal. FMVSS No. 212 regulates windshield retention for cars and LTVs.

- FMVSS No. 108 requires red-and-white conspicuity tape on heavy truck trailers. The tape reflects another vehicle’s headlights strongly and it is highly visible in the dark. Although this device is furnished on heavy trailers, not cars or LTVs, it is the occupants of cars and LTVs who primarily benefit by avoiding collisions with the trailers. The tape saved an estimated 161 car and LTV occupants in 2012.

- FMVSS No. 216, “Roof crush resistance” is associated with the redesign of true hardtops as pillared hardtops or sedans during the 1970s. True hardtops had no B-pillars to support the roof, making it more susceptible to crush in a rollover. If cars were still built that way there might have been 122 additional fatalities in 2012.

- FMVSS No. 226, “Ejection mitigation” began to phase in during MY2014. Curtain air bags that deploy in rollover crashes are the key technology for meeting the standard. Rollover curtains have already been available in some production vehicles since 2002. They are effective in preventing ejection and mitigating interior impact. They saved an estimated 43 lives in 2012.

- The rear-impact test of FMVSS No. 301, “Fuel system integrity” was substantially upgraded during the past decade. The upgrade saved an estimated 9 lives in 2012: people who otherwise would have died of burns in post-crash fires.

Table 4 shows cumulative lives saved from 1960 through 2012: 385,408 car occupants and 225,158 LTV occupants, plus 2,936 pedestrians, bicyclists and motorcyclists saved by car/LTV braking improvements or ESC, for an estimated total of 613,501. Seat belts (329,715) accounted for more than half the total. Frontal air bags had saved 42,856 lives by the end of 2012 and child safety seats, 9,891. The “built in” non-belt technologies regulated by or associated with the remaining 13 FMVSS in Table 4 (Nos. 105/135, 108, 126, 201, 203/204, 206, 212, 214, 216, 226, and 301) sum to 231,039 lives saved; energy-absorbing steering assemblies, improved door locks, occupant protection in interior impact, and side impact protection have cumulatively saved the most lives.

[17] NHTSA’s official estimate in *Traffic safety facts 2012 Data – Occupant Protection* is 284 lives saved directly by child safety seats in 2012.

Table 4: Estimates[18] of Cumulative Lives Saved by Safety Technologies From 1960 Through 2012

FMVSS & Associated Safety Technologies	Car Occupants	LTV Occupants	Pedestrians Bicyclists Motorcyclists	TOTAL
105/135: Dual master cylinders & front disc brakes	10,559	5,001	2,790	18,350
108: Conspicuity tape for heavy trailers	1,524	1,136		2,660
126: Electronic stability control for cars and LTVs	2,420	3,604	146	6,169
201: Instrument panel improvements & head impact protection	24,779	9,698		34,477
203/204: Energy-absorbing steering assemblies	57,112	22,877		79,989
206: Improved door locks	25,377	16,758		42,135
208: Seat belts – all types, all seating positions	187,442	142,274		329,715
208: Frontal air bags	27,765	15,091		42,856
212: Adhesive windshield bonding	7,268	2,585		9,853
213: Child safety seats	7,257	2,634		9,891
214: Side impact protection & curtain/side air bags	28,971	3,317		32,288
216: Roof crush resistance (eliminate true hardtops)	4,913			4,913
226: Curtains that deploy in rollovers	8	171		178
301: Fuel system integrity – rear impact upgrade	14	13		26
TOTAL	385,408	225,158	2,936	613,501

[18] All estimates in this table are rounded to the nearest whole number. Estimates might not add up exactly to row or column totals because of the rounding.

Comments on some assumptions in the "lives saved" model: The fatality-reducing effectiveness estimates used in the model are all derived from published NHTSA evaluation reports. The model only includes a technology if its estimate of fatality reduction in NHTSA evaluations is statistically significant. As stated above, the estimates are based on statistical analyses of crash data. An initial evaluation report usually compares fatality risk in vehicles built just before and just after make-models became equipped with the technology, statistically controlling for factors other than the technology by using double-pair comparison, control groups, logistic regression, or other techniques. For some technologies, including seat belts, frontal air bags, ESC, and curtain and side air bags, the agency has performed follow-up evaluations of crash data involving later vehicles to see if effectiveness might have changed over time.

The basic assumption of the model is that any group of FARS fatality cases involving vehicles equipped with a safety technology known to be effective in that type of crash may be considered evidence that there were additional crashes where that technology saved lives: these additional crashes are not on FARS because the technology made them nonfatal crashes. For example, if there are 100 belted fatality cases on FARS in a type of crash where statistical analysis shows 50-percent belt effectiveness, we surmise that there must have been another 100 people in potentially fatal crashes who were saved by the belt. This is a leap of faith to the extent that we cannot identify those 100 specific occupants who were "saved by the belt" – we assume they must exist, based on our effectiveness estimate.

The model simulates "removing" safety equipment from a modern vehicle one piece at a time, starting with the most recent technology and working backward. Some of these technologies were introduced at about the same time, and it is not always obvious which was first: for some of the earliest ones, limited information is available about their introduction dates. Changing the order in which the technologies are "removed" would still produce the same estimate of overall lives saved, but the allocation among the individual technologies could change.

The model assumes that the belt use of **fatally injured** occupants (not survivors) on FARS is accurately reported. NHTSA has long believed this to be true, based on statistical analyses comparing FARS data with belt use observed in surveys. In the future, conceivably, event data recorders could provide additional evidence on belt use in crash data files.

Finally, when the model says vehicle safety technologies saved 613,501 lives, it estimates that this number of additional fatalities might have occurred from 1960 through 2012, without those technologies, if all other factors had stayed the same: the same increase in VMT from 1960 to 2012, the same driving behaviors. It is a hypothetical estimate. If seat belts and the other modern vehicle safety technologies had never been invented and if occupant fatalities had continued climbing toward 61,000 instead of remaining near 32,000, as shown in Table 2, the public might have demanded much stronger regulation of drivers (e.g., licensing) or the infrastructure (e.g., speed limits). Consumers might have purchased a different mix of vehicles and some people might have been more reluctant to travel during the riskiest hours (e.g., weekend nights). Those measures might have prevented at least some of the additional 613,501 fatalities – but surely not as efficiently and with as little impairment of driving enjoyment and mobility as the vehicle safety technologies.

LIVES SAVED BY VEHICLE SAFETY TECHNOLOGIES AND ASSOCIATED FEDERAL MOTOR VEHICLE SAFETY STANDARDS, 1960 TO 2012

FRAMEWORK FOR THE ANALYSIS

NHTSA began to evaluate the effectiveness of vehicle safety technologies and associated Federal Motor Vehicle Safety Standards in 1975, well before Executive Order 12291 (February 1981), Executive Order 12866 (October 1993), Executive Order 13563 (January 2011), and the Government Performance and Results Act of 1993 required Federal agencies to evaluate their existing regulations. By June 2014, NHTSA had issued 82 retrospective evaluations of individual safety standards, programs or technologies; Appendix B of this report summarizes the results of those evaluations.[19]

A typical evaluation estimates the **effectiveness** of a safety technology – a percentage reduction of fatalities, injuries and/or crashes – by statistically analyzing crash data on vehicles produced just before versus just after receiving the technology. It may also estimate the **benefits** of that technology – absolute numbers of lives saved, injuries avoided, or crashes avoided per year – by applying effectiveness estimates to baseline numbers of annual fatalities, injuries or crashes. "Baselines" have typically been the year that a report was written.

NHTSA has evaluated the major crash avoidance and crashworthiness standards in effect for passenger cars and LTVs (which comprise pickup trucks, SUVs, CUVs, minivans and full-size vans) as of June 2014. The agency has also evaluated consumer information on vehicle safety such as NCAP and statistically analyzed safety technologies that are not mandatory for cars or LTVs under Federal regulations, such as pretensioners and load limiters for seat belts.

By now, the agency has evaluated virtually all the life-saving technologies introduced in cars and LTVs from about 1960 up to 2010. Having estimated the lives saved by each individual technology, we are now ready to assess the overall effect of vehicle safety improvements by essentially adding up the individual estimates. "Building up an estimate one technology at a time" is the most empirical and defensible way to estimate how many lives are saved by all the vehicle safety technologies. It is preferable to a complex statistical analysis of the long-term reduction in overall fatality rates per 100,000,000 VMT that attempts to tease out the relative effects of vehicle, behavioral, roadway and demographic factors.

Estimating the combined net lives saved by the vehicle safety technologies, as well as the lives saved by each individual technology in each year updates a 2004 NHTSA report that presented an estimate of 328,551 lives saved from CY 1960 through 2002.[20]

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[19] "Executive Order 12291 – Federal Regulation," *Federal Register* 46 (February 19, 1981): 13193; "Executive Order 12866 – Regulatory Planning and Review," *Federal Register* 58 (October 4, 1993): 51735; ; "Executive Order 13563 – Improving Regulation and Regulatory Review," *Federal Register* 76 (January 21, 2011): 3821; *Government Performance and Results Act of 1993*, Public Law 103-62, August 3, 1993.
[20] Kahane (2004, October).

Basic analysis method

We will rely on the individual effectiveness estimates (percentage reductions) developed in past NHTSA evaluations. But it is not as simple as merely adding up past reports' estimates of lives saved per year. The absolute estimates in the various reports are not directly comparable and they are no longer accurate today, because they involve many different, past baselines: typically, the baseline is the number of fatalities on FARS in the year the report was written and this number varies from year to year.

Instead, a process is needed that applies the effectiveness estimates in a consistent manner to appropriate "baseline" numbers of fatalities. FARS data serves as the starting point, indicating the actual number of fatalities every year from 1975 to 2012 in the fleet of cars and LTVs that was on the road. The FARS cases comprise a mix of vehicles, some built recently and meeting many of the FMVSS, others quite old and pre-FMVSS. Because the number of fatalities varies somewhat from one calendar year to the next, applying the effectiveness estimates will result in estimates of lives saved that vary somewhat from year to year.

Every 100 actual fatality cases on FARS represent a potentially even greater number of fatalities that could have happened if the vehicles had not been equipped with any of the safety technologies associated with the FMVSS. The process begins with the actual FARS fatality cases and computes how many additional fatalities there would have been if the vehicles had not been equipped with any safety technologies. The computations rely on the effectiveness estimates from past evaluations. For example, given that 3-point belts reduce fatality risk by 45 percent in cars, 100 belted FARS fatality cases are equivalent to 100/(1 - .45) = 182 fatalities without belts – i.e., we surmise there must have been 182 belted occupants involved in crashes that would have been potentially fatal without belts, but 82 of them did not become FARS fatality cases, because the belts saved the occupant's life. The process is repeated for other safety technologies until all of them have been "removed" from the vehicle – until the vehicle has been downgraded to a level of safety performance characteristic of the 1950s rather than its actual model year. The technologies are removed in the reverse chronological order that they were historically introduced into vehicles. At each step back into the past, the model tallies the lives saved by the latest safety technology – i.e., the additional fatalities that would have occurred if that technology had been removed. This is the process that NHTSA already uses to estimate the number of lives saved by frontal air bags, seat belts, and child safety seats, but expanded to also count the benefits of the other technologies associated with the FMVSS.[21] "Reverse chronological order" is not the only approach that could have been used in the model; alternative approaches are considered in Part 2 of this report (Summary of the Estimation Method). However, the various techniques would have generated the same estimate of overall lives saved in 1960 to 2012, differing only in how they allocated that total among the individual safety technologies.

The model produces unbiased estimates of the lives saved by the various technologies and it is not an exercise in double counting, because the effectiveness estimates in past evaluations are based on analyses of vehicles produced **just after** versus **just before** the installation of the technology in question (e.g., two MY just after versus two MY just before the installation). They estimate the **incremental** effect of that technology on a vehicle that is already equipped with all of the earlier technologies. For example, NHTSA's evaluation of frontal air bags was a study of

[21] *Traffic safety facts 2012 Data – Occupant Protection*.

cars, some without air bags and some with frontal air bags, but all equipped with 3-point belts and energy-absorbing steering columns. The evaluation of 3-point belts was based on older cars equipped with energy-absorbing steering columns but not yet with air bags. The evaluation of energy-absorbing steering columns was based on even older cars without air bags or 3-point belts. These effectiveness estimates are incremental, and they may be applied in reverse-chronological sequence to estimate the total fatality reduction for the combination of the three technologies.[22]

What is included and what is excluded?

This will be a study of the lives saved from 1960 to 2012 by vehicle safety technologies that had been implemented in large numbers cars or LTVs from approximately 1960 until 2010, or that were implemented in other vehicles but benefited occupants of cars and LTVs. The short explanation for limiting the study to vehicle safety technologies in general and to these vehicles and this timeframe in particular is that they are the technologies that have been evaluated by NHTSA (see Appendix B) – inclusively enough to add up the lives saved by the individual technologies and say, "Here is the overall impact of the vehicle safety program."

The benefits of roadway improvements, behavioral safety programs such as the effort to prevent drunk driving, and EMS enhancements are not explicitly included here. One exception: the benefits of two vehicle safety technologies, seat belts and child safety seats, would not have been anywhere near what they are today without all the buckle-up programs that have increased use; the benefits of these behavioral "occupant protection programs" are implicitly and inseparably part of the benefit of seat belts and safety seats. Unlike the vehicle safety technologies, there are generally no easy statistical methods to estimate the effectiveness of specific, individual behavioral or roadway programs. NHTSA does not have a comprehensive set of effectiveness estimates for behavioral or roadway programs, based directly on statistical analysis of crash data, corresponding to what it has for the vehicle programs.

For passenger cars, NHTSA has thoroughly evaluated the life-saving benefits of safety technologies associated with the FMVSS. The set of estimates for LTVs is almost as complete and where there are some gaps, estimates can in most cases be plausibly inferred from the results for cars. The list of evaluations for motorcycles, heavy trucks, and buses is not as complete (although this is a future priority for NHTSA).

The timeframe of vehicle technologies is as up-to-date as feasible. However, some of the rules or technologies introduced after 2005 or so cannot be included because NHTSA is only now acquiring, or has not yet acquired enough crash data to evaluate their effectiveness in production vehicles.

[22] Kahane, C. J. (1996, August). *Fatality reduction by air bags: Analyses of accident data through early 1996*. (Report No. DOT HS 808 470, pp. 7-9). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/808470.PDF; Kahane, C. J. (2000, December). *Fatality reduction by safety belts for front-seat occupants of cars and light trucks*. (Report No. DOT HS 809 199, pp. 5-10). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809199.PDF; Kahane, C. J. (1981, January). *An evaluation of Federal Motor Vehicle Safety Standards for passenger car steering assemblies*. (Report No. DOT HS 805 705, pp. 197-203). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/805705.PDF.

For the beginning of the timeframe, it seems most logical to start with the technologies regulated by the initial FMVSS of January 1, 1968. Many of these technologies, however, were actually introduced some years before 1968. For a full picture of the benefits of the FMVSS-era technologies, it makes sense to take the analysis back to 1960, as long as we keep separate accounts of lives saved in pre-FMVSS and FMVSS-compliant vehicles. The oldest technologies regulated by the initial FMVSS include lap belts, introduced in the late 1950s and early 1960s; improvements to door locks throughout the 1960s; and many effective devices introduced in 1965 to 1967. There does not seem to be much point in going back before 1960 or attempting to predict how many fatalities there would be today if cars still had, say, 1905 technology; in any case, NHTSA has not evaluated safety improvements that long preceded the FMVSS era, such as enclosed, metal car bodies, hydraulic brakes, safety glass, or electric headlamps.

One feature of the estimation model in Part 2 of this report is that estimates for the later technologies (such as air bags or 3-point belts) are unaffected by the inclusion or exclusion of any technology that preceded them. Thus, readers have the option of just subtracting the benefits for the earliest technologies on the list (e.g., lap belts or the 1960s improvements to door locks) if, in their opinion, they ought not to have been included in this report.

In 2004, NHTSA issued a report that, based on the agency's cost analyses of individual FMVSS, estimated the total cost and weight added to cars and to LTVs by all the FMVSS, by model year, from 1968 to 2001.[23] NHTSA plans to update the report to the most recent MY possible; it will be a companion to this report. A supplement to these two reports will compare overall lives saved and costs on a substantial "core" group of FMVSS for which NHTSA has evaluated effectiveness as well as costs.[24]

List of FMVSS, safety technologies, and effectiveness evaluations

Part 1 of this report is a review of 26 FMVSS, plus the NCAP program that provides consumers with information about vehicle safety performance. Part 1 is grouped into 21 chapters. These FMVSS either regulate cars and/or LTVs or they regulate other vehicles/equipment but result in benefits to occupants of cars and LTVs. Part 1 reviews 53 individual safety technologies directly or indirectly associated with FMVSS/NCAP, including 44 that NHTSA has evaluated based on statistical comparisons of the crash experience of vehicles built before and after the introduction of those technologies.

Each FMVSS has a number. The 100-series are crash avoidance standards; the 200-series, crashworthiness; and the 300-series, post-crash fire prevention. Within each series, the numbering is usually chronological.

Each chapter of Part 1 presents the rationale for a FMVSS (or a related group of FMVSS), the safety problem it addresses, and its regulatory history, including major *Federal Register* cita-

[23]Tarbet, M. J. (2004, December). *Cost and weight added by the Federal Motor Vehicle Safety Standards for model years 1968-2001 in passenger cars and light trucks*. (Report No. DOT HS 809 834). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809834.PDF.

[24] The supplementary report in 2004 was: Kahane, C. J. (2004, December). *Cost per life saved by the Federal Motor Vehicle Safety Standards*. (Report No. DOT HS 809 835). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809835.PDF.

tions. For each individual safety technology, Part 1 summarizes what was added or changed in vehicles and how this equipment works, when it was introduced and by whom, and why it might be expected to reduce fatalities, injuries or crashes. The data and statistical methods of NHTSA's evaluations are summarized, with examples if possible and so are the principal findings on effectiveness, benefits, and side effects (if any). NHTSA has statistically analyzed the fatality reduction of almost all technologies discussed in Part 1, although, as discussed below, not all of these analyses showed a statistically significant fatality reduction. Analyses of crash reduction are limited to the 100-series, crash avoidance standards. Nonfatal injury reduction is analyzed when sufficient data is available; however, NHTSA's primary source of detailed data on serious injuries, NASS-CDS is a sample of crashes, not a census like FARS, the agency's database of fatal crashes. For some of the technologies, NASS-CDS does not have enough injury cases to evaluate serious-injury reduction. For technologies that require some action by drivers or other occupants (e.g., seat belts, manual on-off switches for air bags, ABS, head restraints), Part 1 also describes how to use them most effectively.

Table 1-1 lists the 44 safety technologies reviewed in Part 1 that NHTSA has evaluated, grouped by chapter (FMVSS). It summarizes the effectiveness of each technology in reducing fatalities, injuries or crashes (100-series only) of cars and LTVs.

- Yes = NHTSA's evaluation found a statistically significant reduction
- No = the evaluation did not find a significant reduction, despite ample data
- Limited data = the evaluation did not find a significant reduction, but data still limited
- Mixed results = significant reduction on some crash types, significant increase on others
- (Yes), (No) = inferred by analogy (e.g., LTVs from cars, injuries from fatals/crashes)
- Unknown = NHTSA has not performed an evaluation
- N/A = the safety technology was not installed on this type of vehicle

NHTSA's evaluations demonstrated significant benefits of some type – if not a fatality reduction then at least a reduction of injuries, crashes or fires – for 37 of the 44 technologies. The evaluations of rear window defoggers, rear-wheel ABS, DRL, seat back locks, and glass-plastic windshields did not show a significant net benefit despite substantial data (and of these, only seat back locks are required by a FMVSS; rear-wheel ABS and glass-plastic windshields have been phased out of vehicles for some time). The evaluations of LED stop lamps and rear impact guards for heavy trailers also did not show a significant net benefit, but this may have been due to the limited data.

Table 1-1: Safety Technologies Evaluated by NHTSA

FMVSS	SAFETY TECHNOLOGY	Effectiveness: Cars Fatals	Cars Injuries	Cars Crashes	LTVs Fatals	LTVs Injuries	LTVs Crashes
103: Windshield defrosting and defogging							
	Rear-window defoggers	Unknown	Unknown	No	Unknown	Unknown	Unknown
105: Hydraulic brake systems 135: Light vehicle brake systems							
	Dual master cylinders	Yes	Yes	Yes	Yes	Yes	Yes
	Front disc brakes	Yes	Yes	Yes	Yes	Yes	Yes
	Rear-wheel ABS for LTVs		N/A		No	No	No
	4-wheel antilock brake systems (ABS)	No	Yes	Yes	No	Yes	Yes
108: Lamps, reflective devices							
	Side marker lamps	No	Yes	Yes	No	Yes	Yes
	Center high mounted stop lamps	No	Yes	Yes	No	Yes	Yes
	Retroreflective tape on heavy trailers[25]	Yes	Yes	Yes	Yes	Yes	Yes
	Daytime running lights	No	No	No	No	No	No
	Amber turn signals[26]	Unk	Yes	Yes	Unk	(Yes)	(Yes)
	LED stop lamps		Limited data			Limited data	
121: Air brake systems							
	ABS for heavy trucks and trailers[27]	Lim dat	(Yes)	Yes	Lim dat	(Yes)	Yes
126: Electronic stability control							
	ESC[28]	Yes	(Yes)	Yes	Yes	(Yes)	Yes

[25] Tape installed on heavy trailers is effective in preventing cars and LTVs from hitting those trailers.
[26] Result for LTVs inferred from the evaluation of cars.
[27] ABS on heavy vehicles helps them avoid hitting cars and LTVs; injury reduction inferred from the crash reduction.
[28] Injury reduction inferred from the crash reduction.

Table 1-1 (continued): Safety Technologies Evaluated by NHTSA

		Effectiveness			
		Cars		LTVs	
FMVSS	SAFETY TECHNOLOGY	Fatals	Injuries	Fatals	Injuries
201: Occupant protection in interior impact					
	Voluntary middle and lower instrument panel improvements	Yes	Yes	Yes	Yes
	1999-2003 head injury protection upgrade	Yes	Yes	Yes	Yes
202: Head restraints					
	Head restraints for outboard front seat occupants	No	Yes	(No)[29]	Yes
203: Impact protection from the steering control 204: Steering control rearward displacement					
	Energy-absorbing steering assemblies	Yes	Yes	Yes	Unknown
205: Glazing materials					
	High-penetration resistant (HPR) windshields	No	Yes	(No)	(Yes)
	Glass-plastic windshields	No	No	N/A	N/A
206: Door locks					
	Improved locks, latches and hinges for side doors[30]	Yes	(Yes)	(Yes)	(Yes)
207: Seating systems					
	Seat back locks for 2-door cars	No	No	N/A	N/A

[29] Result for LTVs inferred from the evaluation of cars.
[30] Injury reduction and LTV fatality reduction inferred from the fatality reduction in cars.

Table 1-1 (continued): Safety Technologies Evaluated by NHTSA

		Effectiveness			
		Cars		LTVs	
FMVSS	SAFETY TECHNOLOGY	Fatals	Injuries	Fatals	Injuries
208: Occupant crash protection 209: Seat belt assemblies 210: Seat belt assembly anchorages					
	Lap belts for front seat occupants	Yes	Yes	Yes	(Yes)[31]
	Lap belts for rear seat occupants	Yes	Yes	Yes	(Yes)
	Manual 3-point belts for outboard front seat occupants	Yes	Yes	Yes	(Yes)
	3-point belts for rear seat occupants	Yes	Yes	Yes	(Yes)
	Automatic seat belts	Yes	Unknown	N/A	N/A
	Pretensioners and load limiters for seat belts	Yes	Unknown	Yes[32]	Unknown
	Barrier-certified frontal air bags[33]	Yes	Yes	Yes	Yes
	Manual on-off switches for passenger air bags	Mixed results[34]			
	Sled-certified frontal air bags[35]	Yes	(Yes)	Yes	(Yes)
	Advanced frontal air bags[36]	Yes	(Yes)	Yes	(Yes)
212: Windshield mounting					
	Adhesive windshield bonding[37]	Yes	Yes	(Yes)	(Yes)

[31] "(Yes)" indicates result for LTV injuries inferred from the results for passenger car injuries and LTV fatalities (lap belts and 3-point belts, front and rear seats).
[32] Fatality reduction in CUVs and minivans.
[33] Except that fatalities increased for certain groups of child passengers in cars and LTVs.
[34] Prevents harm if the switch is turned off for child passengers; thwarts the benefit of the air bag if the switch is turned off for adult passengers.
[35] Significantly reduce fatality and injury risk relative to no frontal air bags; also significantly reduce risk for child passengers relative to barrier-certified air bags while preserving the effectiveness of barrier-certified air bags for adult and adolescent occupants.
[36] Significantly reduce fatality and injury risk relative to no frontal air bags; significantly reduce risk for child passengers relative to barrier-certified air bags while preserving the effectiveness of barrier- and sled-certified air bags for adult and adolescent occupants; by allowing phase-out of manual on-off switches, reduced risk of switches being turned off for adult passengers.
[37] "(Yes)" indicates results for LTVs inferred from corresponding results for cars.

Table 1-1 (continued): Safety Technologies Evaluated by NHTSA

		Effectiveness			
		Cars		LTVs	
FMVSS	SAFETY TECHNOLOGY	Fatals	Injuries	Fatals	Injuries
213: Child restraint systems					
225: Child restraint anchorage systems					
	Child safety seats	Yes	Yes	Yes	(Yes)[38]
	Riding in the rear seat	Yes	Unknown	Unknown	Unknown
214: Side impact protection					
	Side door beams	Yes	Yes	Yes	Unknown
	TTI(d) improvement by structure and padding	Yes	Unknown	N/A	N/A
	Curtain and side air bags	Yes	Unknown	Yes	Unknown
216: Roof crush resistance					
	Redesign of true hardtops as pillared hardtops or sedans	Yes	Unknown	N/A	N/A
223/224: Rear impact guards for heavy trailers[39]				Limited data	
226: Ejection mitigation					
	Rollover curtains	(Yes)[40]	Unknown	Yes	Unknown
301: Fuel system integrity					
	1975-1977 upgrade: rollover, rear- and lateral-impact tests	No	Yes[41]	No	No
	2007-2009 rear-impact upgrade	Yes	Unknown	Yes	Unknown
NCAP: New Car Assessment Program					
	Frontal NCAP-related improvements, vehicles w/o air bags	Yes	Unknown	Unknown	Unknown
	IIHS offset-frontal impact	Yes	Unknown	Unknown	Unknown

[38] "(Yes)" indicates result for LTV injuries inferred from the results for passenger car injuries and LTV fatalities.
[39] Rear impact guards on heavy trailers are potentially effective in mitigating fatality and injury risk for occupants of cars and LTVs hitting those trailers.
[40] Result for cars inferred from the evaluation of LTVs.
[41] Significant reduction of crashes with post-crash fires.

The evaluations showed a statistically significant fatality reduction for 31 technologies. The effectiveness estimates for those 31 technologies are the basis for the model that estimates lives saved by vehicle safety technologies in Part 2 of this report. The evaluations of ABS for cars and LTVs, amber rear turn signals, ABS for heavy vehicles, head restraints, HPR windshields, and the 1975-to1977 upgrade of FMVSS No. 301 showed significant reductions of crashes or nonfatal injuries, but they did not show a significant fatality reduction. The effectiveness estimates in Part 1 may be found in published NHTSA reports. Those NHTSA publications are cited in footnotes and listed in the References at the end of this report. Moreover, Appendix B provides capsule summaries of 82 evaluations published as of June 2014, in reverse chronological order.

The effectiveness of a safety technology can vary over time if there are changes in the design of that technology, in the crash environment, or in other features of vehicles (such as installation of other safety technologies). Effectiveness should be reevaluated periodically if feasible. The initial evaluation is often straightforward, statistically comparing vehicles just before versus just after a technology was introduced. Follow-up evaluations of later model-year vehicles may require more complicated statistical tools, because these vehicles may not be directly comparable to the vehicles produced just before the technology was introduced. For many technologies, NHTSA has published only one evaluation; this report assumes the effectiveness in specific crash types has stayed about the same in subsequent years. However, for quite a few technologies, NHTSA has completed one or more follow-up evaluations.

- Technologies with especially large potential benefits: 3-point belts for outboard front seat occupants, frontal air bags, ESC;
- Safety devices whose design has changed over the years: frontal air bags, curtain and side air bags, child safety seats;
- Technologies whose effectiveness might vary as the crash environment or other features vehicles change: 3-point belts, side impact protection by structure and padding; and
- Crash avoidance technologies whose effectiveness may change over time as a result of drivers' knowledge or familiarity with them: ABS, CHMSL, ESC.

The follow-up evaluations showed that the fatality-reducing effectiveness of 3-point belts for outboard front seat occupants, frontal air bags, ESC, and the other technologies listed above have not changed significantly over time. Belt effectiveness has remained stable despite the numerous changes in vehicle design and the crash environment.

Part 1 also summarizes the vehicle modifications and rationale for nine safety technologies that are already available in production cars and/or LTVs, but NHTSA has not yet fully studied the reduction of fatalities, injuries, or crashes, based on statistical analysis of crash data.

- FMVSS No. 138 – tire pressure monitoring systems (TPMS)
- 2010-to-2012 head restraint upgrade of FMVSS No. 202
- Tethers or attachments for child safety seats and their anchorages in the vehicle
- Booster seats (analysis, so far, is limited to nonfatal injuries)
- 2013-to-2016 roof crush resistance upgrade of FMVSS No. 216
- Frontal NCAP-related modifications in vehicles with air bags
- Modifications related to Side NCAP or IIHS side impact testing
- Rollover resistance NCAP-related modifications

Furthermore, the statistical evaluations of side impact protection by structure and padding and of curtain/side air bags have so far been limited to front seat occupants, because data on rear seat occupants is still quite limited – i.e., the estimates of lives saved by vehicle safety technologies will not count any rear seat occupants saved by these two technologies. Later on, when there is sufficient FARS data distinguishing between booster seats and other child safety seats, NHTSA will obtain separate estimates of fatality reduction for booster seats, but for the time being, the agency will assume a single effectiveness number for child safety seats and booster seats.

In addition to the 26 FMVSS reviewed in Part 1, there are 24 other FMVSS (in effect as of June 2014) that regulate new cars, new LTVs, or car/LTV components that have not been evaluated by NHTSA. The evaluation of FMVSS No. 139, "New pneumatic radial tires for light vehicles" will be combined with the future evaluation of the effect of TPMS on crash rates. The following FMVSS definitely or quite possibly resulted in tangible changes to vehicles, but were not evaluated because existing or potentially available data does not adequately identify what vehicles were modified; or because the type of crashes/injuries mitigated by the FMVSS cannot be singled out in available data (or cannot be identified at all); or because there is currently little hope of obtaining enough data for a statistically meaningful analysis of the effect, if any, that could reasonably be expected for that FMVSS.

- 114: Theft protection
- 116: Motor vehicle brake fluids
- 118: Power-operated windows
- 124: Accelerator control systems
- 125: Warning devices
- 129: New non-pneumatic tires for passenger cars
- 219: Windshield zone intrusion
- 302: Flammability of interior materials
- 303: Fuel system integrity of compressed natural gas vehicles
- 304: Compressed natural gas fuel container integrity
- 305: Electric-powered vehicles: electrolyte spillage and electrical shock protection
- 401: Interior trunk release

The following standards have not been evaluated even though they may regulate vehicle subsystems that are important for safety (e.g., tires, mirrors). The agency believes they probably did not result in extensive changes to those subsystems or does not know if they have resulted in changes. In many cases, the FMVSS may have largely incorporated other organizations' standards or industry-wide practices that vehicles had already been meeting for quite some time before 1968.

- 101: Controls and displays
- 102: Transmission shift lever sequence
- 104: Windshield wiping and washing systems
- 106: Brake hoses
- 109: New pneumatic tires
- 110: Tire selection and rims
- 111: Rearview mirrors
- 113: Hood latch systems

- 117: Retreaded pneumatic tires
- 119: New pneumatic tires for vehicles other than passenger cars
- 120: Tire selection and rims for vehicles other than passenger cars

Part 1 ends with Tables 1-2, 1-3 and 1-4 summarizing the effectiveness of safety technologies: their estimated percentage reductions in fatalities, nonfatal injuries and crashes (always specifying to what group of crashes/injuries these percentages apply). Tables 1-3 and 1-4 also specify estimated numbers of nonfatal injuries and crash prevented per year, if such estimates appeared in a NHTSA evaluation report. However, those individual estimates of benefits do not add up to the overall annual crash avoidance and nonfatal-injury reduction by all the technologies, because the agency has not estimated them for all technologies. NHTSA does not have enough "building blocks" to develop models for overall crash avoidance and injury reduction comparable to the analysis of fatal crashes in Part 2 of this report. Furthermore, these individual estimates, in general, are not directly comparable, because the various evaluation reports compute them using different baseline years.

What has changed from NHTSA's 2004 report?

As stated above, NHTSA issued a report in 2004 that estimated vehicle safety technologies had saved 328,551 lives from CY 1960 through 2002.[42] This report updates the estimates through 2012 by incorporating FARS data from 2003 through 2012 into the analysis and by including the effects of safety technologies that NHTSA has evaluated since the previous report.

The effectiveness estimates for the 31 technologies with statistically significant fatality reductions drive the current model to estimate lives saved. Only 22 of those technologies were considered in the model of the 2004 report. Seven of the remaining nine were already available in some production vehicles of MY 2002 or earlier – ESC, curtain and side air bags, the head-impact upgrade of FMVSS No. 201, belt pretensioners and load limiters, manual switches for passenger air bags, redesigned frontal air bags, and rollover curtains – but NHTSA did not yet have estimates of fatality reduction based on crash data. The other two technologies – advanced frontal air bags and the 50 mph rear-impact test for FMVSS No. 301 – were still in the future. Furthermore, the earlier report's effectiveness estimate for side-impact structures and padding is superseded by a 2007 analysis. (The earlier report's estimates for car/LTV ABS are also superseded, by a 2009 analysis, but only for nonfatal crashes and injuries; it will not affect the computation of lives saved.)

The estimates of lives saved in the current report are identical to the 2004 report from CY 1960 (115 lives saved) through CY 1985 (6,389 lives saved). Small differences begin in 1986 (8,531 lives saved here, 8,523 in the earlier report). The current report has new estimates of the effects of side-impact structures and padding. These improvements began gradually on a voluntary basis in MY 1986, even though the upgrade to FMVSS No. 214 did not phase in until MY 1994 to 1997. Because technologies whose effects are included here but not in the earlier report – ESC, curtain and side air bags, etc. – proliferated after 1995, the current report's estimates of lives saved become progressively somewhat higher than the earlier report's (e.g., 25,691 versus 24,561 in 2002).

[42] Kahane (2004, October).

Estimating lives saved by safety technologies, 1960 to 2012

Part 2 of this report focuses on the safety technologies that have significantly reduced fatality risk. The individual effectiveness estimates and the basic analysis method, described above, are applied to FARS data to estimate how many lives were saved from 1960 to 2012. The tables in Part 2 also estimate how many lives were saved.

- In each calendar year
- By each individual safety technology
- Technologies grouped by associated FMVSS
- By vehicle type:
  - Car occupants
  - LTV occupants
  - Pedestrians and motorcyclists saved by car/LTV braking improvements or ESC
- Distinguishing between lives saved by technologies compliant with FMVSS that were in effect at the time and "voluntary" saves such as:
  - Improvements introduced before the effective date of a FMVSS
  - Technologies not required for meeting any FMVSS, although perhaps indirectly associated with a FMVSS because they address the same general safety problem

Part 2 compares the actual number of fatalities from 1960 to 2012, or in any specific year to the number that potentially would have occurred, given the same driving exposure, if none of the cars and LTVs had been equipped with any of the safety technologies. It computes the percentage of the potential fatalities that were saved by the technologies. Part 2 also compares the trends in fatalities per 100,000,000 VMT – with and without the vehicle safety technologies.

Every life-saving technology in Table 1-1 is included in Part 2. Child passengers' "riding in the rear seat," although listed in Table 1-1, is not included in Part 2 because it is not a technology, but the objective of a behavioral safety initiative. Just as Part 2 does not count lives saved by the recent shift of child passengers from front to rear seats among the "benefits of the vehicle safety technologies," it does not count the effects of other market shifts between existing vehicle types, such as between:

- 2-door cars and 4-door cars;
- Large cars and small cars;
- Passenger cars and LTVs; or
- Truck-based SUVs and CUVs.

While these shifts can and do affect the number of fatalities, they cannot be considered benefits of new safety technologies of the FMVSS era. Part 2 considers only their implicit effects on the year-to-year changes in actual and potential fatalities.

PART 1

Review of 26 Federal Motor Vehicle Safety Standards And the New Car Assessment Program

Comprising 53 Safety Technologies

And Their Effectiveness in Reducing Fatalities, Injuries and Crashes for Passenger Cars and LTVs

Following the review of the FMVSS and NCAP, Tables 1-2, 1-3 and 1-4 summarize the fatality-, injury- and crash-reducing effectiveness (percentage reductions) of the safety technologies. Tables 1-3 and 1-4 also summarize annual benefits of individual technologies: injuries and crashes avoided per year. Part 2 of this report estimates the annual fatality reduction, for each technology individually and for all of them together.

FMVSS No. 103, "Windshield defrosting and defogging systems"

A vehicle modification whose safety benefits have been evaluated by NHTSA is grouped with this standard merely because the functions are similar:

- **Rear window defrosting and defogging systems**

FMVSS No. 103 regulates windshield defrosting and defogging. One of NHTSA's initial safety standards, effective on January 1, 1968, it required passenger cars and SUVs to have windshield defroster/defoggers and it set performance requirements for them, incorporating SAE Recommended Practices dating back to 1964. Cars and LTVs had windshield defroster/ defoggers well before 1968. They remained unchanged during the mid-to-late 1960s.[43]

FMVSS No. 103 has never required or proposed to require rear-window defoggers. Their development has been voluntary on the part of the industry, in response to customer demand. Drivers obviously want a clear rear window, and they like a device that clears it for them automatically, so they do not have to wipe or scrape it repeatedly.

History of rear window defoggers: *Ward's Automotive Yearbooks*[44] began to include rear window defoggers in MY 1973 among their statistics for factory-installed equipment in domestic cars by make-model. In that year, 16 percent of new cars were equipped with them; presumably, they were offered in smaller numbers some years before that. Installations grew steadily in the 1970s and 1980s. By 1992, over 90 percent of new cars were equipped with them. By MY 2001, they were standard equipment on most cars, SUVs and minivans, but not pickup trucks or full-size vans; 94 percent of new cars were equipped with them.[45]

How they work: Current rear-window defoggers are grids of electric wires attached to the rear window. The wires are thin enough not to obstruct vision. Controlled by a switch on the instrument panel, they heat up to evaporate condensation or melt ice and snow. The switch automatically turns off after a certain number of minutes, in order to save wear and tear on the system, and the driver has to turn it back on if the window is not clear. During the 1970s some defoggers consisted of an electric heater and blower-motor. That type was gone by 1982.

Rear-window defoggers are potentially useful when: (1) environmental factors such as rain, snow or cold fog or ice up the window; (2) the driver turns on the switch. In warm, dry, sunny conditions, windows are normally clear and defoggers are not needed. The situations that might put condensation, snow or ice on the window include any kind of precipitation; early morning hours when water vapor in the outside air condenses as dew; and very cold weather that can make water vapor inside the vehicle condense on windows. Whereas rear-window defoggers rap-

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[43] *Federal Register* 32 (February 3, 1967): 2414; Up-to-date text of NHTSA regulations may be downloaded from the electronic Code of Federal Regulations, Title 49, www.ecfr.gov/cgi-bin/text-idx?c=ecfr&tpl=/ecfrbrowse/Title49/49tab_02.tpl. Regulations other than FMVSS are referenced as Part numbers (e.g., Part 563, "Event data recorders"). FMVSS are referenced as Part 571 followed by the FMVSS number (e.g., Part 571.103 = FMVSS No. 103, "Windshield defrosting and defogging systems").

[44] Southfield, MI: Penton Media, Inc.

[45] Morgan, C. (2004, March). *Evaluation of rear window defrosting and defogging systems*. (Report No. DOT HS 809 724, pp. 1-4). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809724.PDF.

idly dispel condensation, they cannot melt large amounts of ice, but they make it easier to scrape off.

Expected benefits: Based on the preceding descriptions of how rear-window defoggers work, here are some hypotheses of the types of crashes where statistical analyses might show benefits. This discussion of "expected benefits" as well as similarly titled discussions in most of the FMVSS chapters of Part 1 of this report are akin to opening statements in a jury trial. They are not a presentation of facts or evidence; rather, they set the stage and help identify what types of statistical analyses of crash data would be most useful for demonstrating effectiveness and benefits.

Rear-window defoggers might help prevent collisions by allowing a driver to see through the back window, either directly or via the inside rear-view mirror – but only when there are environmental conditions that are fogging or icing up the windows, and when the driver has activated the defoggers. Specifically, there are two maneuvers where a driver must know, or at least ought to know what is behind the vehicle. The maneuvers could result in rear-impact collisions if performed in an unsafe manner:

- Backing up: obviously, the driver needs to know what is directly behind the vehicle, and that is much easier if he or she can look through a rear window that has been cleared by a defogger. Without a defogger (and before the advent of rear-mounted video cameras), the driver's alternative strategies would be relying on outside mirrors, getting out of the car to look around/wipe the window, or just backing up a short distance very slowly and hoping for the best.
- Changing lanes: good, defensive driving includes periodic scanning to the rear of the vehicle to know if it will be safe to change lanes should it suddenly become necessary. Obviously, this is easiest with a correctly positioned inside rear-view mirror and a clear window. Without them, the driver would have to rely more on outside mirrors, change lanes with less confidence that it is safe, or even forego lane changes unless they are absolutely necessary.

Analysis of crash avoidance – passenger cars: NHTSA's study, published in 2004, used crash data from Michigan (1981-91) and Florida (1986-99). The basic analysis method was to compare the number of rear-impacts involving either of the pre-crash maneuvers where rear-window defoggers might be effective – backing up or changing lanes – to the number of rear-impact involvements where the vehicle had been standing still for some time and was hit by somebody else. The latter are a control group, because the drivers did nothing to cause the crash, and rear-window defoggers would not have prevented it. Did the ratio of impacts while backing up or changing lanes to impacts while standing still decrease with rear window defoggers – in the types of environmental conditions when defoggers might be in use (precipitation, early morning, winter)?[46]

This is a difficult statistical analysis. Neither the police-reported data elements nor the VIN included on the Michigan and Florida files indicate if any specific vehicle was equipped with rear-window defoggers. The VIN only identifies the make-model and the model year. *Ward's Auto-*

[46] *Ibid.*, pp. 9-14.

motive Yearbooks indicate the percentage of vehicles with rear-window defoggers by make-model and MY. However, unlike most other safety technologies that went from 0 to 100 or near-100 percent of vehicles from one MY to the next, rear-window defoggers increased their market share of nearly all make-models gradually, a few percent more each year. That precluded a relatively simple 3-way contingency table analysis (yes/no defogger, impact type, environmental condition) and necessitated logistic regressions on each State's data. The dependent variable was the type of rear impact (backing-up or changing-lanes versus control group). The independent variables were the proportion of vehicles of that make-model and MY equipped with defoggers, the environmental conditions (precipitation, early morning or winter versus none of the above), vehicle age, driver age/gender, calendar year, and the specific make-model. However, the key independent variable was the interaction term between rear-window defogger and adverse environmental conditions. If defoggers are effective, there should be a significant reduction in backing-up/changing-lanes involvements under adverse environmental conditions.[47]

The statistical analyses showed little or no effect for defoggers in either State. The evaluation was unable to conclude that rear-window defoggers reduce police-reported crashes. It may be that the complexity of the analysis, necessitated by the data, made it harder to identify an effect. It may also be that rear-window defoggers are not that essential to bottom-line safety. As explained in "Expected Benefits," drivers usually have alternative strategies to compensate for the absence of a defogger: more reliance on outside mirrors, getting out of the car to look around or wipe the window when that can be done safely, or simply backing up and changing lanes less frequently/more gradually. These alternatives are, at best, inconvenient and sometimes unnerving. Therefore, we would expect most drivers will continue wanting to have rear-window defoggers on their vehicles.[48]

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[47] *Ibid*., pp. 4-8 and 14-17.
[48] *Ibid*., pp. v-vi and 18-27.

FMVSS No. 105, "Hydraulic and electric brake systems"

FMVSS No. 135, "Light vehicle brake systems"

NHTSA has evaluated four innovative braking technologies for passenger vehicles:

- **Dual master cylinders,**
- **Front disc brakes,**
- **Rear-wheel antilock (RWAL) brake systems for LTVs, and**
- **Four-wheel antilock brake systems (ABS) for passenger cars and LTVs.**

The goal of dual master cylinders is to provide dual hydraulic circuits, so that a fault in one hydraulic system will not lead to a catastrophic loss of all braking power. They have been standard equipment on most passenger cars since MY 1967. Front disc brakes enhance a driver's control by providing a more linear pedal "feel" than drum brakes. They are also less prone to "fade" from overheating or exposure to water. They have been standard on most cars since MY 1977. Rear-wheel antilock (RWAL) brake systems are designed to prevent rear-wheel lockup and loss of control during braking. Four-wheel antilock brake systems (ABS) do what RWAL does and additionally allow drivers to keep control of a vehicle and steer it during severe braking. From approximately 1993 through 2004, antilock brakes were installed as standard or optional equipment on approximately 70 percent of new cars (4-wheel) and LTVs (4-wheel or rear-wheel). However, 4-wheel ABS gradually superseded RWAL in LTVs; RWAL was gone by 2004. ABS installations again began to increase in MY 2005 and reached 100 percent of new cars and LTVs in MY 2012.

FMVSS No. 105 regulated all hydraulic brake systems until 2000-2002, when it was superseded by FMVSS No. 135 for vehicles with GVWR up to 3500 kg.[49] FMVSS No. 105 is a performance standard, specifying stopping distances or deceleration rates for a series of stopping tests under various conditions. It does not prescribe technologies. However, dual master cylinders satisfied the FMVSS No. 105 requirement for a dual or split braking system. Front disc brakes helped vehicles pass the fade and water-recovery tests added to FMVSS No. 105, effective September 1, 1975. FMVSS No. 135 is a standard harmonized with requirements in other countries; it is equivalent to the current European standard ECE R13-H. It also upgrades some requirements of FMVSS No. 105 – e.g., it lowers the maximum allowable pedal effort in a case of partial systems failure – while retaining other features of FMVSS No. 105. ABS has never been required for vehicles with a GVWR less than 10,000 pounds, but Congress asked NHTSA in 1991 to consider an ABS requirement in FMVSS No. 105. However, FMVSS No. 126 required ESC in all new cars and LTVs in MY 2012. Because, to date, every ESC system includes within it the components needed to perform ABS functions, FMVSS No. 126 has *de facto* put ABS into all new cars and LTVs. NHTSA's evaluations of these four technologies will now be discussed, one-by-one.

Dual master cylinders

Regulatory history: Before it was superseded by FMVSS No. 135 in 2000-2002, FMVSS No. 105 applied to all motor vehicles with hydraulic brakes. The first version of FMVSS No. 105

[49] 49 CFR, Parts 571.105 and 571.135. However, after 2002, FMVSS No. 105 continued to apply to vehicles with a GVWR greater than 3,500 kg.

was one of NHTSA's initial safety standards, with an effective date of January 1, 1968, for passenger cars. To a large extent, it incorporated SAE Recommended Practices dating back to 1966. FMVSS Nos. 105 and 135 allow two alternatives for hydraulic brakes: (1) Vehicles may have a "split service brake system" – i.e., "a brake system consisting of two or more subsystems actuated by a single control, designed so that a single failure in any subsystem (such as a leakage-type failure of a pressure component of a hydraulic subsystem…) does not impair the operation of any other subsystem" that enables the vehicle to stop within a specified distance even "in the event of any one rupture or leakage type of failure in any component of the service brake system." Dual or tandem master cylinders met the requirement. (2) Alternatively, vehicles may have a single hydraulic circuit if they can meet even more stringent stopping tests in the partial failure mode.[50] Dual master cylinders were installed on 9 percent of MY 1962 and 1963 cars, 7 percent of MY 1964 and 1965 cars, and most new cars from MY 1967 onwards. It is likely that dual master cylinders were also installed in LTVs at about the same time (although FMVSS No. 105 was only extended to LTVs effective September 1, 1983).[51]

How dual master cylinders work: Without dual master cylinders, a significant loss of pressure in the hydraulic system due to a leak can result in a complete, catastrophic loss of braking power. Moreover, when there is a slow leak that will eventually lead to a loss of pressure, the vehicle does not send an early warning that can be easily understood by the average driver. The Indiana Tri-Level Study of the Causes of Accidents suggested that approximately 2 percent of all crashes in cars with 1960s technology were caused by some type of catastrophic brake failure, most commonly hydraulic failures.[52]

A dual braking system consists of two separate hydraulic circuits – typically split front-and-rear in rear-wheel-drive cars, or diagonally in front-wheel-drive cars. Both circuits are activated by the brake pedal through one master cylinder that has two chambers, called a "dual master cylinder." If one of the circuits fails, the other is still available. The car can be stopped from high speeds, although of course not as quickly as when both circuits are intact. A second important feature is that the dual master cylinder has a sensor to detect the relative pressure in the chambers. If there is an imbalance, it activates a warning light on the instrument panel. It is an unambiguous early warning that the brake system needs repair.[53]

Expected benefits Dual master cylinders should prevent many of the crashes involving catastrophic brake failure, specifically those due to failures in the hydraulic system. Possible exceptions could include certain types of failure within the master cylinder or cases where the driver ignores the warning light. Since catastrophic brake failures can occur in fatal and injury crashes, dual master cylinders ought to have an effect on fatalities and injuries. Moreover, when brake

[50] *Ibid*., Part 571.105 S4, S5.1.2.1 and S5.1.2.2; *Federal Register* 32 (February 3, 1967): 2414; SAE. (1967). *1967 SAE Handbook*. New York: Society of Automotive Engineers., pp. 856-857.
[51] Kahane, C. J. (1983, February). *A preliminary evaluation of two braking improvements for passenger cars – Dual master cylinders and front disc brakes*. (Report No. DOT HS 806 359, pp. 1-7). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/806359.PDF; *Federal Register* 46 (January 2, 1981): 55.
[52] Treat, J. R., Tumbas, N. S., McDonald, S. T., Shinar, D., Hume, R. D., Mayer, R. E., Stansifer, R. L., &Castellan, N. J.. (1977). *A tri-level study of the causes of traffic accidents*, Vol. 1. (Report No. DOT HS 805 085). Washington, DC: National Highway Traffic Safety Administration.
[53] The sensor in some vehicles also detects low fluid level in the master cylinder reservoirs.

failure in one vehicle results in a collision with another vehicle or pedestrian, preventing the brake failure in that one vehicle will prevent the fatalities or injuries of every crash partner, including the other vehicles' occupants and pedestrians.

Crash avoidance – passenger cars: NHTSA's evaluation was published in 1983. It is based on crash data from North Carolina (1971 to 1981) and Texas (1972, 1974, and 1977).[54] The data allow comparison of the proportion of crash involvements in which "defective brakes" are a "contributing factor" for cars with single versus dual master cylinders. However, it is important to control for vehicle age, since the rate of brake defects increases strongly as a vehicle ages. The analysis method is linear regressions of the proportion of crash involvements (in a given MY and CY) in which defective brakes are a contributing factor, by percentage of cars with dual master cylinders, vehicle age, and other control variables. The regressions attributed an unequivocal, statistically significant reduction of brake defects upon the introduction of dual master cylinders. The effectiveness estimate is a 0.7-percent reduction of all police-reported crashes involving at least one car, when all cars are equipped with dual master cylinders.[55] The incidence of "defective brakes" was reduced by approximately 35 percent (0.7/2.0). Using 1979 to 1980 as the "baseline" years, the evaluation estimated that dual master cylinders would prevent 40,000 police-reported crashes per year when all cars on the road were equipped with them.[56]

Injury reduction – passenger cars: Estimates of injury reduction were obtained by limiting the preceding analyses of North Carolina and Texas data to injury-producing crashes – i.e., crashes where at least one occupant in any of the involved vehicles (not necessarily the vehicle equipped with a dual master cylinder) was injured.[57] The regression showed virtually the same effectiveness in injury-producing crashes as in property-damage crashes. The evaluation estimated that dual master cylinders prevent 0.7 percent of injury-producing crashes, resulting in a reduction of 24,000 injuries per year.[58]

Fatality reduction – passenger cars: The preceding regression analyses were also performed with 1975-81 FARS data.[59] They showed a statistically significant reduction for dual master cylinders, proportionately about the same as in the nonfatal crashes. The evaluation assumed that brake defects are a contributing factor in similar percentages of fatal and nonfatal crashes (i.e., 2 percent of crashes, in cars without dual master cylinders). It estimated that dual master cylinders prevent 0.7 percent of fatal crashes that involve passenger cars, saving 260 lives per year.[60]

LTVs: The 1983 evaluation addressed only passenger cars. However, FMVSS No. 105 also applies to LTVs. Both types of vehicles use fairly similar hydraulic braking technology. It seems likely that dual master cylinders could have about the same effect in LTVs as in cars: a 0.7-percent reduction of crashes, injuries and fatalities.

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[54] Kahane (1983, February), pp. 15-38.
[55] *Ibid*., p. 43; 90 percent confidence bounds: 0.58 to 0.82 percent.
[56] *Ibid*., pp. 55-57; 90 percent confidence bounds: 33,000 to 47,000 crashes prevented.
[57] *Ibid*., pp. 28-29.
[58] *Ibid*., pp. 55-57; 90 percent confidence bounds: 19,000 to 28,000 injuries prevented.
[59] *Ibid*., pp. 38-40.
[60] *Ibid*., pp. 55-57; 90 percent confidence bounds: 220 to 310 lives saved.

Front disc brakes

Regulatory history: Front disc brakes began to appear on domestic passenger cars in MY 1965. Consumers welcomed the new technology. It jumped from 13 percent of new cars in 1968 to 86 percent by 1973. In 1970, NHTSA proposed FMVSS No. 105a, incorporating more stringent stopping distance, fade- and water-recovery tests than the original FMVSS No. 105, with a proposed effective date of October 1, 1972. After several revisions, this regulation took effect for passenger cars on January 1, 1976, and LTVs on September 1, 1983. Although some cars with four-wheel drum brakes could and did pass the new tests, it was easier to meet them with front disc brakes. Furthermore, the superior self-adjusting characteristics of disc brakes allowed for increased vehicle stability during the high-speed stopping tests in FMVSS No. 105. By MY 1978, most cars and LTVs produced for sale in the United States were equipped with front disc brakes. (FMVSS No. 105 or 135 have never explicitly required disc brakes.)[61]

How front disc brakes work: Disc brakes are calipers equipped with abrasive pads that squeeze rotors, metal plates parallel to the wheels that rotate with the wheels. Drum brakes are shoes with abrasive linings that press against the insides of drums that rotate with the wheels. Whereas drum brakes readily heat up from overuse or fill up with water upon immersion, resulting in losses of braking ability, disc brakes are ventilated to dissipate heat or shed water quickly. Furthermore, drum brakes have a "self-energizing capability" (friction building up more rapidly than pedal pressure) that makes drivers prone to lock the wheels. Disc brakes have a more linear relationship between pedal pressure and vehicle deceleration, making it easier for drivers to deliver just the right amount of pressure short of locking the wheels.[62]

Expected benefits: Front disc brakes might prevent some crashes involving catastrophic brake failure, especially on mountain roads, where brakes could fade from overuse on the downhills, or on flooded roads, where water gets into the wheels. If drivers use the more linear pedal feel to advantage, that could manifest itself in two ways in the crash data: if locking the wheels is reported as "defective brakes," a reduction in lockup could result in fewer reported brake defects. If drivers can better optimize their deceleration rate short of lockup, they will stop in a shorter distance, possibly reducing the risk of frontally hitting other vehicles in the rear. Since brake failures/defects can occur in fatal and injury crashes, front disc brakes could have an effect on fatalities and injuries. Moreover, when brake failure in one vehicle results in a collision with another vehicle or pedestrian, preventing the brake failure in that one vehicle will prevent the fatalities or injuries of every crash partner, including the other vehicles' occupants and pedestrians.

Crash avoidance – passenger cars: NHTSA's 1983 evaluation has several analyses of the proportion of crash involvements in which "defective brakes" are a "contributing factor" for cars with drum versus front disc brakes. The most reliable one is based on North Carolina data (1971 to 1981). It subdivides the data by make-model as well as MY, since front disc brakes were in-

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[61] *Ibid*., p. 7; *Federal Register* 35 (November 11, 1970): 17345, 37 (September 2, 1972): 17970, 38 (May 18, 1973): 13017, 39 (February 22, 1974): 6708, 40 (June 9, 1975): 24525, 46 (January 2, 1981): 55; *Ward's Automotive Yearbook*. (1975 to 1979). Detroit: Ward's Communications.

[62] *Ibid*., pp. 6-10; Ballard, C., & Andrade, D. (1976). *Systems and hardware effects of FMVSS 105-75*. (Paper No. 760216). Warrendale, PA: Society of Automotive Engineers; Kahane, C. J., & Ichter, K. D. (1984). *Statistical evaluation of brake safety improvements for passenger cars*. (Paper No. 841236). Warrendale, PA: Society of Automotive Engineers.

troduced earlier in some models than in others.[63] The analysis method is a linear regression of the proportion of crash involvements (in a given make-model, MY, and CY) in which defective brakes are a contributing factor, by percentage of cars with front disc brakes, vehicle age, and other control variables. The regressions attributed a statistically significant reduction of brake defects upon the introduction of front disc brakes, equivalent to a 0.17-percent reduction of all police-reported crashes involving at least one car.[64] Using 1979 to 1980 as the "baseline" years, the evaluation estimated that front disc brakes would prevent 9,800 police-reported crashes per year when all cars on the road were equipped with them.[65] Other analyses of North Carolina data showed reductions of "defective brake" crashes on hilly and wet roads with front disc brakes, but not necessarily greater reductions than on other roads.[66] The analysis of front-to-rear crashes attributed to front disc brakes a 0.2-percent reduction in the likelihood of being the striking car, but this was not statistically significant.[67]

Injury reduction – passenger cars: Estimates of injury reduction were obtained by limiting the preceding analysis of North Carolina data (by make-model) to injury-producing crashes.[68] The regression showed virtually the same effectiveness in injury-producing crashes as in property-damage crashes. The evaluation estimated that front disc brakes prevent 0.17 percent of injury-producing crashes, resulting in a reduction of 5,700 injuries per year.[69]

Fatality reduction – passenger cars: Regression analyses of 1975-to-1981 FARS data (not subdivided by make-model) attributed a statistically significant 0.55-percent reduction of "defective brake" involvements to front disc brakes.[70] However, the evaluation estimated, more conservatively, that front disc brakes would have proportionately the same effect in fatal as in nonfatal crashes: a 0.17-percent reduction of fatal crashes that involve passenger cars, saving 64 lives per year.[71]

LTVs: The 1983 evaluation addressed only passenger cars. However, front disc brakes have superseded front-wheel drum brakes in LTVs as well as in passenger cars. Both types of vehicles use fairly similar hydraulic braking technology. It seems likely that front disc brakes could have about the same effect in LTVs as in cars: a 0.17-percent reduction of crashes, injuries and fatalities.

Rear-wheel antilock (RWAL) brake systems for LTVs

Regulatory history and voluntary installations: No type of antilock brake system (ABS) has ever been required for passenger vehicles with GVWR less than 10,000 pounds. However, the Highway Safety Act of 1991, Section 2507 instructed NHTSA to consider requiring ABS in passenger vehicles. NHTSA published an ANPRM at the beginning of 1994 asking for information

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[63] Kahane (1983, February), pp. 26-28.
[64] *Ibid*., p. 44; 90 percent confidence bounds: 0.10 to 0.24 percent.
[65] *Ibid*., pp. 55-57; 90 percent confidence bounds: 5,800 to 13,800 crashes prevented.
[66] *Ibid*., pp. 29-31.
[67] *Ibid*., pp. 45-47.
[68] *Ibid*., pp. 28-29.
[69] *Ibid*., pp. 55-57; 90 percent confidence bounds: 3,400 to 8,100 injuries prevented.
[70] *Ibid*., pp. 38-40.
[71] *Ibid*., pp. 55-57; 90 percent confidence bounds: 38 to 90 lives saved.

about the effectiveness and potential benefits of ABS technologies.[72] Based on responses to the 1994 ANPRM, including statistical studies by NHTSA and others that failed to show significant net benefits for voluntarily installed ABS, NHTSA issued a second ANPRM in 1996 deferring indefinitely the ABS requirement.[73]

Rear-wheel antilocks were installed as standard equipment in 1987 Ford F-Series pickup trucks, Bronco and Bronco II. In 1988 to 1990, they were phased into most domestic pickup trucks and SUVs as well as many vans as standard equipment. During the 1990s, 4-wheel ABS increasingly superseded RWAL; by MY 2004, no new domestic LTVs were equipped with RWAL.[74]

How RWAL works: The fundamental safety problem addressed by any ABS system is that few drivers are able to modulate pressure on the brake pedal optimally, given a sudden emergency situation or unexpectedly slippery surface. If excess pedal pressure locks the rear wheels, the vehicle can lose control. LTVs are especially prone to rear-wheel lockup when they are not heavily loaded. RWAL senses if any of the rear wheels have locked, and if so, quickly releases the brakes on that wheel and lets it start rolling again. Cycles of releasing, holding and reapplying brakes are repeated many times per second. RWAL, however, will not prevent front-wheel lockup or assure steering control during braking. If the front wheels lock while the rear wheels turn, the truck will just slow down on a straight line, without yawing. NHTSA conducted stopping tests on five surfaces with RWAL-equipped trucks, and also for the same trucks with the RWAL disabled. RWAL substantially but not completely reduced the frequency and severity of yawing in spike stops. That benefit, however, was offset by a slight (6 to 18%) increase in stopping distances on four of the surfaces.[75]

Expected benefits: If RWAL prevents or substantially reduces yawing, it will help keep trucks from running off a straight road. By keeping the truck on the road, it may prevent the rollovers or impacts with fixed objects or pedestrians that can occur after a vehicle has left the road. Side impacts with fixed objects are especially characteristic of vehicles that have yawed out of control. RWAL would be less effective if the driving task requires steering as well as braking (e.g., on a curved road). It will not affect yawing caused by reasons other than brake-induced rear-wheel lockup (e.g., going around a curve too quickly). To the extent that RWAL is associated with a slight increase in stopping distances, there could be an adverse effect on multivehicle crashes that require a truck to stop in time to avoid hitting another vehicle.

Crash avoidance: NHTSA's initial evaluation published in 1993 and based on crash data from Florida (1990 to 1991), Michigan (1990 to 1991), and Pennsylvania (1989 to 1991) showed some statistically significant reductions of nonfatal rollovers and side impacts with fixed objects in

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[72] *Federal Register* 59 (January 4, 1994): 281.

[73] *Federal Register* 61 (July 12, 1996): 36698.

[74] Kahane, C. J. (1993, December). *Preliminary evaluation of the effectiveness of rear-wheel antilock brake systems for light trucks*. (NHTSA Docket No. 70-27-GR-026, p. 15). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/7027GR.PDF; Kahane, C. J., & Dang, J. N. (2009, August). *The long-term effect of ABS in passenger cars and LTVs*. (Report No. DOT HS 811 182, pp. 5-7). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811182.PDF.

[75] Kahane (1993, December), pp. 7-14; Hiltner, E., Arehart, C., & Radlinski, R. (1991). *Light vehicle ABS performance evaluation*. (Report No. DOT HS 807 813). Washington, DC: National Highway Traffic Safety Administration; Arehart, C., Radlinski, R., & Hiltner, E. (1992). *Light vehicle ABS performance evaluation – Phase II*. (Report No. DOT HS 807 924). Washington, DC: National Highway Traffic Safety Administration.

LTVs equipped with RWAL.[76] However, in 2009, NHTSA issued a follow-up evaluation based on GES data (a national sample) from 1995 to 2007 and comprising a larger list of LTV make-models that had been equipped with RWAL at some point. The follow-up study shows negligible effect for RWAL overall and it does not show a statistically significant effect in any specific type of crashes, such as rollovers.[77] Involvements in crashes of interest where RWAL might potentially be effective are compared to a control group of crash involvements in which RWAL would not likely have been a factor. The control group consists of vehicles involved in multivehicle crashes that were stopped, parked, entering or leaving a parking space, backing up, or moving at 10 mph or less prior to the collision; were struck in the rear; or the crash occurred on a dry road and their driver was not culpable. Here are the counts of unweighted GES cases (to provide an idea of the sample sizes) and nationally weighted counts (used for computing the overall effect of RWAL).

GES 1995 to 2007	Crash Involvements of Interest	Control Group	Risk Ratio
Unweighted Cases			
Last 2 MY without RWAL	6,971	6,260	
First 2 MY with RWAL	8,334	7,465	
Weighted Counts			
Last 2 MY without RWAL	847,914	813,267	1.043
First 2 MY with RWAL	1,006,270	940,476	1.070

The weighted counts show a negligible increase in crashes involvements of interest, relative to the control group, in the LTVs with RWAL.

Fatality reduction: Statistical analyses by the same method of 1995-to-2007 FARS data showed a 4-percent reduction of fatal crash involvements with RWAL, relative to the control group, an effect that is not statistically significant.[78] Because FARS is a national census, it is not necessary to weight the cases; the analysis may be performed directly on the actual case counts.

FARS 1995 to 2007	Crash Involvements of Interest	Control Group	Risk Ratio
Last 2 MY without RWAL	8,722	3,577	2.438
First 2 MY with RWAL	9,840	4,185	2.351

Collisions with pedestrian and bicyclists were the only subgroup of crashes where the analysis showed a statistically significant change relative to the control group: a 15-percent reduction with RWAL. It is not clear why RWAL would be directly of help if a pedestrian suddenly ap-

[76] Kahane (1993, December), pp. 19-44.
[77] Kahane & Dang (2009, August), pp. 57-60.
[78] *Ibid*., pp. 33-38.

pears in front of the driver. The goal of RWAL is to prevent rear-wheel lockup that could result in a loss of control and lane departure. It has little effect on stopping distance or ability to steer the vehicle while braking. Perhaps over time drivers of LTVs equipped with RWAL have become acclimatized to braking immediately and aggressively, as they have become less afraid that it could result in rear-wheel lockup that would be dangerous for them. That extra braking effort may be just enough to avoid hitting some pedestrians. However, by the same logic, a reduction in collisions with other vehicles might be expected, but none was observed.

Four-wheel antilock brake systems for passenger cars and LTVs

Regulatory history and voluntary installations: As described above, during the 1990s NHTSA considered, but then deferred any requirement for ABS on passenger vehicles with GVWR less than 10,000 pounds. But eventually FMVSS No. 126 required ESC in cars and LTVs by MY 2012. Because, to date, every ESC system can perform ABS functions, all new cars and LTVs now have 4-wheel ABS.

Modern 4-wheel ABS was first offered as standard equipment in 1985 on some lines of BMW, Lincoln and Mercedes and in 1986 on Chevrolet Corvette. Availability of ABS increased gradually from 1987 to 1990 and dramatically in 1991 and 1992, when it became standard on the majority of GM cars. From 1994 to 2001, about 60 to 65 percent of new passenger cars were equipped with ABS. At that time, ABS was usually standard on the larger and more expensive cars, optional and not too frequently sold on small economy cars. Four-wheel ABS installations for LTVs began in 1989 on some GM Astro/Safari minivans, Jeep Cherokee and Jeep Wagoneer. The market share for 4-wheel ABS in new LTVs steadily increased during the 1990s, as RWAL was phased out, and had reached about 90 percent by 2004.[79]

How ABS works: Few drivers are able to modulate pressure on the brake pedal optimally, given a sudden emergency situation or unexpectedly slippery surface. If excess pedal pressure locks only the front wheels, the vehicle will continue in a straight path, but the driver will be unable to steer it and avoid obstacles. If it locks the rear wheels, the vehicle can lose control. ABS senses if any of the four wheels have locked, and if so, quickly releases the brakes on that wheel and lets it start rolling again. Cycles of releasing, holding and reapplying brakes are repeated many times per second.

ABS activation causes noise and pedal vibration in some vehicles, and steering may not be as easy as in normal operation. Nevertheless, a reasonably alert driver familiar with the system will maintain pressure on the pedal, stop in a minimum distance and be able to steer the vehicle throughout the crash avoidance maneuver. During the mid-1990s, the safety community worked hard to inform the public about the correct use of ABS (“Don’t let up on the brakes”; “Stomp, stay, and steer”).[80]

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[79] Kahane, C. J. (1994, December). *Preliminary evaluation of the effectiveness of antilock brake systems for passenger cars*. (Report No. DOT HS 808 206, pp. 9 and 119-128). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/808206.PDF; Kahane & Dang (2009, August), pp. 5-7; Kahane (1993, December), p. 15.

[80] Kahane & Dang (2009, August), pp. 11-12.

NHTSA conducted stopping tests on straight and curved paths and various surfaces with ABS-equipped cars, and also for the same cars with the ABS disabled. Results were impressive. Yawing was nearly eliminated and steering control maintained. Furthermore, on most surfaces, especially wet pavements, cars stopped in a shorter distance with ABS activated and steady pedal pressure than with ABS disabled and the trained test driver attempting to modulate and optimize the pedal pressure. The principal exception was a gravel surface, where ABS, although maintaining directional stability and control, took 28 percent longer to stop than just slamming on the brakes and sliding.[81]

Expected benefits: The experience on the test track suggested that ABS could have safety benefits in many crash situations. Maintaining steering control and cutting stopping distances, especially on wet roads, could reduce frontal impacts into other vehicles and collisions with pedestrians. By preventing yaw and preserving steering control, ABS can help drivers keep their vehicle on a straight or curving road, and could prevent run-off-road crashes such as rollovers or fixed-object impacts. However, there could be some adverse impact due to longer stopping distances on gravel and other loose surfaces away from the road.

Crash avoidance – passenger cars: NHTSA's initial evaluation, published in 1994 and based on 1990-to-1992 crash data from Florida, Missouri and Pennsylvania did not lead to a conclusion on the overall crash avoidance for ABS. Crash involvements as a frontally impacting car in a multivehicle collision were significantly reduced, especially on wet roads.[82] But some types of run-off-road crashes significantly increased with ABS.[83] A clearer picture emerged from NHTSA's follow-up evaluation in 2009, based on GES data from 1995 to 2007 for a larger list of make-models. ABS reduced culpable involvements in multivehicle crashes by a statistically significant 17 percent, whereas the effect in run-off-road crashes had become negligible (1% increase). The following table shows how these involvements decreased, relative to the control group, for a list of make-models that switched from no ABS or from a low percentage optional installations to standard ABS or to a high percentage of optional installations.[84]

GES 1995 to 2007	Culpable Multi-Veh Involvements	Control Group	Risk Ratio
Unweighted Cases			
2 MY with 7% ABS	8,896	14,478	
Next 2 MY, with 88% ABS	8,961	16,489	
Weighted Counts			
2 MY with 7% ABS	1,062,451	1,802,565	.589
Next 2 MY, with 88% ABS	1,069,673	2,114,616	.506

This is a 14-percent reduction in culpable involvements for the group with 88 percent ABS relative to the group with 7 percent ABS. It amounts to a 17-percent reduction for standard ABS rel-

81 *Ibid*., pp. 2-4; Hiltner et al. (1991); Arehart et al. (1992).
82 Kahane (1994, December), pp. 10-57.
83 *Ibid*., p. 84-92.
84 Kahane & Dang (2009, August), pp. 47-55.

ative to no ABS (confidence bounds: 13 to 22%). Overall, a statistically significant 6-percent reduction in police-reported crash involvements can be attributed to ABS (confidence bounds: 4 to 8%).

Fatality reduction – passenger cars: Initial statistical analyses in the United States and Sweden showed statistically significant increases in fatal run-off-road crashes, especially rollovers and side impacts with fixed objects, offset by reductions in collisions with other vehicles on wet roads and in collisions with pedestrians and bicyclists. The studies did not attribute an overall fatality reduction to ABS.[85] Hypotheses for the observed increases in run-off-road crashes focused especially on drivers inexperienced with ABS letting up on the brake pedal. As stated above, the safety community worked in the mid-1990s to inform the public about the correct use of ABS. Three statistical analyses issued in 2000 to 2002 showed some alleviation of the increase in run-off-road crashes.[86]

NHTSA's follow-up evaluation in 2009 is based on 38,251 FARS cases from 1995 to 2007: substantially more cases and a larger list of make-models than previous studies. It does not show a statistically significant overall effect for ABS. The observed reduction of fatal crash involvements relative to the control group is 1 percent (confidence bounds: -2 to 4%). However, there is a statistically significant 9 percent increase in run-off-road crashes, offset by a statistically significant 13-percent reduction of collisions with pedestrians and bicyclists and a non-significant 4-percent reduction of culpable involvements in multivehicle crashes.[87]

Crash avoidance – LTVs: Numerous LTV make-models were initially equipped with RWAL in the late 1980s and then upgraded to 4-wheel ABS about 5 model years later. Correspondingly, NHTSA's 2009 report analyzes the effect of 4-wheel ABS for LTVs in two steps: first, the effect of RWAL relative to no ABS (discussed above); then, the effect of switching from RWAL to 4-wheel ABS. The crash avoidance for 4-wheel ABS relative to no ABS is the composite of these two intermediate effects. Overall, a statistically significant 8-percent reduction in police-reported crash involvements is attributed to ABS (confidence bounds: 3 to 11%). That includes a statistically significant 20-percent reduction of culpable involvements in multivehicle crashes (confidence bounds: 12 to 28%) and a non-significant 11-percent reduction of run-off-road crashes (confidence bounds: -2 to 22%).[88]

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[85] Kahane (1994, December); Hertz, E., Hilton, J., & Johnson, D. M. (1995b). *An analysis of the crash experience of passenger cars equipped with antilock braking systems.* (Report No. DOT HS 808 279). Washington, DC: National Highway Traffic Safety Administration; Farmer, C. M., Lund, A. K., Trempel, R. E., & Braver, E. R. (1996). *Fatal crashes of passenger vehicles before and after adding antilock brake systems*. Arlington, VA: Insurance Institute for Highway Safety; Kullgren, A., Lie, A., & Tingvall, C. (1994). The effectiveness of ABS in real life accidents. *Proceedings of the Fourteenth International Technical Conference on the Enhanced Safety of Vehicles*. (Paper No. 94-S4-O-07). Washington, DC: National Highway Traffic Safety Administration.
[86] Hertz, E. (2000). *Analysis of the crash experience of vehicles equipped with all wheel antilock braking systems (ABS) – A second update including vehicles with optional ABS*. (Report No. DOT HS 809 144). Washington, DC: National Highway Traffic Safety Administration; Farmer, C. M. (2001). New evidence concerning fatal crashes of passenger vehicles before and after adding antilock braking systems. *Accident Analysis and Prevention*, *33*, pp. 361-369; Harless, D. W., & Hoffer, G. E. (2002). The antilock braking system anomaly: A drinking driver problem? *Accident Analysis and Prevention*, *34*, pp. 333-341.
[87] Kahane & Dang (2009, August), pp. 17-28.
[88] *Ibid*., pp. 60-65.

Fatality reduction – LTVs: NHTSA's initial analysis of 4-wheel ABS in LTVs in 1995 showed increases of rollovers and side impacts with fixed objects not unlike the early results for passenger cars (although not statistically significant).[89]

NHTSA's follow-up evaluation in 2009 does not show a statistically significant overall effect for ABS. Fatal crash involvements increase by 1 percent (confidence bounds range from a 6% increase to a 4% reduction). Fatal run-off-road crashes increase by a non-significant 6 percent and culpable involvements in multivehicle crashes increase by a non-significant 1 percent. However, there is a statistically significant 14-percent reduction of collisions with pedestrians and bicyclists.[90]

Injury reduction: The percentages of nonfatal-injury crashes avoided with ABS are approximately the same as the percentages of overall crash avoidance.[91]

Summary of results from the 2009 evaluation: Here are the estimated percent crash reductions for cars and LTVs.[92] Blue shading indicates a statistically significant reduction, yellow shading a significant increase.

	All Crashes		**Fatal Crashes**	
	Cars	**LTVs**	**Cars**	**LTVs**
Overall	**6**	**8**	1	- 1
All run-off-road crashes	- 1	11	**- 9**	- 6
Side impacts with fixed objects	**- 20**	- 9	**- 30**	none
First-event rollovers	3	17	- 11	- 10
All other run-off-road crashes	5	15	- 3	- 5
Pedestrian/bicyclist			**13**	**14**
Culpable involvements w other veh	**17**	**20**	4	- 1

ABS is clearly beneficial in preventing nonfatal crash involvements of cars and LTVs, but has little or no net effect on fatal crashes. Whatever unfavorable effects ABS may have had on some types of run-off-road crashes (and the record is unclear because many of those findings are not statistically significant) will in the future be offset by the much larger benefits of ESC in these types of crashes.

The model to compute lives saved in Part 2 of this report only includes safety technologies for which past NHTSA evaluations showed statistically significant fatality reductions. The model will consider ABS to be a safety technology without a significant net effect on fatalities and will simply omit it from the calculations, like other technologies that prevent crashes or injuries but have not significantly reduced fatalities – e.g., CHMSL or head restraints. While it is conceivable that ABS might have changed the distribution of fatalities (fewer pedestrians, more run-off-road

[89] Hertz, E., Hilton, J., & Johnson, D. M. (1995a). *An analysis of the crash experience of light trucks equipped with antilock braking systems*. (Report No. DOT HS 808 278). Washington, DC: National Highway Traffic Safety Administration.

[90] Kahane & Dang (2009, August), pp. 39-45.

[91] *Ibid*., p. 56.

[92] *Ibid*., p. ix.

crashes), such changes are too tenuous to include in the model, because the observed effects for the various crash types are in many cases not statistically significant.

FMVSS No. 108, "Lamps, reflective devices, and associated equipment"

NHTSA has evaluated six innovative lighting and conspicuity technologies for vehicles. The first three are required and regulated by FMVSS No. 108. The last three are not required by a NHTSA regulation, but are available on large numbers of production vehicles.

- **Side marker lamps**
- **Center high mounted stop lamps**
- **Retroreflective tape on heavy trailers**
- **Daytime running lights**
- **Amber rear turn signals**
- **LED stop lamps and CHMSL**

The goal of side marker lamps is to make the sides of vehicles more visible in the dark, and to prevent nighttime angle collisions. They have been standard equipment on all cars and LTVs since MY 1970. CHMSL are designed to enhance the effect of stop lamps and reduce front-to-rear collisions, by day and night. They have been standard on cars since model year 1986 and were phased into LTVs during MY 1991 to 1994. Retroreflective tape makes heavy trailers more visible from the side and the rear, in the dark, so other vehicles will not hit them. It has been standard on new trailers over 10,000 pounds GVWR since December 1, 1993, and also has been required as a retrofit on older trailers still on the road since June 1, 2001. Daytime running lights potentially make vehicles more visible from the front, in the daytime. Amber turn signals may be considered both a safety and a styling feature. Their safety goal is to facilitate a following driver's recognition whether the driver ahead is already braking (red stop lamp) or merely intends to turn sometime soon (amber). They have been standard equipment on numerous make-models since the 1960s or earlier. LED stop lamps and CHMSL light up faster than incandescent bulbs, providing an earlier signal to a following driver to slow down. Selected make-models have been equipped with them since 2000.

The second paragraph of FMVSS No. 108 states, "The purpose of this standard is to reduce traffic accidents … by providing adequate illumination of the roadway and by enhancing the conspicuity of motor vehicles … so that their presence is perceived and their signals understood, both in daylight and in darkness."[93] FMVSS No. 108 regulates many lamps, reflectors, bulbs and flashers on the vehicle exterior, and the systems for controlling them. Most of those devices existed well before NHTSA, were specified in SAE standards subsequently incorporated into FMVSS No. 108, and remained unchanged or at most, underwent gradual or subtle changes after 1968. The above technologies are five exceptions where a fundamentally new safety device was required or became available. NHTSA's evaluations of these five technologies will now be discussed, one-by-one.

Side marker lamps

Regulatory history: FMVSS No. 108, one of NHTSA's initial safety standards, took effect for vehicles over 80 inches wide (large trucks and buses) on January 1, 1968. It was extended to passenger cars and LTVs, effective January 1, 1969. Side marker lamps and/or reflectors were re-

[93] 49 CFR, Part 571.108.

quired from the start. Vehicles must have two combination lamp/reflectors on each side, an amber one as close as possible to the front and a red one close as possible to the rear. (Vehicles more than 30 feet long require an additional amber lamp/reflector at the midpoint.) However, to give manufacturers of cars and LTVs some more lead time, the standard allowed use of just a lamp, or just a reflector, in lieu of a lamp/reflector, during CY 1969. Since January 1, 1970, all cars and LTVs must have four lamp/reflectors. The side marker lamp requirement primarily incorporates SAE Recommended Practice J592. Although issued by the SAE in 1964, it did not immediately put side marker lamps on all domestic cars and LTVs, because it was only a Recommended Practice, not a Standard. Instead, the proportion of new cars and LTVs with side marker lamps increased gradually from 5 percent in MY 1964 to 13 percent in 1967, then jumped to 88 percent in 1968 and reached 100 percent in 1970.[94]

How side marker lamps work: Before side marker lamps, a car or LTV was very hard to see from the side, in the dark. A vehicle entering a right-angle intersection, or pulling out of a driveway onto unlit or weakly illuminated roads was virtually invisible to cross traffic, or at least did not provide any visual cues to catch the attention of other drivers. Headlamps, in particular, focus their beams straight ahead and may barely be visible from the side (unless the approaching vehicle is still a substantial distance to the left or right, and there are no vision obstructions such as trees or buildings).

Side marker lamps make cars visible from the side, in the dark and enable other drivers to avoid collisions. Moreover, the use of amber in the front and red in the back sends a visual cue: "You are approaching the side of a vehicle – here's how big it is, and it's not necessarily getting out of your way." The two colors distinguish the front of a car (white or amber light) from its rear (red light). Side marker lamps are on whenever the parking lights are on, and when they are not (e.g., on a parked vehicle), the reflectors throw back some of the light from other vehicles' headlamps.

Two systems have been used to meet the standard. One makes the existing parking lamps and tail lamps visible from the side by designing their lens/reflectors to "wrap around" the sides of the vehicle. The other approach is to install dedicated side marker lamps, separate from the parking lamps and tail lamps. Both methods are acceptable under FMVSS No. 108 and are believed to be essentially equivalent. FMVSS No. 108, like SAE Recommended Practice J592, requires at least 0.62 candela for amber side marker lamps, and 0.25 candela for red ones, as measured from 9 specified observation points. That makes them considerably less bright than, for example, tail lamps, let alone stop lamps. Side marker lamp/reflectors are too dim to make vehicles more conspicuous by day, and perhaps even to be seen from a long enough distance, in the dark, to avoid high-speed, potentially fatal collisions.[95]

Expected benefits: Side marker lamps ought to reduce the number of angle collisions in reduced lighting conditions: dark not lighted, dark lighted, dawn or dusk. The definition of an "angle" collision varies but generally includes crashes where two vehicles approach one another at an

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[94] Kahane, C. J. (1983, July). *An evaluation of side marker lamps for cars, trucks and buses*. (Report No. DOT HS 806 430, pp. 1-7 and 29-32). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/806430.PDF; *Federal Register* 32 (February 3, 1967): 2414, 32 (December 16, 1967): 18033; SAE. (1983). *1983 SAE Handbook*, Vol. 2, Warrendale, PA: Society of Automotive Engineers.

[95] Kahane (1983, July), pp. 1-7 and 29-32; Cole, B. L., Dain, S. J., & Fisher, A. J. (1977). *Study of motor vehicle signal systems*. (HSL Publication No. DOT HS 022 690). Melbourne: Road Safety Information Service.

angle, typically 90°, or where the front of one vehicle hits the side of the other. The lamps should have little or no effect on daytime crashes. When two vehicles approach at an angle in the dark, the potential benefit of the lamps likely depends on the pre-crash scenario. Typically, if vehicle 1 proceeds on a road while vehicle 2 slowly enters an intersection from a side street or pulls/backs out of a driveway, a side marker lamp on vehicle 2 would likely help driver 1 see vehicle 2, whereas a side marker lamp on vehicle 1 would probably not be noticed by driver 2 (who, if attentive, would likely already have seen the headlamps of vehicle 1). Occasionally, if vehicles 1 and 2 approach a perpendicular intersection at about the same speed, lamps on either one of the vehicles might help the other driver avoid a crash. When the lamps prevent a crash, they not only save the lamp-equipped vehicle from damage, but also the other vehicle that would have been in the crash. Furthermore, if any occupant of either vehicle would have been injured, these injuries are prevented. As stated above, it is doubtful if the lamps would have much effect on fatal crashes.

Crash avoidance: NHTSA's evaluation was published in 1983. It is based on crash data from North Carolina (1971 to 1980) and Texas (1972 to 1974).[96] The data allow a tally of vehicle involvements in angle collisions under reduced-light conditions. They also allow counting a control group of involvements in daytime angle collisions. The database created for the evaluation only identifies the model year of the crash-involved "case" vehicle. It does not identify the model year of the "other" vehicle in the collision – i.e., it is unknown if the other vehicle is equipped with side marker lamps. It also does not provide any details on the pre-crash scenario: whether it is a crash where side marker lamps might primarily be helpful on the case vehicle (e.g., the case vehicle was pulling out of a driveway), or primarily be helpful on the other vehicle, or be about equally helpful on both vehicles (e.g., both approaching an intersection at about equal speed). Tallies of case vehicles in these angle collisions are compared for MY 1967 case vehicles, when only 13 percent of cars, trucks and buses had side marker lamps, and MY 1968 case vehicles, when 88 percent of cars, trucks and buses were equipped with the lamps:

	Angle Collisions		
	Night[97]	Day	Ratio of Night/Day
NORTH CAROLINA			
MY 1967 (13% with side marker lamps)	5,971	20,755	.288
MY 1968 (88% with side marker lamps)	7,075	26,351	.268
TEXAS			
MY 1967 (13% with side marker lamps)	7,738	30,324	.255
MY 1968 (88% with side marker lamps)	8,715	36,618	.238

In both States, the ratio of nighttime to daytime crashes is a statistically significant 6.7 percent lower in the MY 1968 case vehicles. The arithmetic in the preceding tables works out to 8.8 per-

[96] Kahane (1983, July), pp. 39-48.
[97] Includes dark not lighted, dark lighted, dawn and dusk.

cent fewer nighttime angle collisions when the case vehicle has the lamps than when the case vehicle does not have the lamps.[98] With this database, where there are no details on the crash configuration, it is unknown if the lamps would have been more useful on the case vehicle or on the other vehicle. In close to half the crashes on this database, lamps would have been helpful primarily on the other vehicle, not the case vehicle. The data shows an 8.8-percent crash reduction merely from adding the lamps to the case vehicle (even though, in close to half of the crashes, lamps would primarily have been helpful on the other vehicle). That means 16.8 percent fewer nighttime angle collisions when **both** vehicles have the lamps than when neither has them.[99] Nearly identical effectiveness estimates were obtained when the data was expanded to two, three, or four model years before and after the 1968 shift to side marker lamps, or in regression analyses of the ratio of nighttime to daytime angle-collision involvements by presence of side marker lamps and other factors such as vehicle age.[100] The evaluation concluded that the best estimate of side marker lamp effectiveness, based on one of these regressions, is a 16.8-percent reduction of nighttime angle collisions when both vehicles have the lamps.[101] Using 1979 to 1980 as the "baseline" years, the evaluation estimated that side marker lamps would prevent 106,000 police-reported nighttime angle collisions per year when all cars, trucks and buses on the road were equipped with the lamps.[102]

Injury reduction: Estimates of injury reduction were obtained by limiting the preceding analyses of North Carolina and Texas data to injury-producing crashes – i.e., crashes where at least one occupant in any of the involved vehicles (not necessarily the vehicle equipped with side marker lamps) was injured. All of these analyses show a somewhat stronger reduction of injury-producing crashes than property-damage-only crashes. The evaluation's best estimate of side marker lamp effectiveness is a 21-percent reduction of injury-producing nighttime angle collisions when both vehicles have the lamps.[103] The evaluation estimated that side marker lamps would prevent 93,000 injuries in nighttime angle collisions per year.[104]

Fatality reduction: When the preceding contingency-table and regression analyses were performed with 1975-to-1981 FARS data, they did not show any reduction of fatal angle collisions, in the dark, with side marker lamps. A case-by-case review of Multidisciplinary Accident Investigations (MDAI) showed that the great majority of fatal nighttime angle collisions (but not nearly so many nonfatal collisions) involved at least one of these two factors that would make the lamps unlikely to help prevent a crash: (1) a vehicle traveling at least 50 mph, too fast for the driver to see the relatively dim lamps in time to take evasive action; (2) two vehicles approaching at right angles at relatively similar speeds, where drivers ought to see each other's headlamps more easily than the side marker lamps. In addition, many nighttime fatal crashes involve alcohol-impaired drivers who are not likely to be alert to the lamps. The evaluation concluded that

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[98] $(1 - .067) = [.88(1-.088) + .12] / [.13(1-.088) + .87]$

[99] $.168 = 1 – [(1-.088)(1-.088)]$; the database differs from those in other crash avoidance analyses because it does not identify which of the two vehicles involved in a crash could have benefited from the lamps; in the CHMSL analysis, for example, the database identifies a rear-impacted vehicle that could benefit from CHMSL and a frontally-impacting vehicle where CHMSL are irrelevant.

[100] *Ibid*., pp. 69-85.

[101] *Ibid*., pp. 120-122; 90 percent confidence bounds: 10 to 22 percent.

[102] *Ibid*., pp. 136-139; 90 percent confidence bounds: 65,000 to 149,000 crashes prevented.

[103] *Ibid*., pp. 48-53, 86-89, and 123; 90 percent confidence bounds: 12 to 29%.

[104] *Ibid*., pp. 141-143; 90 percent confidence bounds: 51,000 to 132,000 injuries prevented.

side marker lamps, although highly effective in reducing nonfatal crashes and their injuries, have little effect in fatal crashes.[105]

Center high-mounted stop lamps

Regulatory history: After much experimental research (1974 to 1979), on-the-road testing (1976 to 1979) and regulatory analysis, NHTSA amended FMVSS No. 108 in October 1983 to require CHMSL on new passenger cars, effective September 1, 1985. CHMSL were standard equipment on all MY 1986 cars; also on 1985 Cadillacs. In addition, consumers welcomed the lamps, purchased about 4,000,000 retrofit kits and installed them on their pre-1986 cars. An April 1991 amendment extended the CHMSL requirement to pickup trucks, vans and SUVs manufactured on or after September 1, 1993. All LTVs had the lamps in MY 1994, some make-models as early as 1991.[106]

How CHMSL work: Stop lamps are a basic tool for preventing rear-impact collisions, daytime and nighttime. When a driver applies the brake pedal, the lamps alert the following driver to slow down immediately, maintain a safe distance, and be ready to stop. Conventional stop lamps by themselves, without supplementary CHMSL are less than optimal for accomplishing their mission. They are low and off toward the sides of the vehicle, not where the following driver is looking most of the time. During quick scanning, they might be confused with adjacent taillights and turn signals, and misinterpreted to mean a car is proceeding or turning, rather than slowing down.

NHTSA and the insurance industry tested various configurations of experimental stop lamps, in the laboratory and on the road, and concluded that the best system supplemented the two existing stop lamps with a third red lamp, mounted in the center of the vehicle, and if possible higher than the other two. A report by NHTSA staff on *The Technical Basis for CHMSL* summarized test findings: the central and raised location of CHMSL puts them in the area where the following driver most often glances; it separates them from tail lamps and turn signals and minimizes confusion; the high mounting might make it visible through the windows of a following vehicle and enable the driver of the third vehicle in a chain to react to the first vehicle's braking; and the three lamps form a triangle that might be an additional cue to get a driver's attention and a warning to keep a safe following distance. As a consequence, CHMSL significantly reduced the average time for drivers to apply their brakes in response to the signal from the vehicle in front of them.[107]

Road tests with fleets of taxicabs and telephone-company cars were very encouraging, showing a 35-percent reduction of rear-impact collisions in the CHMSL-equipped cars relative to control-

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[105] *Ibid*., pp. 62-66, 100-112 and 125-130; Cole, Dain, & Fisher (1977).
[106] Kahane, C. J., & Hertz, E. (1998, March). *The long-term effectiveness of center high mounted stop lamps in passenger cars and light trucks*. (Report No. DOT HS 808 696, pp. 1-2, 9 and 62-63). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/808696.PDF; *Federal Register* 48 (October 18, 1983): 48235, 56 (April 19, 1991): 16015; NHTSA. (1983). *Final Regulatory Impact Analysis, Federal Motor Vehicle Safety Standard 108, Center High-Mounted Stop Lamps*. (NHTSA Docket No. 81-02-N02-001). Washington, DC: National Highway Traffic Safety Administration.
[107] Kahane & Hertz (1998, March), pp. 1-2; Digges, K. H., Nicholson, R. M., & Rouse, E. J. (1985). *The technical basis for the center high mounted stoplamp*. (Paper No. 851240). Warrendale, PA: Society of Automotive Engineers.

group cars with conventional stop lamps. They paved the way for the CHMSL regulation by suggesting the lamps would be highly beneficial and cost-effective.[108]

Two questions arose during the CHMSL rulemaking in the early 1980s. One was if the high effectiveness in the fleet tests would persist after the lamps became standard equipment on millions of vehicles, or if drivers would gradually become acclimatized to the lamps and less conscious of them. This would be examined by repeated evaluations of CHMSL for about 10 years after they became standard on passenger cars. The other was if CHMSL would be effective on pickup trucks, where they would likely be on top of the cab, far away from all other lamps, or on full-sized vans, where they might be above the following driver's usual line of vision. As a consequence, CHMSL were required on passenger cars as of September 1, 1985, but the requirement was not extended to LTVs until September 1, 1993, after additional research satisfied NHTSA that they would be effective there.[109]

Expected benefits: CHMSL ought to reduce the probability of being struck in the rear by another vehicle, daytime or nighttime.[110] That will help prevent simple two-vehicle front-to-rear collisions and chain collisions involving three or more vehicles. When the lamps prevent a crash, they not only save the struck, CHMSL-equipped vehicle from damage, but also the striking vehicle. Furthermore, if any occupant of either vehicle would have been injured, these injuries are prevented. To the extent that fatal rear-impact crashes involve much higher speeds and different crash conditions from the nonfatal ones, it is not clear if the lamps would have much effect, if any, on fatal crashes.

Crash avoidance – passenger cars: NHTSA evaluated CHMSL in 1987, 1989, and 1998; only the last evaluation, which superseded the earlier results, will be discussed here.[111] It is based on 1986-to-1995 crash data from eight States: Florida, Indiana, Maryland, Missouri, Pennsylvania, Texas, Utah, and Virginia. These State files identify each crash-involved car's MY and impact site (rear impact versus other). The basic contingency tables compare the last model year(s) before CHMSL became standard equipment to the first model years they were standard. They tally how many cars were struck in the rear, and how many cars were involved in any other kind of

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[108] Kahane & Hertz (1998, March), pp. 2-3; Kohl, J. S., & Baker, C. (1978). *Field test evaluation of rear lighting systems*. (Report No. DOT HS 803 467). Washington, DC: National Highway Traffic Safety Administration; Rausch, A., Wong, J. I., & Kirkpatrick, M. (1981). *A field test of two single center high-mounted brake light systems*. (NHTSA Docket No. 81-02-N01-031). Arlington, VA: Insurance Institute for Highway Safety; Reilly, R. E., Kurke, D. S., & Buckenmaier, C. C. (1980). *Validation of the reduction of rear end collisions by a high mounted auxiliary stoplamp*. (Report No. DOT HS 805 360). Washington, DC: National Highway Traffic Safety Administration.

[109] (1983). *Evaluation plan for center high-mounted stop lamps*. (NHTSA Docket No. 81-02-N02-002). Washington, DC: National Highway Traffic Safety Administration; NHTSA. (1991). *Final regulatory impact analysis, amendment to FMVSS 108 to require center high-mounted stop lamps on light trucks and buses*. (NHTSA Docket No. 81-02-N10-001). Washington, DC: National Highway Traffic Safety Administration.

[110] Unlike side marker lamps in angle collisions, CHMSL are beneficial only on the struck vehicle. When two vehicles approach at a 90-degree angle, either driver may see the other vehicle's side marker lamps, but when two vehicles travel in the same direction, only the following driver can see the other vehicle's CHMSL.

[111] Kahane & Hertz (1998, March), pp. 7-41; Kahane, C. J. (1987, March). *The effectiveness of center high mounted stop lamps: A preliminary evaluation*. (Report No. DOT HS 807 076). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS807076.PDF; Kahane, C. J. (1989, July). *An evaluation of center high mounted stop lamps based on 1987 data*. (Report No. DOT HS 807 442). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807442.PDF.

impact (the control group). The following example is based on Florida data for CY 1987, comparing the crash experience of MY 1985 and 1986 cars:

	Collision Involvements		
Florida, CY 1987 crashes	Rear Impacts	Others	Ratio of Rear/Other
MY 1985 (10% with CHMSL[112])	6,773	22,959	.295
MY 1986 (100% with CHMSL)	7,161	25,989	.276

In this example, the ratio of rear impacts to other-type crash involvements is a statistically significant 6.6 percent lower in the MY 1986 cars than in the 1985 cars, indicating a benefit for CHMSL. However, this analysis understates the effectiveness of CHMSL because it does not adjust for vehicle age. Newer cars in general have relatively more rear impacts (and are less often the striking vehicle), inflating the "ratio of rear/other crashes." The evaluation developed a regression analysis that adjusted for vehicle age and yielded unbiased estimates of the effectiveness of CHMSL. The effect was positive and statistically significant in each of the eight States. When the results from the eight States are combined, the weighted-average effectiveness of CHMSL is statistically significant in each separate CY. However, the effect was highest in 1987, dropped in half by 1989, and then leveled off:

Calendar Year	Rear Impact Reduction by CHMSL (%)	Calendar Year	Rear Impact Reduction by CHMSL (%)
1986	5.1	1991	5.0
1987	8.5	1992	5.0
1988	7.2	1993	3.2
1989	4.3	1994	3.4
1990	5.3	1995	3.9

Effectiveness dropped significantly in 1988 and 1989, but there was no statistically significant downward trend after 1989. The average effectiveness in 1989-95, 4.3 percent, may be considered the long-term effectiveness of CHMSL. The initial and long-term effectiveness estimates, and their 90 percent confidence bounds,[113] are:

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[112] Assumed to be equipped with CHMSL retrofit kits (not explicitly noted in the crash data).

[113] Kahane & Hertz (1998, March), pp. 39-40 and 81-83 computes 95 percent confidence bounds; they have been scaled back to 90 percent confidence bounds here (by taking ± 1.645 rather than ± 1.96 standard deviations), for consistency with most of the other NHTSA evaluations.

Calendar Year Group	Rear Impact Reduction by CHMSL (%)	90% Confidence Bounds
1986	5.1	2.9 to 7.3
1987	8.5	6.6 to 10.5
1988	7.2	5.2 to 9.1
1989-95 (long-term effect)	4.3	3.1 to 5.5

The decline in effectiveness to 4.3 percent long-term from 8.5 percent in 1987 (and from 35 percent in the test fleets of taxicabs and telephone-company cars) is consistent with the hypothesis that motorists would become acclimatized to the lamps. CHMSL are no longer startling, but their good location continues to make them effective.

More detailed analyses of data from five States (Florida, Maryland, Missouri, Pennsylvania, and Utah) show CHMSL effective in the dark but even more so in daytime. They are effective regardless whether the following driver is young or old, male or female. In general, the simpler the crash scene, and the less a driver is distracted by other lights or traffic features, the more effective the CHMSL – e.g., at locations away from traffic signals, in rural areas, in simple two-vehicle collisions.[114]

Injury reduction – passenger cars: Detailed analyses from five States show CHMSL are almost equally effective in preventing nonfatal-injury and property-damage crashes. In other words, the lamps' long-term effect will be to prevent 4.3 percent of the nonfatal injuries to occupants of any of the vehicles involved in front-to-rear collisions, including occupants of the striking, frontally-impacting vehicles.[115]

Fatality reduction – passenger cars: When the basic crash avoidance analysis was performed with 1986-to-1995 FARS data, it did not show a statistically significant reduction of fatal rear-impact collisions with CHMSL in any specific CY, or in all of the CY combined. The lamps had little or no effect on fatal crashes at any time during 1986 to 1995. A closer look at the data reveals that, in the majority of fatal rear impacts, the struck vehicle was not slowing or braking at all prior to the impact: the CHMSL was not activated and could not have had an effect.[116]

Effectiveness – LTVs: Pickup trucks, vans and SUVs received CHMSL in 1991, 1992, 1993 or 1994, depending on the make-model. NHTSA analyzed 1994-to-1996 crash data from six States that record the impact site and the VIN, allowing identification of make-model and MY: Florida, Maryland, Missouri, North Carolina, Pennsylvania and Utah. The crash avoidance analysis, similar to the one for passenger cars, estimated that CHMSL in LTVs reduced rear impacts by a statistically significant 5.0 percent. The 90 percent confidence bounds are 1.0 to 8.7 percent. For practical and statistical purposes, this is more or less the same as the 4.3 percent long-term effec-

[114] Kahane & Hertz (1998, March), pp. 43-53.
[115] *Ibid*., pp. 53-54.
[116] *Ibid*., pp. 54-60.

tiveness estimate for passenger cars. The data did not show any significant variations in CHMSL effectiveness between pickup trucks, vans and SUVs.[117]

Summary of benefits: Using 1994 as the "baseline" year, and based on a 4.3 percent long-term effectiveness in LTVs as well as cars, the evaluation estimated that CHMSL would prevent 92,000 to 137,000 police-reported rear-impact crashes per year, plus 102,000 unreported crashes, when all cars and LTVs on the road are equipped with the lamps. That will save 43,000 to 55,000 people from injury in the police-reported crashes, and 15,000 in the unreported crashes, for a total of 58,000 to 70,000 injuries avoided per year. At 1994 costs and prices, the value of the property damage avoided, even without counting anything for the injuries prevented, far exceeds the consumer cost of CHMSL, making them a highly cost-effective safety device.[118]

Retroreflective tape on heavy trailers

Regulatory history: After extensive research, on-the-road testing and analysis, NHTSA amended FMVSS No. 108 in December 1992 to require retroreflective tape or sheeting, or reflex reflectors, on the sides and rear of heavy trailers (i.e., at least 80 inches wide and with GVWR over 10,000 pounds), effective December 1, 1993. Retroreflective tape has been used almost exclusively for meeting the standard, and it is the subject of NHTSA's evaluation. On new trailers manufactured on or after December 1, 1993, the tape outlines the bottom of the sides of the trailers, and the top corners, bottom and underride guard of the rear of the trailers. It is applied in a pattern of alternating red and white segments to the side, rear and underride guard, and in white to the upper rear corners. FMVSS No. 108, like other FMVSS, applies to new vehicles at the time they are manufactured or imported.[119]

In addition, the Federal Motor Carrier Safety Administration and its predecessor, the Bureau of Motor Carrier Safety within the Federal Highway Administration issued a regulation in March 1999 requiring all heavy trailers on the road on or after June 1, 2001, including older trailers manufactured before December 1, 1993, to have a conspicuity treatment. The FMCSA regulation allows older trailers some flexibility on the location and colors of the tape. Before 1992, quite a few manufacturers voluntarily equipped their trailers with tape, but not always according to the pattern subsequently chosen by NHTSA. In other words, FMCSA accepts those patterns for the time being and did not require an immediate retrofit to the NHTSA pattern. However, as of June 1, 2009, FMCSA required all heavy trailers on the road to have the NHTSA pattern: many pre-1993 trailers had been retired by then, but if not, they would have needed a retrofit. Furthermore, the FMCSA regulation applies to trailers-in-use. Conspicuity treatments have to be maintained "good-as-new" and may be inspected as long as trailers are on the road. When tape deteriorates or peels over time, it must be repaired or replaced.[120]

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[117] *Ibid*., pp. 61-70.
[118] *Ibid*., pp. 71-75.
[119] Morgan, C. (2001, March). *The effectiveness of retroreflective tape on heavy trailers*. (Report No. DOT HS 809 222). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809222.PDF; *Federal Register* 57 (December 10, 1992): 58406.
[120] *Federal Register* 64 (March 31, 1999): 15587.

Although these regulations do not apply directly to passenger cars and LTVs, they are included here because their benefits – lives saved, injuries and damages avoided – will accrue primarily to the occupants of the passenger vehicles that are at risk of hitting the trailers.

How retroreflective tape works: Heavy trailers are quite difficult for drivers of other vehicles to see in the dark, and even harder to recognize for what they are. The surfaces of most trailers are not shiny and are barely seen until they suddenly loom up, too close to stop in time. Tail lamps, clearance lamps and side marker lamps theoretically outline a trailer, but they are isolated points of light on a large surface. Drivers might not see enough of them at the same time to understand, "There's a heavy trailer in front of me." Collisions of passenger vehicles into heavy trailers are intrinsically dangerous, day or night, because of the weight and height mismatch of the vehicles. In the dark, those collisions were resulting in over 500 fatalities per year during the 1980s.

Human-factors research suggested that continuous or semi-continuous retroreflective tape with alternating red and white segments would highlight and identify trailers. The tape reflects a car's headlights strongly and it is highly visible in the dark. The red and white pattern flags its bearer as a heavy trailer. Since the pattern extends around the sides and rear, a driver can identify a trailer as soon as the headlamps shine on any part of the tape. The standard-length segments in alternating colors additionally help drivers gauge their distance from the trailer and their rate of approach.[121]

A 1983-to-1985 road test of 1,910 trailers equipped with tape and 1,910 control-group trailers showed statistically significant reductions of side and rear impacts with the tape, 21 percent in the dark and, interestingly, 16 percent in daylight. NHTSA proceeded with the rulemaking, predicted a 15-to-25 percent reduction of side and rear impacts in the dark but, conservatively, did not presume a reduction of daylight crashes.[122]

Expected benefits: As stated above, retroreflective tape ought to reduce impacts by other vehicles into the side or rear of a heavy trailer, in the dark. The tape should not affect single-vehicle crashes of tractor-trailers or crashes where a truck frontally runs into a car. Highest effectiveness is expected on unlighted roads, where a trailer is least visible without the tape, and the reflection from the tape stands out the most strongly relative to the background. Less benefit is expected on lighted roads, or in twilight, because trailers are more visible, and the tape does not stand out as

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[121] Burger, W.J., et al. (1981). *Improved commercial vehicle conspicuity and signalling systems, Task I – Accident analysis and functional requirements*. (Report No. DOT HS 806 100). Washington, DC: National Highway Traffic Safety Administration; Ziedman, K., et al. (1981). *Improved commercial vehicle conspicuity and signalling systems, Task II – Analyses, experiments and design recommendations*. (Report No. DOT HS 806 098). Washington, DC: National Highway Traffic Safety Administration. The research indicated that the tape did not have to be fully continuous on the sides of trailers – as little as 50 percent coverage accomplished safety objectives – and FMVSS No. 108 accordingly requires at least 50 percent coverage on the sides and continuous tape on the rear; however, many trailers have fully continuous coverage on the sides and rear.

[122] Burger, W.J., Mulholland, M. U., & Smith, R. L. (1985). *Improved commercial vehicle conspicuity and signalling systems, Task III – Field test evaluation of vehicle reflectorization effectiveness*. (Report No. DOT HS 806 923). Washington, DC: National Highway Traffic Safety Administration; NHTSA. (1991). *Preliminary Regulatory Evaluation – Proposed Amendment to FMVSS No. 108 to Require Retroreflective Material on the Side and Rears of Heavy Trailers*. (NHTSA Docket No. 80-02-N09). Washington, DC: National Highway Traffic Safety Administration.

much. Even less benefit, if any, is expected in daylight, because trailers are easily visible without the tape, although the red and white pattern might help as an additional warning.

When the tape prevents a crash, it prevents the injuries to the occupants of any of the vehicles that would have been involved in the crash: the vehicle striking the trailer as well as the tractor pulling the trailer. Of course, most of those injuries would have been in the striking vehicle, and most of the striking vehicles would have been cars or LTVs. Unlike side marker lamps and CHMSL, there is every reason to hope that the tape will save lives, since impacts of passenger vehicles into trailers can easily be fatal at the speeds and sighting distances where the tape is likely to be effective.

The tape might be more effective in rear impacts than side impacts, if only because in most rear-impacts the passenger vehicle's headlights would point at the trailer, and the driver of the passenger vehicle is culpable for not slowing down or stopping in time – whereas in many side impacts the passenger vehicle's headlights might not point at the trailer (e.g., sideswipes), or they might not illuminate the trailer soon enough for the car/LTV driver to take action (e.g., high-speed intersection collisions), or trailer conspicuity is not an issue because the truck driver's action (e.g., sudden lane departure) precipitates the crash.

Crash avoidance: NHTSA's evaluation was published in 2001. The analysis classifies crash involvements of heavy trailers (and the tractors that pull them) according to three binomial parameters: (1) tape-equipped versus unequipped trailer; (2) dark versus daytime crash; (3) rear- or side-impact versus control group crash (where trailer visibility is not an issue – single-vehicle crashes and frontal impacts by tractor trailers). Since none of NHTSA's crash data at hand identified whether trailers had retroreflective tape, NHTSA worked out agreements with Florida and Pennsylvania State police to supplement their reports on crashes involving tractor trailers from 1997 to 1999 with a special form for each trailer specifying whether it was equipped with tape and describing the condition of the tape.[123]

The basic analysis[124] is a three-dimensional contingency table of the crash involvements of heavy trailers by the three binomial parameters. Here are the combined results for Florida and Pennsylvania:

[123] Morgan (2001, March), pp. 7-21.
[124] *Ibid*., pp. 23-37.

	Side & Rear Impacts	Control Group Crashes	Ratio: S & R/ Control Gp	Excess S & R in the Dark
TRAILERS WITHOUT TAPE				
Crashes in the dark[125]	499	597	.836	1.199
Crashes in daylight	930	1,334	.697	
TRAILERS WITH TAPE				
Crashes in the dark	1,038	1,609	.645	0.851
Crashes in daylight	1,897	2,502	.758	

Among trailers without tape, in the dark, there are almost as many side and rear impacts (499) as control group involvements (597 single vehicle crashes and frontal impacts): a ratio of .836. In daylight, that ratio is only .697. Side and rear impacts are overrepresented in the dark by a factor of 1.199 = .836/.697, presumably, because other road users are unable to see the trailers in time to avoid a crash.

Among trailers with the tape, the statistics are reversed. The ratio of side and rear impacts to control group crashes is lower in the dark (.645) than by day (.758) – as it ought to be, since night is a time of lower traffic density, more single-vehicle crashes, and fewer multivehicle crashes resulting in side and rear impacts. Side and rear impacts are now, appropriately, underrepresented in the dark by a factor of 0.851. This is a 29-percent reduction of side and rear impacts in the dark, relative to trailers without the tape, and it is statistically significant.[126] The actual effectiveness of the tape has exceeded the predictions in NHTSA's regulatory analysis (15 to 25%).

As expected, the tape is by far the most effective on dark-not-lighted roads, reducing side and rear impacts by a statistically significant 41 percent. In dark-lighted, dawn and dusk conditions, the tape did not significantly reduce crashes. The tape also did not significantly reduce crashes in daylight. Also as expected, the tape appears to be somewhat more effective in preventing rear impacts than side impacts. The tape is more effective when the driver of the impacting vehicle is 15 to 50 years old than when he or she is over 50 years old. A possible explanation of the difference is that older drivers are less able to see, recognize and/or react to the tape in time to avoid hitting the trailer.[127]

The evaluation estimates that after June 1, 2001, by which time all heavy trailers on the road had been retrofitted or equipped with retroreflective tape, it would prevent approximately 7,800 police-reported crashes per year.[128]

Injury reduction: Estimates of injury reduction were obtained by limiting the basic analysis to nonfatal, injury-producing crashes – i.e., crashes where at least one occupant in any of the in-

[125] Includes dark not lighted, dark lighted, dawn and dusk.
[126] 1 – (0.851/1.199) = 29%; 90 percent confidence bounds: 19 to 39%; statistical significance was tested by the CATMOD procedure in SAS.
[127] Morgan (2001, March), pp. 39-50.
[128] *Ibid*., pp. 51-52.

volved vehicles (usually a passenger vehicle that hit the heavy trailer) was injured. The tape is especially effective, reducing injury-producing side and rear impacts in the dark by a statistically significant 44 percent. The evaluation estimates that retroreflective tape is preventing approximately 3,100 to 5,000 nonfatal injuries per year.[129]

Fatality reduction: When these Florida and Pennsylvania analyses are limited to the fatal crashes, they show a statistically significant reduction of side and rear impacts in the dark, with tape. NHTSA's 2001 evaluation estimates that retroreflective tape would save 191 to 350 lives per year.[130]

Daytime running lights (DRL)

Canada, the five Scandinavian countries, and other lands have required DRL for new cars and LTVs (starting with Sweden in 1977) to make the front of the vehicle more conspicuous during the day, especially in northern lands where the sun does not shine so strongly. "Being equipped with DRL" might simply mean running with the headlamps on at all times or the DRL might be separate front lamps, usually less powerful than the headlamps. In 1990, GM petitioned NHTSA to allow DRL on new cars and LTVs sold in the United States. On January 11, 1993, NHTSA amended FMVSS No. 108 to allow DRL on new vehicles. They began to appear on some GM vehicles in MY 1995 and on all of them by MY 1997. During MY 1997 to 2005, 25 to 30 percent of new cars and LTVs were DRL-equipped. GM again petitioned in 2001, this time to mandate rather than merely allow DRL on new vehicles. In 2008, NHTSA evaluated the crash-reducing effectiveness of DRL based on 2000-to-2005 data from FARS and from nine State crash files. Daytime involvements in two-vehicle crashes (excluding front-to-rear impacts, where the conspicuity of the frontally impacting vehicle would usually not be an issue) are compared to nighttime involvements in such crashes, relative to the corresponding day-to-night ratios for control-group, single-vehicle crash involvements – for vehicles of the first two MY equipped with DRL relative to vehicles of the last two MY without DRL (three-dimensional contingency table analysis, similar to the evaluation of retroreflective tape). None of the analyses showed a statistically significant effect for DRL; the observed overall effect was a non-significant 0.1-percent reduction of daytime involvements in two-vehicle crashes. On June 29, 2009, the agency denied the GM petition to mandate DRL in the United States.[131]

Amber rear turn signals

History of amber turn signals: Europe, Japan, Australia, and other countries have long required amber rear turn signals. Before the FMVSS, most cars and LTVs sold in the United States were equipped with red turn signals, but some with amber. FMVSS No. 108 allows a choice of red or

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[129] *Ibid*., pp. 48-49 and 52; the 44 percent estimate includes dark not lighted, dark lighted, dawn and dusk conditions; 3,100 to 5,000 is not an interval estimate, but two point estimates, one based on 29% effectiveness (result for analysis of crashes of all severities), the other based on 44 percent.

[130] *Ibid*., pp. 48-49 and 52-53; 191 and 350 are two point estimates, based on 29% and 44 percent effectiveness, respectively, as in the analysis of nonfatal injuries.

[131] Wang, J. (2008, September). *The effectiveness of daytime running lights for passenger vehicles*. (Report No. DOT HS 811 029). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811029.pdf; *Federal Register* 58 (January 11, 1993): 3500, 74 (June 29, 2009): 30993.

amber. Since the 1970s, a substantial proportion of vehicles have had amber turn signals. But red signals have also remained common, perhaps because they allow sharing of components between the stop lamp and the turn signal or because they are perceived by some as a styling feature. In fact, numerous make-models have switched back and forth between amber and red signals over the years.[132]

How amber turn signals work: If vehicles' stop lamps and turn signals are the same color (red), the driver of a following vehicle, upon first seeing a bright red light, may be uncertain whether the lead driver is already braking or merely signaling an intention to turn sometime in the near future (although the CHMSL helps because it only lights up for braking). The driver of the following vehicle may hesitate while trying to discern whether the lamp stays on (braking) or flashes (turning) and lose precious time before applying brakes. But if vehicles have different colors for stop lamps (red) and turn signals (amber), the following driver will know almost immediately if the lead vehicle is braking (red). Furthermore, the driver will be alert that the vehicle will turn sometime soon and will know almost immediately not to swerve or pass the lead vehicle on the side to which it intends to turn.[133]

Crash avoidance: NHTSA's evaluation was published in 2009. It is based on 33 "switch groups": make-models that switched turn-signal colors sometime between MY 1983 and 2005 (28 cars and 5 LTVs, 20 switching from red to amber and 13 from amber to red). It uses crash data from 14 State files (Alabama, Florida, Georgia, Illinois, Indiana, Kentucky, Maryland, Michigan, Missouri, North Carolina, Nebraska, Pennsylvania, Texas, and Utah) for the calendar years they are available at NHTSA: from 1989 to 2006, or a subset of those years, depending on the State. This is far more data than previous analyses.[134]

The statistical analysis considers front-to-rear crashes in which the driver of the rear-impacted vehicle was turning or preparing to turn. The crash involvements of interest are the rear-impacted vehicles in these collisions, specifically, those belonging to any of the 33 switch groups, within 2 MY before or after the switch year. Control group involvements are the frontally impacting vehicles in these collisions, likewise belonging to the switch groups. The "cleanest" analysis is limited to the 11 of the 33 switch groups where **nothing** changed from one MY to the next except the color of the lens housing the turn signal: the lighting configuration and the remainder of the vehicle stayed essentially the same. A contingency table compares the rear impacts and control-group involvements with red and amber turn signals in the 14 States.[135]

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[132] Allen, K. (2009, April). *The effectiveness of amber rear turn signals for reducing rear impacts*. (Report No. DOT HS 811 115, pp. 1 and 6). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811115.PDF; Stern, D. (2012). *Preventing crashes with amber turn signals*. Teaneck, NJ: Allpar, LLC. Available at www.acarplace.com/cars/turn-signals.

[133] Allen (2009, April), pp. 1-2; Luoma, J., Flannagan, M. J., Sivak, M., Aoki, M., & Traube, E. C. (1997). Effects of turn-signal color on reaction times to brake signals. *Ergonomics*, *40*, pp. 62-68.

[134] Allen (2009, April).

[135] *Ibid*., p. 12.

14 State Files	Rear-Impacted While Turning	Control Group	Risk Ratio
Red turn signals	7,219	7,061	1.022
Amber turn signals	6,629	6,848	.968

This is a statistically significant 5.3-percent reduction in rear impacts, while turning, for the vehicles with the amber turn signals. A broader analysis comprising all 33 switch groups supports the result: when the 33 groups are analyzed one-by-one, the risk ratio is lower with the amber turn signals in 24 of the 33 groups (significantly more than half of them). The median of the 33 effectiveness estimates is 8.4 percent and the mean is 4.9 percent.[136]

Injury reduction: When the preceding contingency table is limited to crashes that resulted in injuries, the observed effectiveness for amber turn signals rises from 5.3 to 8.3 percent, but the estimate is not statistically significant at the two-sided .05 level because of the limited amount of data; it is borderline significant at the one-sided .05 level.[137] It may be reasonable to assume the injury reduction for amber turn signals is similar to the overall crash reduction (5.3%).

Fatality reduction: NHTSA has not performed corresponding analyses of fatal crashes based on FARS data. Given that side marker lamps and CHMSL had little effect on fatal crashes, the agency will not assume that amber turn signals are effective in reducing fatalities.

LED stop lamps and CHMSL

History of LED stop lamps and CHMSL: FMVSS No. 108 specifies optical performance standards for lamps, not their design or technology. Light-emitting diodes are an available technology that may be advantageous for durability or styling, but may have cost implications. LED tail lamps date back to the 1990s. However, the 2000 Cadillac DeVille was the first vehicle with LED stop lamps and CHMSL. By 2009, over a million production cars or LTVs had been equipped with LED stop lamps and LED CHMSL.[138]

How LED stop lamps work: A potential safety advantage of LED stop lamps and CHMSL is that they have a faster "rise time" than current incandescent lamps – i.e., a shorter lag from the application of the brake until the light becomes visible to a human observer. The rise-time to 90 percent of full output is about 60 nanoseconds for LEDs, while it is about 140 milliseconds for incandescent bulbs. Logically, if two lamps are equal in all other respects, the one with the faster rise time must have a safety benefit of alerting a following driver earlier that he or she must slow down. Laboratory tests confirmed that the faster rise time for LED stop lamps translated into quicker response by test subjects.[139]

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[136] *Ibid*., p. 10.
[137] *Ibid*., pp. 12-13.
[138] Greenwell, N. K. (2013, February). *Effectiveness of LED stop lamps for reducing rear-end crashes: Analyses of State crash data*. (Report No. DOT HS 811 712, p. 1). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811712.PDF.
[139] *Ibid*., pp. 1-2.

Crash avoidance: NHTSA's evaluation was published in 2013. It is based on 17 "switch groups": make-models that switched from incandescent stop lamps and CHMSL to LED stop lamps and CHMSL, or vice-versa sometime between MY 2000 and 2008 (14 cars and 3 LTVs, 15 switching to LEDs and 2 returning to incandescent bulbs). It uses crash data from 12 State files (Alabama, Florida, Georgia, Illinois, Kentucky, Maryland, Michigan, Missouri, Nebraska, New Jersey, North Carolina, and Pennsylvania) for calendar years they are available at NHTSA: from 1998 to 2009, or a subset of those years, depending on the State.

The statistical analysis considers all types of front-to-rear crashes involving two vehicles. The crash involvements of interest are the rear-impacted vehicles in these collisions, specifically, the rear-impacted vehicles belonging to any of the 17 switch groups, within 2 MY before or after the switch year. Control group involvements are the frontally impacting vehicles in these collisions, likewise belonging to the switch groups. The basic contingency-table analysis for the 17 switch groups shows a statistically significant 3.6-percent reduction in rear impacts, relative to control-group involvements, for the vehicles with LED stop lamps and CHMSL.[140]

However, there are three issues that preclude an unequivocal attribution of the overall reduction to the LED stop lamps and CHMSL: (1) There is not a single "clean" switch group where **nothing** changed from one MY to the next except the light source (in the analysis of amber turn signals, by contrast, there were 11 "clean" switch groups); (2) a large proportion of the data comes from a single high-sales model that substantially changed the rear lighting configuration when it changed to LED; and (3) when the 17 groups are analyzed one-by-one, the risk ratio is lower with LED stop lamps and CHMSL in only 8 of the 17 groups, not even half (in contrast to the analysis of amber turn signals, where it was lower in 24 of 33 groups, an overwhelming majority). The report concludes that "the real-world crash data does not demonstrate that LED stop lamps and LED CHMSL are more beneficial than incandescent lamps, but also fails to rule out such a possibility."[141]

[140] *Ibid*., Table 6 on p. 20.
[141] *Ibid*., p. 22.

FMVSS No. 121, "Air brake systems"

This standard regulates one safety technology for heavy vehicles with GVWR over 10,000 pounds that has been evaluated by NHTSA and that could potentially benefit occupants of cars and LTVs if it enables the drivers of the heavy vehicles to avoid hitting the cars or LTVs:

- **Antilock brake systems for heavy trucks and trailers**

Antilock brakes are designed to prevent wheel lockup and to allow drivers to keep control of a vehicle and steer it during severe braking. ABS became a requirement between 1997 and 1999, depending on the type of vehicle, but was available on some commercial vehicles before that time.

Regulatory history: FMVSS No. 121 originally went into effect for trucks, buses, and trailers on January 1, 1975, specifying performance standards and tests for air brake systems. In 1996, NHTSA issued final rules amending FMVSS No. 121 (and also FMVSS No. 105) to require ABS and a malfunction indicator lamp(s) on all new vehicles with GVWR greater than 10,000 pounds. The ABS requirement went into effect for air-brake truck tractors manufactured on or after March 1, 1997, for air-brake trailers and single-unit trucks manufactured on or after March 1, 1998, and for hydraulic-brake trucks manufactured on or after March 1, 1999. The requirement for the malfunction indicator lamp on the vehicle went into effect simultaneously with the ABS requirement; furthermore, starting March 1, 2001, the truck tractor was required to display, within the cab, a malfunction indicator lamp for each trailer attached to it.[142]

How ABS works, expected benefits: ABS for heavy vehicles involves similar technology and capabilities as ABS for cars and LTVs. ABS senses if any of the wheels have locked, and if so, quickly releases the brakes on that wheel and lets it start rolling again. Cycles of releasing, holding and reapplying brakes are repeated many times per second. Locked wheels may result in loss of directional control, loss of steering control, and/or suboptimal stopping distances. Thus, ABS might help maintain directional stability and control during braking and possibly reduce stopping distances on some road surfaces, especially on wet roads. ABS may prevent crashes involving loss of control, skidding, jackknife, or inability to stop in time to avoid hitting another vehicle. Occupants of cars and LTVs might obtain a benefit from ABS on heavy vehicles if, as a consequence, the drivers of the heavy vehicles are able to avoid hitting the cars or LTVs.

Crash avoidance: NHTSA's evaluation, published in 2010, is similar to the studies of ABS in cars and LTVs in that it compares crashes of interest to a control group of crash involvements where ABS is less likely to have any effect.[143] Here, however, there are four possible combinations of technologies on tractor-trailer combinations: ABS on the tractor, on the trailer, on both, or on neither. The statistical comparison of these four alternatives is based on Florida data from 1998 to 2007 and special supplementary data collected by the North Carolina State Highway Patrol from 2005 to 2007. Those are the only databases that indicate the MY of the trailer and/or whether it was equipped with ABS. This analysis shows that ABS on the tractor, with or without

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[142] 49 CFR, Part 571.121; *Federal Register* 61 (May 31, 1996): 27290.

[143] Allen, K. (2010, July). *The effectiveness of ABS in heavy truck tractors and trailers*. (Report No. DOT HS 811 339). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811339.pdf.

ABS on the trailer, significantly reduces involvements in some types of crashes, especially jackknife and collisions with fixed objects.[144] A second analysis, focusing only on whether the tractor is equipped with ABS, allows extending the database to include Georgia, Missouri, Ohio, and Wisconsin files (which report the MY of the tractor, but not the trailer). This analysis estimates a statistically significant 10-percent reduction of culpable involvements in multivehicle crashes, relative to the control group, when the tractor is equipped with ABS. In other words, occupants of cars and LTVs are benefiting because ABS helps tractor-trailers avoid hitting the cars or LTVs. The analysis also shows a 53-percent reduction in jackknife, 21 percent fewer rollovers, and 15 percent fewer collisions with fixed objects when the tractor is equipped with ABS; these reductions are all statistically significant.[145]

Fatality reduction: Analysis of 1995-to-2007 FARS data, similar to the above but also controlling for rural/urban, speed limit (less than 55 mph, 55+), and light condition (daylight, other) explores the effect of ABS on the tractor in fatal crash involvements. The analysis estimates a 4.5-percent reduction of culpable involvements in multivehicle crashes, relative to the control group, but it is not statistically significant (confidence bounds, -1.6 to 10.2%).[146] Given the limited fatal-crash data, NHTSA cannot yet conclude whether the effect of ABS on fatal culpable involvements is similar to its effect on nonfatal culpable involvements (10%), or smaller, or nonexistent. The model to compute lives saved in Part 2 of this report will not attribute any fatality reduction for car or LTV occupants to ABS enabling heavy vehicles not to hit the cars or LTVs. (The analysis, however, does show a statistically significant 23 percent reduction in fatal single-vehicle rollovers for ABS on truck tractors, but this, by itself, does not save lives of car or LTV occupants.)

[144] *Ibid*., pp. 2-10.
[145] *Ibid*., Table 13 on p. 16.
[146] *Ibid*., Table 23 on p. 28.

FMVSS No. 126, "Electronic stability control systems"

This standard regulates one safety technology for cars and LTVs:

- **Electronic stability control (ESC)**

ESC systems detect when a vehicle is about to lose traction and automatically apply the brakes to individual wheels and/or reduce engine torque to help the driver stay on course. They are a highly effective crash avoidance technology. ESC was first offered on selected MY 1997 cars. By MY 2012, all new cars and LTVs were equipped with ESC.

Regulatory history: Voluntary installations of ESC after 1997 soon established evidence, first individual cases and then statistics, of remarkable effectiveness in preventing rollovers, fixed-object impacts, and other crashes involving loss of control. On April 6, 2007, NHTSA issued FMVSS No. 126 to require ESC on passenger cars, multipurpose vehicles, trucks, and buses with a GVWR of 10,000 pounds or less: all new vehicles by MY 2012, with a phase-in comprising 55 percent of MY 2009 sales, 75 percent of MY 2010, and 95 percent of MY 2011.[147]

Installation history: Mercedes-Benz first offered ESC in 1997 as standard equipment on top-of-the-line subseries or as an option on other subseries of its S and SL luxury cars. The next year, BMW was the first with ESC standard on an entire make-model, its 700-series. By 2000, it was standard on most BMW and Mercedes cars, Cadillac Seville and a few other GM luxury models, Lexus LS and GS, and Acura RL. Among SUVs, ESC was standard on Mercedes ML in 1999, on Lexus LX in 2000, followed by Toyota 4Runner and Landcruiser and Lexus RX the next year. Also in 2001, NHTSA's annual *Buying a Safer Car* brochures began to inform the public which make-models are equipped with ESC.[148] ESC was installed on 7.4 percent of vehicles sold in MY 2003. ESC sales expanded year-to-year, at first primarily on SUVs and the more expensive cars. By MY 2007, over half of new LTVs were equipped with ESC, but still less than 25 percent of cars. By MY 2009, the industry was well ahead of the phase-in schedule for FMVSS No. 126; over 80 percent of new LTVs had ESC that year. By MY 2010 or 2011, ESC had become standard on most pickup trucks and inexpensive cars.[149]

How ESC works: ESC systems detect and automatically assist drivers in oversteer and understeer situations that lead to loss of control and occur especially in unfavorable conditions such as rain, snow, sleet, or ice. "Oversteer" is when the vehicle turns more than the driver wants. "Understeer" is when the vehicle turns less than the driver tells it to. Sensors monitor the speed of each wheel, the steering wheel angle, and the yaw rate and lateral acceleration of the vehicle. The yaw rate is the rate of change of the vehicle's heading. The system compares the measured yaw rate of the vehicle to the driver's intended rate of change of heading (as evidenced by the steering wheel angle) consistent with the speed and lateral acceleration of the vehicle. For example, a yaw rate measurement greater than that consistent with the speed and lateral acceleration

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[147] 49 CFR, Part 571.126; *Federal Register* 72 (April 6, 2007): 17236.

[148] Available for 2000 to 2005 at icsw.nhtsa.gov/safe_car_new/ (click on SaferCar2000, SaferCar2001, BASC2002, BASC2003, BASC2004, or BASC2005) and for 2006 to 2010 at www.safercar.gov/Vehicle+Shoppers/Resources/Buying+a+Safer+Car+brochures.

[149] Sivinski, R. (2011, June). *Crash prevention effectiveness of light-vehicle electronic stability control: An update of the 2007 NHTSA evaluation*. (Report No. DOT HS 811 486, pp. 1-2). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811486.pdf.

of the vehicle indicates oversteer. ESC rapidly and automatically intervenes to correct the vehicle heading by applying the brakes to individual wheels and possibly reducing engine torque to help the driver stay on the road. If the vehicle was experiencing the onset of oversteer in a left curve, ESC would momentarily apply the brake to the right front wheel to counteract the excessive yaw rate and stabilize the vehicle. Some systems may then slow down the vehicle to a speed more appropriate for conditions. All current vehicles with ESC are also equipped with ABS and traction control systems; the ESC to a large extent builds on ABS technology and shares ABS components.[150]

Expected benefits: ESC would appear to be most effective in preventing single-vehicle run-off-road crashes including rollovers and collisions with fixed objects. That is because many of them involve a loss of directional stability or control during the pre-crash sequence of events. For example, if adverse conditions on the road trigger a skid, ESC could stabilize the vehicle and prevent the entire off-road excursion. Even if a careless driver has already drifted off the road with two wheels, ESC may help maintain directional control and stability, making it easier for the driver to get back on the road and avoid a crash. Presumably, ESC would have much less effect on collision involvements on the road with other vehicles, pedestrians or animals, because a smaller proportion of these crashes are preceded by a loss of directional stability. A unique feature of ESC that could make it especially effective is that it can activate without any action by a driver (unlike, for example, ABS, which cannot activate unless the driver applies the brakes).

Fatality reduction – passenger cars: NHTSA has monitored ESC since it first became available on production vehicles and has issued four statistical analyses over the years as crash data accumulated and ESC installation spread from luxury vehicles to all new cars and LTVs.[151] Similar to the analyses of ABS for cars and LTVs, contingency table compares the numbers of FARS crash involvements of interest in the first model years with ESC to the last years without it, relative to the numbers of control-group crash involvements on FARS – in this case, for a selected list of make-models that switched from not having ESC to being equipped with ESC. Non-culpable involvements in multivehicle crashes on dry roads are the control group. The four groups of crashes of interest are: (1) first-event rollovers; (2) collisions with pedestrians, bicyclists, or other non-occupants; (3) all other single-vehicle crashes; and (4) culpable involvements in multivehicle crashes.

The following table from the most recent analysis, based on FARS data from 1994 to 2011, demonstrates the profound reduction of fatal first-event rollovers with ESC, relative to the control group. (It is limited to make-models that became equipped with ESC but **not** with rollover curtains, in order to avoid counting the benefit of the curtains as part of the benefit of ESC).

[150] Dang, J. N. (2004, September). *Preliminary results analyzing the effectiveness of electronic stability control (ESC) systems*. (Report No. DOT HS 809 790). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809790.PDF.

[151] Dang (2004, September); Dang, J. N. (2007, July). *statistical analysis of the effectiveness of electronic stability control (ESC) systems – Final report*. (Report No. DOT HS 810 794). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810794.pdf; Sivinski (2011, June); Kahane, C. J. (2014, May). *Updated estimates of fatality reduction by ESC*. (Report No. DOT HS 812 020). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/812020.pdf.

FARS 1994 to 2011	First-Event Rollovers	Control Group	Risk Ratio
Last 3 MY without ESC	353	1,437	.2457
First 3 MY with ESC	98	986	.0994

This is a statistically significant 60-percent reduction of fatal first-event rollovers, relative to the control group (confidence bounds, 49 to 68%). ESC does not have a statistically significant effect on fatal collisions with pedestrians and bicyclists. In all other fatal single-vehicle crashes (mostly impact with fixed objects after running off the road), the reduction for ESC is a statistically significant 31 percent (confidence bounds, 22 to 39%). ESC reduces culpable involvements in fatal multivehicle crashes by a statistically significant 16 percent (confidence bounds, 4 to 26%).[152]

Crash avoidance – passenger cars: NHTSA's 2011 evaluation, based on GES data from 1997 to 2009, generates national estimates of the effect of ESC on police-reported crash involvements by methods similar to the above FARS analysis. ESC reduces first-event rollovers by a statistically significant 72 percent. The observed effects on other types of single-vehicle crashes and on culpable involvements in multivehicle crashes are not statistically significant.[153]

However, NHTSA's 2007 evaluation does show a statistically significant 45-percent reduction in run-off-road crashes that are not rollovers and a statistically significant 13-percent reduction in culpable involvements in multivehicle crashes (as well as a statistically significant 64% reduction in rollovers). The 2007 evaluation is based on crash data from seven State files (California, Florida, Illinois, Kentucky, Missouri, Pennsylvania, and Wisconsin) for CY 1997 to 2003 (or the subset of those years available at NHTSA, depending on the State).[154]

Fatality reduction – LTVs: NHTSA's most recent analysis, based on FARS data from 1994 to 2011 shows even higher effectiveness for LTVs than for passenger cars – e.g., the following table of fatal first-event rollovers (again limited to make-models that became equipped with ESC but **not** with rollover curtains).

FARS 1994 to 2011	First-Event Rollovers	Control Group	Risk Ratio
Last 3 MY without ESC	857	1,995	.4296
First 3 MY with ESC	104	931	.1117

It is a statistically significant 74-percent reduction of fatal first-event rollovers, relative to the control group (confidence bounds, 68 to 79%). ESC does not have a statistically significant effect on fatal collisions with pedestrians and bicyclists. In all other fatal single-vehicle crashes,

152 Kahane (2014, May).
153 Sivinski (2011, June), p. iv.
154 Dang (2007, July), p. 39.

the reduction for ESC is a statistically significant 45 percent (confidence bounds, 39 to 51%). ESC reduces culpable involvements in fatal multivehicle crashes by a statistically significant 16 percent (confidence bounds, 8 to 24%).[155]

Crash avoidance – LTVs: NHTSA's 2011 evaluation, based on GES data, estimates statistically significant reductions in first-event rollovers (64%) and impacts with fixed objects (67%). The observed effect on culpable involvements in multivehicle crashes is not statistically significant.[156] However, NHTSA's 2007 evaluation, based on State data, does show a statistically significant 13 percent drop in culpable involvements in multivehicle crashes (as well as reductions of 64 percent in rollovers and 69 percent in impacts with fixed objects, both statistically significant).[157]

[155] Kahane (2014, May).
[156] Sivinski (2011, June), p. iv.
[157] Dang (2007, July), p. 41.

FMVSS No. 138, "Tire pressure monitoring systems"

This standard regulates a safety technology for cars and LTVs for which NHTSA has evaluated on-the-road performance, but has not yet evaluated the effect on safety:

- **Tire pressure monitoring systems**

When properly calibrated, TPMS warns the driver if one or more tires are inflated to a pressure that is 25 percent or more below the recommended level. Underinflation can adversely affect traction and fuel economy. TPMS first became available in the United States in MY 1997. By MY 2008, all new cars and LTVs were equipped with TPMS, as required by FMVSS No. 138.

Regulatory history: Section 13 of the TREAD Act of 2000 directed NHTSA to upgrade tire performance, including a requirement for systems that warn the driver when a tire is significantly underinflated – a situation that poses a safety risk, increasing the chance of skidding, hydroplaning, longer stopping distances, and crashes due to flat tires and blowouts. On April 8, 2005, NHTSA issued a new safety standard, FMVSS No. 138, "Tire pressure monitoring systems," requiring TPMS in all new cars and LTVs with GVWR up to 10,000 pounds built after September 1, 2007 (MY 2008). The two-year phase-in period required TPMS on 20 percent of MY 2006 vehicles and 70 percent of MY 2007.[158] A vehicle's TPMS must warn the driver when one or more of the vehicle's tires is severely underinflated – i.e., has fallen to 25 percent or more below the nominal pressure to which the TPMS has been calibrated. Ordinarily, the TPMS should be calibrated to the "placard" pressure recommended by the manufacturer for that vehicle. The display, a warning light on the instrument panel, must activate within 20 minutes of underinflated travel at speeds of 50 to 100 km/h and must remain illuminated until the underinflation is remedied. The system must also have a malfunction lamp in addition to a low-pressure warning lamp that alerts the driver if the vehicle's TPMS is not functioning properly.

The industry installed TPMS ahead of the phase-in schedule for FMVSS No. 138. It was standard equipment on over 20 percent of new cars and LTVs in MY 2004 and over 30 percent in MY 2005 and 2006.[159]

How TPMS works: Two TPMS technologies have appeared in production vehicles: direct and indirect systems. Direct TPMS uses a battery-powered pressure sensor and a radio transmitter inside each tire that periodically broadcasts the tire pressure to a central processing unit in the vehicle. The sensors are most often located on the interior end of a tire's valve stems. Some direct systems, in addition to the warning light, display the actual pressure of each tire on the dash, allowing the driver to diagnose overinflation as well as underinflation. The batteries have a finite life, variously estimated to range from 3 to 12 years or from 50,000 to 100,000 miles. When one or more batteries expire, the entire wheel sensor must be replaced for each battery. Sensors may potentially be damaged as a result of improperly replacing, exchanging, or filling tires or after hitting road hazards. If the owner has snow tires mounted on separate wheels for seasonal use,

[158] 49 CFR, Part 571.138; *Federal Register* 70 (April 8, 2005): 18136.

[159] Sivinski, R. (2012, November, p. 3). *Evaluation of the effectiveness of TPMS in proper tire pressure maintenance*. (Report No. DOT HS 811 681). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811681.pdf.

they would need their own sensors. The systems may need to be recalibrated after replacing tires and possibly other situations.

In vehicles equipped with ABS, indirect TPMS relies on the ABS system, which has sensors that continually monitor the speed of the four wheels. If one tire has low pressure, it would have a smaller diameter and rotate more often than the other wheels, triggering the warning light if the difference in speeds is large enough. Early indirect systems were installed on some vehicles before FMVSS No. 138 went into full effect (September 1, 2007). These systems were unable to detect, for example, if all four wheels were equally underinflated (because the four wheels' speeds would all be the same); these systems would not have met FMVSS No. 138, which requires a warning if one **or more** tires are underinflated. Starting MY 2009, however, some vehicles have indirect systems compliant with FMVSS No. 138 because they can integrate information from the ABS, ESC and other sensors to recognize when multiple tires are underinflated. Indirect systems do not have batteries that need replacement or sensors inside the valve stems that could be damaged, but they do need recalibration in some situations.[160]

Expected benefits: Underinflation is the most common cause of tire failure. Underinflated tires experience a greater amount of sidewall flexion than properly inflated tires, resulting in decreased fuel economy, sluggish handling, longer stopping distances, increased stress to tire components, and heat buildup that can lead to catastrophic failure of the tire, such as cracking, component separation, or blowout. These catastrophic failures can cause loss of vehicle control and may result in a crash. If the warnings from TPMS influence drivers to maintain proper inflation, there should be a reduction in crash involvements attributable to catastrophic tire failures and perhaps also in other crash involvements attributable to excessive stopping distances or unsuccessful evasive maneuvers due to sluggish handling.

On-the-road performance: During CY 2011, NHTSA sponsored a survey by the NASS teams. They measured tire pressure in all four tires on a probability sample of 6,103 vehicles (4,391 of which were equipped with TPMS) of MY 2004 to 2011. The survey found a large, statistically significant gain in proper tire inflation with direct TPMS. MY 2004-to-2007 cars and LTVs equipped with direct TPMS were 56 percent less likely (confidence bounds, 36 to 69%) to have one or more severely underinflated tires – i.e., 25 percent or more below the vehicle manufacturer's recommended cold tire pressure – than vehicles of the same age without any TPMS.[161] Moreover, because there is more air in the tires of vehicles equipped with TPMS, NHTSA estimates that, on the average, over the first eight years of a vehicle's lifetime, TPMS will save 9 gallons of fuel in passenger cars and 28 gallons in LTVs.[162] NHTSA has not yet analyzed crash data to evaluate the safety effects of TPMS, but the on-the-road performance augurs well for the future safety evaluation.

The survey, however, also indicated that TPMS was substantially more effective in reducing underinflation in MY 2006 and 2007 vehicles (relative to vehicles without TPMS of the same MY) than in MY 2004 and 2005, which were 6 to 7 years old at the time of the CY 2011 survey. There are several possible explanations for the lower effectiveness in the somewhat older vehi-

[160] *Ibid*., pp. 2-3.
[161] *Ibid*., Table 3 on p. 18.
[162] *Ibid*., pp. 30-36.

cles, including the possibility that there might not be functional TPMS systems in all of the tires of these older vehicles. Owners might not have replaced expired batteries or otherwise not maintained and properly calibrated their systems. NHTSA is currently developing an additional survey to assess the frequency and causes of vehicles having a TPMS system that is not functional, as well as the costs associated with repair and maintenance of these systems, as a function of vehicles' age and mileage.

FMVSS No. 201, "Occupant protection in interior impact"

This standard is indirectly associated with one vehicle modification whose safety benefits NHTSA evaluated and directly associated with another that the agency also evaluated:

- **Redesign of middle and lower instrument panels with improved occupant protection, and**
- **1999-2003 head injury protection upgrade.**

There are also some connections between FMVSS No. 201 and curtain air bags, but that technology is covered in the chapter on FMVSS No. 214. The first paragraph of FMVSS No. 201 says, "This standard specifies requirements to afford impact protection for occupants."[163] Primarily, FMVSS No. 201 consists of performance requirements limiting the amount of force allowed when a headform is impacted into various sections of the vehicle interior that are frequently contacted by occupants' heads during crashes. FMVSS No. 201 was one of NHTSA's initial safety standards, effective for passenger cars on January 1, 1968. It was extended to pickup trucks, vans and SUVs up to 10,000 pounds GVWR, effective September 1, 1981. More recently, performance requirements for cars and LTVs were upgraded by adding a 15 mph free-motion headform (FMH) impact test of the upper interior components, with a phase-in from September 1, 1998, to September 1, 2002.

NHTSA believes that most passenger cars met the original head-impact requirements of FMVSS No. 201 quite a few years before their effective date of January 1, 1968. The substantial vehicle modifications close to 1968 were in the middle and lower instrument panel, frequently areas of contact with the occupant's torso and knees. These areas had been contemplated, but ultimately not included for regulation by FMVSS No. 201.

Redesign of middle and lower instrument panels with improved occupant protection

Regulatory history: Instrument panel tops that were padded in some form were standard or optional on most passenger cars by 1963. SAE issued Recommended Practice J921, defining a 15 mph headform impact test with the instrument panel, in June 1965. NHTSA's original, December 1966 NPRM for FMVSS No. 201 incorporated the SAE Recommended Practice and extended it to other likely head contact areas such as seat backs, sun visors, armrests and other projections in head impact areas. The August 16, 1967 final rule finalized specifications for instrument panels, seat backs, sun visors, and armrests. The final rule set a peak deceleration of 80 g's over 3 milliseconds for impact tests of instrument panels and seat backs and certain design criteria for the sun visor and armrest components. Most cars were apparently meeting the various head-impact requirements of FMVSS No. 201 well before 1968.[164]

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[163] 49 CFR, Part 571.201.

[164] Kahane, C. J. (1988, January). *An evaluation of occupant protection in frontal interior impact for unrestrained front seat occupants of cars and light trucks*. (Report No. DOT HS 807 203, pp. 2-3). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807203.PDF; Campbell, B. J. (1963). *A study of injuries related to padding on instrument panels*. (Report No. VJ-1823-R2). Buffalo: Cornell Aeronautical Laboratory; *Federal Register* 31 (December 3, 1966): 15212; *1967 SAE Handbook*, pp. 881-884.

On the other hand, this NPRM also contemplated force limits for "knee" and "child" impact areas – i.e., the lower and middle instrument panel areas anterior to an adult RF passenger's chest and legs (and that a small child's head might also contact) – but they did not become part of FMVSS No. 201. In 1970, NHTSA again proposed a knee impact test, but did not issue a final rule. Thus, even though FMVSS No. 201 never actually regulated the middle and lower instrument panels, the repeated proposals to do so may have influenced the ultimately voluntary improvements to crashworthiness in those areas.[165]

NHTSA's 1970 NPRM also proposed to extend the original FMVSS No. 201 requirements to LTVs. That part of the proposal was adopted and took effect on September 1, 1981.[166]

Vehicle modifications and their purpose: In the 1960s, most RF passengers were unrestrained.[167] Safety researchers such as Daniel at Ford and Wilson at GM grasped that the instrument panel was the principal energy-absorbing "ride-down" mechanism for the unrestrained passenger in a frontal impact. They believed that the panel should decelerate the occupant as completely, but gradually as possible, at no time applying a dangerous level of force to the occupant. For the most part, instrument panels of the 1960s were too rigid and needed to be softened – but not so much that the occupant would break through to the even more rigid structures in front of the panel. Daniel believed panels with 1,200 pounds maximum force deflection for the chest in a 20 mph impact, and 1,400 pounds optimum for the knees in a 12 mph impact could protect even unrestrained occupants in 30 mph barrier impacts.[168]

A second objective was to "tune" the relative rigidity of the middle and lower instrument panels so that the occupant would remain upright during a frontal impact. For example, an excessively rigid lower panel might cause the occupant to pitch forward, head first. A third objective was to bring the panel as close to the occupant as possible and extend it downwards, consistent with the occupant's comfort. The sooner contact begins and the more extensive the engagement with the occupant's knees, the more gradual the ride-down.

Happily, the new insight on the design of the panel coincided with the increasing practicability and economy of plastics or thinner steel rather than heavy steel panels for assembling interior components.

NHTSA measured the geometry and force deflection characteristics of instrument panels in 21 cars ranging from MY 1965 to 1983. The analysis confirmed that manufacturers significantly

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[165] Kahane (1988, January), pp. 2-3; Williams, A.F., Wong, J., & O'Neill, B. (1979). Occupant protection in interior impacts – An analysis of FMVSS No. 201. *Proceedings of the Twenty-Third Conference of the American Association for Automotive Medicine*. Morton Grove, IL: American Association for Automotive Medicine; *Federal Register* 31 (December 3, 1966): 15212, 35 (September 25, 1970): 14936.
[166] *Federal Register* 44 (November 29, 1979): 68470.
[167] Even as late as 1977 to 1979, belt use by sub-teen, teenage, and adult RF passengers was only 3 to 7 percent; see Phillips, B. M. (1980, May). *Safety belt usage among drivers*. (Report No. DOT HS 805 398, pp. 44-50). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS805398.PDF.
[168] Kahane (1988, January), pp. 9-15; Daniel, R. P. (1970). Vehicle interior safety constraint systems. *1970 International Automobile Safety Conference Compendium*. (Paper No. 700423). New York: Society of Automotive Engineers; Wilson, R. A. (1969). Evaluating knee-to-instrument panel impacts. *Thirteenth Stapp Car Crash Conference*. (Paper No. 690801). New York: Society of Automotive Engineers.

changed instrument panel design in the directions that their researchers believed to be safety-favorable, especially in the late 1960s and continuing into the early 1970s. Panels became less rigid, extended downwards, and were contoured in a manner that occupants would feel comfortable sitting closer to them.[169]

The implementation dates for these changes in LTVs are unknown. However, other safety improvements of that era, such as 3-point belts and energy-absorbing steering assemblies, typically appeared in LTVs about 5 to 10 years after cars. That suggests the panels may have been modified in LTVs more or less throughout the 1970s, which also was the decade between the NPRM to extend FMVSS No. 201 to LTVs (1970) and its final effective date (September 1, 1981).

Expected benefits: Since the instrument panel was by far the most common source of life-threatening as well as moderate injury for unrestrained RF passengers in frontal crashes, the improvements of the late 1960s and early 1970s could be expected to reduce injuries and fatalities.[170]

Injury reduction – passenger cars: NHTSA's study, published in 1988, uses data from the 1977-to-1979 National Crash Severity Study.[171] It compares non-minor (AIS $\geq$ 2) injury rates, due to instrument panel contact, per 100 front seat passengers involved in frontal towaway crashes, for four MY groups of cars: 1960-to-1966, 1967-to-1970, 1971-to-1974 and 1975-to-1978. After controlling for delta V (an indicator of crash severity), the three later MY groups each have significantly lower injury rates from instrument-panel contacts than the 1960-to-1966 cars. The reductions are 23, 36 and 21 percent relative to the 1960-to-1966 group, respectively. The average reduction for all 1967-to-1978 cars, relative to the 1960-to-1966 cars, is a statistically significant 29 percent.[172] The differences among the three post-standard groups (1967-to-1970, 1971-to-1974 and 1975-to-1978) are not statistically significant. The reduction of injuries due to contact with the instrument panel is not offset by any increase of injuries from other sources. Using 1982 as the "baseline" year, the evaluation estimates that when the pre-1967 cars are phased out and all cars on the road have the improved instrument panels, AIS $\geq$ 2 injuries to RF passengers will decrease by an estimated 8,000 per year.[173]

The 1988 study also documents computer simulations of frontal crashes that are consistent with the NCSS results. MVMA2D is a computer program to simulate an occupant's motion and compute the injury-criterion scores for contacts with the vehicle interior in a straight-ahead frontal crash. As stated above, NHTSA measured the geometry and force-deflection characteristics of instrument panels (and other structures) in 21 cars ranging from MY 1965 to 1983. This data was used to set up MVMA2D, which was run six times for each car to simulate the motion of an unbelted RF passenger: for 50th percentile male, 5th percentile female and 95th percentile male dummies, each at 25 mph and 30 mph frontal barrier impacts. In each of these 126 simulations,

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[169] Kahane (1988, January), pp. 43-109.
[170] *Ibid*., pp. xxvii and 15-20.
[171] Kahane, C. J., Smith, R. A., & Tharp, K. J. (1977). The National Crash Severity Study. *Report on the Sixth International Technical Conference on Experimental Safety Vehicles*. (Report No. DOT HS 802 501, pp. 493-515). Washington, DC: National Highway Traffic Safety Administration.
[172] 90 percent confidence bounds: 10 to 48 percent.
[173] Kahane (1988, January), pp. 21-41.

MVMA2D estimates the head injury criterion (HIC), the chest g's and deflection, the femur load, and six other injury criteria for the head, chest and neck.[174]

Injury scores are compared on a nonparametric basis[175] – i.e., the analysis shows if one group of cars is significantly safer than another, but does not estimate the percentage reduction of injury risk. The trends are the same as in the NCSS data. The 1969-to-1971 cars and the 1976-to-1983 cars both have significantly lower overall injury risk than the 1965-to-1966 cars. The average injury risk in MY 1976 to 1983 is slightly but not significantly lower than in 1969 to 1971. Injury risk to the head/neck, chest, and femur are all lower in MY 1969 to 1971 and 1976 to 1983 than in 1965 to 1966.

Moreover, the MVMA2D simulations generate results that are consistent with researchers' intuition about what sort of panel modifications would benefit safety. Reductions in the rigidity of the middle and lower panels and lengthening the panels by extending them downwards and towards the occupant are associated with significant injury reductions.

Injury reduction – LTVs: NHTSA analyzed overall AIS ≥ 2 injury rates per 100 unrestrained RF passengers in frontal towaway crashes in 1982-to-1985 NASS and 1977-to-1979 NCSS data. In those days, LTVs accounted for a smaller share of the market than they do now, and there were not enough cases to adjust the rates for delta V or other factors or to single out injuries due to contact with the instrument panel.[176] The analysis does not show a clear reduction in the injury rates. In NASS, the injury rate for MY 1971-to-1974 LTVs is 43 percent lower than in 1966-to-1970 LTVs. But the reduction relative to MY 1966-to-1970 subsequently dwindles to 29 percent in 1975 to 1978, 5 percent in 1979 to 1981, and 16 percent in 1982 to 1985. In NCSS, the MY 1971-to-1974 LTVs have 33 percent lower injury rate than 1961-to-1970 LTVs, but the 1975-to-1978 LTVs have the highest rate, 24 percent higher than in 1961 to 1970. While the reductions in MY 1971 to 1974 are effects in the right direction, the subsequent trends toward higher injury rates are inconsistent with the idea that panel improvements continued throughout the 1970s. Small samples and an inability to control for delta V or other factors made it difficult to obtain statistically meaningful results.[177]

Fatality reduction – passenger cars: The fatality "risk index" of RF passengers in frontal crashes is computed by model year (1964 to 1984), based on a three-step analysis of CY 1975-to-1984 FARS data. The first step is the computation of an absolute risk index for drivers. The analysis compares the ratio of driver fatalities in head-on (front-to-front) collisions between cars of two different model years. For example, in head-on collisions between MY 1975 and 1979 cars, 37 drivers of the MY 1975 cars and 90 drivers of the MY 1979 cars were fatalities. In these unadjusted data, relative vehicle mass is the dominant factor: since many of the MY 1979 cars had been downsized, they had higher risk in the head-on collisions with the MY 1975 cars. Next, a logistic regression estimates the expected fatality risk of each driver in a head-on collision, giv-

[174] *Ibid*., pp. 43-109 and 205-220.
[175] Using a weighted average of the normalized rank order scores for the various criteria, for the six simulations on each car.
[176] LTVs constituted 22 percent of the light vehicles on the road in 1980 and 44 percent in 2011: NHTSA. (2013). *Traffic safety facts 2011*. (Report No. DOT HS 811 754, pp. 24 and 26). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811754AR.pdf
[177] *Ibid*., pp. 165-173.

en only the curb weights of the two cars and the age, gender and belt use of the two drivers. In each model year's cars, the actual number of fatalities in the head-on collisions is compared to the number that would have been expected, based on their own and their collision partners' curb weight, driver age, gender and belt use. The fatality risk index is the ratio of actual to expected fatalities (normalized to 100). The fatality risk index for drivers averages 117.3 in MY 1964-to-1966, drops sharply to 103 by 1968-to-1970, and remains close to 100 throughout 1973 to 1984.[178]

The second step is the computation of a risk index for RF passengers relative to drivers. It is based on the ratio of RF passenger to driver fatalities in frontal impacts (including, but not limited to head-on collisions) in cars of a given model year that were occupied by a RF passenger as well as a driver, both unrestrained. For example, in frontal impacts of MY 1975 cars with both seats occupied, 1410 RF passengers and 1472 drivers were fatalities. Next, a logistic regression predicts the fatality risk of each driver and each passenger in these impacts, given only the age and gender of the two occupants and the exact impact location (pure frontal, left front, right front – i.e., FARS principal impact points 12, 11, or 1, respectively). In each model year's cars, the actual ratio of RF to driver fatalities is compared to the predicted ratio, based on the two occupants' age/gender and the impact location. The fatality risk index is the actual ratio divided by the predicted ratio (normalized to 100).

The relative risk index is 120-125 in MY 1960-to-1965, drops sharply in the late 1960s, and continues decreasing slowly, leveling out at close to 100 in 1975 to 1984. In other words, the RF seat was at one time substantially more dangerous than the driver's seat. But the safety gap was closed, despite the introduction of energy-absorbing steering assemblies that benefited only drivers. Something(s) that is even more effective than the energy-absorbing steering assemblies must have been introduced for passengers.[179]

The third and last step is computing the absolute fatality risk index for RF passengers. It is the product of the driver and the passenger-relative-to-driver indices. This index averages 135.7 in MY 1964-to-1966, 109.1 in 1968-to-1970, and 99.7 in 1973-to-1984. The drop from 135.7 to 109.1 is a 20-percent reduction, equivalent to 665 lives saved per year. The more gradual change from 109.1 to 99.7 is an additional 9-percent reduction, equivalent to 235 lives saved per year.[180]

The aforementioned design changes to instrument panels was the most important crashworthiness improvement for unrestrained RF passengers in frontal crashes and must have accounted for many of these 665 + 235 = 900 lives saved per year, but it is difficult to estimate how many can be attributed specifically to this as opposed to other automotive safety improvements of that time period. The trend in the fatality risk index closely parallels the trends in the NCSS data and MVMA2D simulations: a strong improvement in the late 1960s, with some additional improvements in the early 1970s and leveling out after that. That is consistent with the hypothesis (but not a proof) that the fatality reduction largely reflects the instrument-panel improvements. It is

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[178] *Ibid*., pp. 111-140; the drop from 117.3 to 103, a 12 percent reduction, corresponds closely to the effectiveness estimate for energy-absorbing steering assemblies – i.e., energy-absorbing steering assemblies significantly reduced the fatality risk of unrestrained drivers in frontal crashes in 1967-68, and no other vehicle modification in 1964-84 had any large effect (see also the FMVSS Nos. 203/204 chapter).

[179] *Ibid*., pp. 140-153.

[180] *Ibid*., pp. 153-156 and 161.

estimated from NCSS data that before 1967, 616 RF passengers per year received fatal injuries from contact with the instrument panel, while Huelke's in-depth investigations suggested the number could be twice as high. If the fatality reduction for improved panels is the same as the AIS ≥ 2 injury reduction, 29 percent, that would amount to annually preventing 180-360 fatalities due to contact with the instrument panel. However, the MVMA2D simulations suggest that the benefits of improved panels are not limited to preventing injuries directly caused by contact with the panel: by providing "ride-down" and keeping the occupant upright, they can reduce the severity of contacts with other interior surfaces. Other safety standards that benefited unrestrained passengers in frontal impacts, such as FMVSS Nos. 205 or 212 are unlikely to have saved more than 100 RF passengers per year. Taking all these considerations into account, NHTSA estimated that improved panels account for approximately 400 to 700 of the 900 passenger lives saved per year in frontal crashes. The point estimate is 550; it is equivalent to a 16-percent reduction of unrestrained RF passenger fatalities in frontal impacts.[181]

Fatality reduction – LTVs: Using 1975-to-1984 FARS data, NHTSA developed fatality risk indices for drivers and RF passengers of LTVs, analogous to the indices for cars. The absolute risk index for RF passengers dropped from an average of 127 in model years 1966-to-1968 to an average of 98 in 1975-to-1980. The drop was sharpest in 1969-to-1975 and gradually leveled out afterwards. That is a 23-percent fatality reduction during the decade when instrument panels were modified in LTVs, similar to the long-term overall reduction in the risk index for car passengers. It suggests that the effectiveness of improved panels may be about the same in LTVs and cars: a 16-percent reduction of unrestrained RF passenger fatalities in frontal impacts.[182]

1999-2003 head injury protection upgrade

Regulatory history: On August 14, 1995, NHTSA issued a final rule extending the head injury protection requirements of FMVSS No. 201. The existing requirements of FMVSS No. 201 remained for the original target areas. However, a new list of target areas in the vehicle's upper interior includes the A-, B- and other pillars, the front and rear roof headers, the roof side rails, and the upper roof, among others. These structures were sources of life-threatening head injuries in existing vehicles. The impact speed for the free-motion headform (FMH) impact test for the new areas is 15 mph, as in the original FMVSS No. 201, but for these new targets, HIC may not exceed 1000 for any 36-millisecond period. Impacts could be directed from a range of vertical and horizontal angles, not just head-on. Manufacturers were offered a choice of several alternative phase-in schedules from September 1, 1998, to September 1, 2002. For example, they could certify the new requirements on at least 10 percent of cars and LTVs manufactured from September 1, 1998, through August 31, 1999; at least 25 percent of cars and LTVs manufactured from September 1, 1999, through August 31, 2000; at least 40 percent of cars and LTVs manufactured from September 1, 2000, through August 31, 2001; at least 70 percent of cars and LTVs

[181] *Ibid*., pp. 15-18, 38-39, 92-106 and 161-163; Huelke, D. F., & Gikas, P. W. (1968, November/December). Causes of death in automobile accidents. *Police*, *13*, pp. 81-89; see also the chapters for FMVSS Nos. 205 and 212 later in this report.
[182] Kahane (1988, January), pp. 174-197.

manufactured from September 1, 2001 through August 31, 2002; and all cars and LTVs manufactured on or after September 1, 2002.[183]

On August 4, 1998, NHTSA amended the rule to facilitate the introduction of curtain air bags. Recognizing that the 15 mph headform test might be a problem in target areas where an undeployed air bag is stored (and, furthermore, an inappropriate test if the bag usually deploys at that speed), NHTSA offered an alternative compliance procedure. Manufacturers have the option to reduce the speed of the headform test to 12 mph on target areas where the bag is stored, provided they can also meet an 18 mph lateral (90-degree) crash test for the full vehicle into a pole – with HIC < 1000. The pole test simulates a head impact with the deployed bag.[184]

Vehicle modifications: The principal modifications are the addition of energy-absorbing padding in the target areas and the addition of curtain air bags. In most make-models of cars and LTVs, padding came first, during the MY 1999-to-2003 phase-in period for the head-impact upgrade of FMVSS No. 201. Curtains usually came later; only 8 percent of MY 2003 cars and LTVs, approximately half of MY 2007 vehicles, but 93 percent of MY 2011 vehicles were equipped with curtains.[185] It is generally unknown to what extent the padding stayed the same in vehicles after the curtains arrived. Some modification or even discontinuation of the padding may occur in components that house the curtains, such as the roof side rails, or possibly in areas that may be protected by curtains, such as pillars. Modification is less likely in areas not protected by curtains, such as the roof interior, although it may have been modified here and there to make room for the undeployed curtains. NHTSA studied the pillar components in three make-models certified to the head-impact upgrade of FMVSS No. 201, before and after these models were equipped with curtains; the average cost of the components was slightly higher in the vehicles with the curtains, suggesting (although not proving) that energy-absorbing materials were not downgraded, at least on these three models, after curtains became available.[186]

The chapter on FMVSS No. 214 presents analyses of the effectiveness of curtain air bags (over and above the benefits of padding – i.e., the fatality reduction for a vehicle with curtains and certified to FMVSS No. 201 relative to a vehicle without curtains but also certified to FMVSS No. 201). The remainder of the discussion in this chapter is limited to the design of the energy-absorbing padding and its effectiveness in vehicles not yet equipped with curtains.

The "padding" or "foam" used for the head-impact upgrade is not a soft cushion. It is rigid to the touch, but deformable enough to limit force to a level where the risk of head injury is relatively low. Approaches used to meet the head-impact upgrade include composite plastic foam padding,

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[183] *Federal Register* 60 (August 18, 1995): 43031.
[184] *Federal Register* 63 (August 4, 1998): 41451.
[185] Kahane, C. J. (2014, January). *Updated estimates of fatality reduction by curtain and side air bags in side impacts and preliminary analyses of rollover curtains*. (Report No. DOT HS 811 882, p. 6). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811882.pdf.
[186] Kahane, C. J. (2011, November). *Evaluation of the 1999-2003 head impact upgrade of FMVSS No. 201 – Upper-interior components: effectiveness of energy-absorbing materials without head-protection air bags*. (Report No. DOT HS 811 538, p. 17). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811538.PDF; Ludtke, N. F., Osen, W., Gladstone, R., & Lieberman, W. (2004, December). *Perform cost and weight analysis, head protection air bag systems, FMVSS 201*. (Report No. DOT HS 809 842; NHTSA Docket No. NHTSA-2011-0066-0007, pp. 3-47 to 3-54 and Appendix A). Washington, DC: National Highway Traffic Safety Administration.

injection-molded ribs in parallel or egg-crate-like (honeycomb) configurations, possibly supplemented with ridges of composite plastic materials molded into the foam; crushable tubes; thicker roof liners; stretchable fabric materials; and configuration changes of the outer trim parts to allow for the flexing of these parts under load to absorb some of the impact energy. The ribs are thin-walled panels with parallel sides molded with the wall configuration in line with the direction of the expected impact load. Among the target areas, a 2006 NHTSA study indicated that A-pillars were substantially modified in almost all vehicles. B-pillars and the interior lining of the roof were almost always modified. The other pillars, roof side rails, the front header and the rear header changed less often.[187]

Test performance: NHTSA compared HIC(d) – the HIC score on the 15 mph headform impact test – at matching target locations in the same or similar make-models before and after the upgrade of FMVSS No. 201.[188] To do so, NHTSA purposively selected 15 compliance test reports of high-sales models of cars and LTVs, comprising a variety of body types and manufacturers. A contractor performed identical headform impact tests, at the same locations as in the compliance tests on 15 pre-upgrade vehicles of the same (or similar) make-models. In all, there were 154 matched pairs of impact test locations in pre- and post-upgrade vehicles. HIC(d) averaged 909.9 in 154 head impact tests on pre-upgrade vehicles, ranging from as low as 426 to as high as 1767. In compliance tests of post-upgrade vehicles, the 154 impacts to matching locations in the same make-models resulted in a range of HIC(d) from 373 to 986 and an average of 667.5. That is a statistically significant average improvement of 242.4 units of HIC per test.

Furthermore, HIC(d) exceeded 1000 in 47 of the 154 locations tested in pre-upgrade vehicles, but was less than 1000 in each of the 154 locations in the post-upgrade vehicles. Only 2 of the 15 pre-upgrade vehicles, but all of the post-upgrade vehicles had HIC(d) ≤ 1000 at each location.

HIC(d) was reduced by an average of 476 units in impacts with the A-pillar, 61 in impacts with the B-pillar, 105 with other pillars, 279 with the upper roof and 245 with the roof side rail. All of these improvements were statistically significant. There was a non-significant average increase of HIC(d) by 35 in impacts with the front or rear header. Performance improvement was the largest on the A-pillar, where pre-upgrade performance was the poorest. In the pre-upgrade vehicles, HIC(d) averaged 1154 for the A-pillar, 737 for the B-pillar, 747 for other pillars, 930 for the roof side rail, 941 for upper roof and 543 for the front and rear header. After FMVSS No. 201, HIC(d) averaged 679 for the A-pillar, 676 for the B-pillar, 642 for other pillars, 684 for the roof side rail, 662 for upper roof and 578 for the front and rear header. In other words, post-upgrade HIC(d) was nearly uniform at about 650 across the upper interior, with larger improvements on the components where HIC(d) was originally higher.[189]

Expected benefits: Head injuries due to contacts with upper-interior components of the vehicle (pillars, headers, roof side rails, and the roof interior) were one of the most frequent types of severe injury. Also, the vast majority of the severe injuries involving upper-interior contact were head injuries. Specifically, before the upgrade to FMVSS No. 201, head injuries due to contacts

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[187] Kahane, C. J., & Tarbet, M. J. (2006, November). *HIC test results before and after the 1999-2003 head impact upgrade of FMVSS 201*. (Report No. DOT HS 810 739, pp. 7-14). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810739.PDF.
[188] *Ibid*., pp. 14-24.
[189] *Ibid*., pp. 19-21.

with upper-interior components constituted 22 percent of all occupant injuries at the AIS 4-to-6 levels. These components accounted for 43 percent of all head injuries at the AIS 4-to-6 levels. But they accounted for only 8 percent of injuries to other body regions at the AIS 4-to-6 levels; 84 percent of the AIS 4-to-6 injuries involving upper interior components are head injuries.[190]

The upgrade to FMVSS No. 201 specifically aimed to reduce the risk of severe head injuries due to contacts with upper interior components. Because they were a large safety problem, there was a large potential for benefits. Effectiveness may be expected for occupants at any interior seating position in cars or LTVs, in a wide variety of crash types. The upgrade cannot be expected to have any effect on injuries not involving contact with upper-interior components and, at most, a quite limited effect on injuries to body regions other than the head.

Injury reduction: NHTSA issued a statistical analysis in 2011. It is based on NASS CDS data from CY 1995 to 2009. The analysis is limited to cars and LTVs equipped with frontal air bags but not yet equipped with curtain or side air bags – in order to isolate the effect of upper-interior padding from the possible effects of the various types of air bags. The database consists of all individual injuries at the AIS 4-to-6 level (severe, critical, or maximum) – i.e., there may be more than one injury per occupant. Injuries to occupants of any interior seating position are included. The contingency-table analysis computes the ratio of AIS 4-to-6 injuries of the head or face due to contact with upper-interior components to control group injuries: AIS 4-to-6 injuries that are not head injuries **and/or** are not from upper interior sources. The ratios are compared for vehicles before and after the upgrade to FMVSS No. 201. Here are the counts of unweighted CDS cases (to provide an idea of the sample sizes) and nationally weighted counts (used for computing effectiveness).[191]

CDS 1995 to 2009	AIS 4-to-6 Head-Upper Interior Injuries	All Other AIS 4-to-6 Injuries	Risk Ratio
Unweighted Cases			
Pre-FMVSS No. 201 upgrade	1,993	6,931	
FMVSS No. 201-certified	424	1,848	
Weighted Counts			
Pre-FMVSS No. 201 upgrade	103,829	354,393	.293
FMVSS No. 201-certified	18,791	93,892	.200

This is a statistically significant 32-percent reduction of AIS 4-to-6 head-upper interior injuries after the upgrade to FMVSS No. 201. In general, the analysis shows approximately equal effectiveness by vehicle type (car or LTV), seating position, specific injury source, and specific type of head injury; however, the observed effectiveness is somewhat higher in first-event rollovers,

[190] Kahane (2011, November), pp. 1-4.
[191] *Ibid*., pp. 23-29; injuries with body regions O (whole body), U (unknown), and N (neck) are not assigned to either group, because it is unclear if FMVSS No. 201 might have an effect.

in head impacts with the A-pillar or roof interior (where HIC was most strongly reduced in head-form tests), and against concussions.[192]

Fatality reduction: A supplement to FARS called the Multiple Cause of Death (MCOD) file catalogs, for fatally injured people, the injuries designated on their death certificate as having "contributed to the fatality." FARS-MCOD specifies body regions of injuries, but it does not specify injury sources. Thus, the data can identify head injuries but it cannot single out the head injuries due to upper-interior contact. NHTSA analyzed the FARS-MCOD files for CY 1999 to 2007, which use the ICD-10 classification of injuries and diseases.[193] The contingency-table analysis computes the ratio of head injuries to injuries of other body regions. The ratios are compared for vehicles before and after the upgrade to FMVSS No. 201. The analysis shows a statistically significant 6.4-percent reduction of head injuries that "contributed to the fatality" after the upgrade to FMVSS No. 201. The result is consistent with the above findings on AIS 4-to-6 injuries due to upper-interior contact.[194]

Based on the CDS and FARS-MCOD results and taking into account the proportion of occupant fatalities primarily attributable to head injuries from upper-interior contacts before the upgrade, NHTSA estimated that the energy-absorbing padding associated with the 1999-to-2003 upgrade of FMVSS No. 201 reduced overall occupant fatality risk by an estimated 4.28 percent (confidence bounds, 2.0 to 6.2%).[195] This estimate can be taken literally for cars and LTVs produced soon after the upgrade, before the make-models were also equipped with curtain air bags: it is the energy-absorbing materials that are saving the lives. Later on, in vehicles with curtains, the situation is not so clear. If a life is saved, to what extent is it saved by the curtain and to what extent by the energy-absorbing materials? That could depend on the type of crash (e.g., whether or not it deploys the curtain), whether the padding was modified or discontinued upon addition of the curtains, the interior component contacted, and/or how and where the occupant's head contacts it – information often not available on the crash database. The "lives saved" model in Part 2 of this report, as explained in the "Summary of the Estimation Method" at the beginning of Part 2 simplifies the computation in this case, as well as in other cases involving combinations of technologies. It attributes to the FMVSS No. 201 upgrade the above-calculated 4.28-percent reduction in fatality risk in all post-upgrade vehicles, including those with curtains; it attributes to curtains the additional reduction in fatality risk of a vehicle equipped with curtains relative to a vehicle equipped with the energy-absorbing materials but not the curtains. These are the effectiveness estimates that are available from the crash data. It could be argued that this method understates the lives saved by the curtains and overstates lives saved by padding (although the two add up to the right total), but it would be difficult to quantify how many should be reallocated to the curtains.

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[192] *Ibid*., pp. 29-33.
[193] WHO. (2005). *International Statistical Classification of Diseases and Health Related Problems, Tenth Revision – ICD-10, Second Edition*. Geneva: World Health Organization. Available at www.who.int/classifications/icd/en.
[194] *Ibid*., pp. 37-42; injuries to the neck or to multiple or unspecified body regions are excluded because it is unclear if FMVSS No. 201 might have an effect; the database is limited to cars and LTVs with frontal air bags but without curtain or side air bags.
[195] *Ibid*., pp. 48-50.

FMVSS No. 202, "Head restraints"

This standard is associated with a vehicle modification whose safety benefits have been evaluated by NHTSA and with an upgrade that phased in during MY 2010 to 2012:

- **Head restraints for outboard front seats**
- **2010-2012 head restraint upgrade (not yet evaluated)**

Head restraints aim to mitigate injury risk in rear impacts, cushioning the heads of drivers, RF passengers, and, in some vehicles, rear seat passengers. They were introduced in passenger cars over model years 1964 to 1969 and in LTVs over a longer period, extending until 1992. The first paragraph of FMVSS No. 202 states, "This standard specifies requirements for head restraints to reduce the frequency and severity of neck injury in rear-end and other collisions."[196]

Head restraints for outboard front seats/original version of FMVSS No. 202

Regulatory history: FMVSS No. 202, applying at first only to the driver's and RF seats of passenger cars, was proposed in December 1967, became a final rule in February 1968 and had an effective date of January 1, 1969. It incorporates parts of General Services Administration Standard 515/22, effective October 1967 for Federally purchased vehicles. The extension of FMVSS No. 202 to the driver's and RF seats of LTVs with GVWR up to 10,000 pounds was issued in September 1989 and took effect on September 1, 1991.[197]

How head restraints work: "Whiplash" is by far the most frequent injury in rear-impact crashes. It is common even in low-speed, non-towaway crashes. It results from strains, tears or microscopic damage to muscles, tendons, ligaments, vertebra or nerves in or near the neck. The most familiar symptoms are pain or stiffness in the neck and upper back. Also common are pain or weakness in the arms or shoulders, and symptoms involving the central nervous system, such as headache, sight or hearing disturbances. Symptoms may appear immediately or not for several days. They may end in a day or two or they may go on, continually or intermittently, for a long time, even years.[198]

The first causal mechanism identified for whiplash was hyperextension of the neck. In a rear impact, a low, pre-FMVSS No. 202 seat back holds the occupant's back in place but the head jerks

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[196] 49 CFR, Part 571.202.

[197] Kahane, C. J. (1982, February). *An evaluation of head restraints - Federal Motor Vehicle Safety Standard 202*. (Report No. DOT HS 806 108, pp. 104-106). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/806108.PDF; Walz, M. C. (2001, April). *The effectiveness of head restraints in light trucks*. (Report No. DOT HS 809 247, p. 1). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809247.PDF; *Federal Register* 31 (March 8, 1966): 4096, 31 (July 15, 1966): 9637, 32 (December 28, 1967): 20865, 33 (February 14, 1968): 2945, 54 (September 25, 1989): 39183.

[198] Kahane (1982, February), pp. 80-83; Walz (2001, April), pp. 2-5; Mertz, H.J., Jr., & Patrick, L.M. (1967). Investigation of the kinematics and kinetics of whiplash. *Proceedings of Eleventh Stapp Car Crash Conference*. New York: Society of Automotive Engineers; States, J. D., Korn, M. W., & Massengill, J. B. (1969). The enigma of whiplash injuries. *Proceedings of the Thirteenth Annual Conference of the American Association of Automotive Medicine*. Morton Grove, IL: American Association of Automotive Medicine; Accident Analkysis and Prevention. (2000, March). *Accident Analysis and Prevention*, *32*.

backward, over the top of the seat back, twisting the neck and injuring it. The remedy was to develop a head restraint that effectively makes the seat back higher, keeps the head upright and in line with the torso, and prevents twisting of the neck. However, subsequent research suggests that hyperextension is by no means the only mechanism of whiplash; other causes may include the longitudinal movement of the head relative to the torso, or rapid changes in spinal column pressure during the impact.

Research on rear impacts and development of prototype head restraints began at the University of California, Los Angeles in the mid-1950s. The manufacturers have developed three main types of head restraints for production vehicles:

- Adjustable head restraints that may be lifted or lowered to suit the occupant. The head restraint should be lifted until the top of the restraint is at least level with the tops of the occupant's ears, or preferably as high as it can go without blocking the driver's vision. Some head restraints can also be adjusted forwards and backwards; if so, they should be moved forward as far as possible consistent with the occupant's comfort.

- Integral head restraints, such as "captain's chairs" or other seat backs that extend upwards behind the driver's head.

- Fixed head restraints, such as padded tubes, shaped like an inverted "U," attached to the top of the seat back.

The test for FMVSS No. 202 requires the top of the head restraint to reach at least 27.5 inches above the "seating reference point" (the level of the seat cushion when the seat is occupied). That height provides adequate support for the head and neck of occupants up to 5'10" tall. If it is an adjustable head restraint, it only needs to achieve this height in the "up" position. The restraint must be able to withstand a static force of 200 pounds in the rearward direction, or meet a dynamic test.[199]

In actual pre-standard cars, the median seat back, without a head restraint, was 23 inches tall, well below the level that would be set by FMVSS No. 202. In actual cars of the 1970s, the median integral or fixed head restraint – and the median adjustable head restraint in the "up" position – reached 29 inches, exceeding the FMVSS No. 202 requirement. However, at that time occupants left 75 percent of adjustable head restraints in the "down" position, at a median height of 26 inches, and did not obtain full protection if they were 5'8" or taller. Integral or fixed head restraints predominated on small cars with bucket seats, but were becoming infrequent on bench or split-bench seats. In all, 30 percent of cars had integral or fixed head restraints, while 70 percent had adjustable head restraints in the 1970s. Although adjustable head restraints were often mispositioned, consumers seemed to prefer them. A 1974 NHTSA proposal to require integral or fixed head restraints for drivers, increase height requirements, and establish a minimum height for adjustable restraints in the "down" position was not adopted. [200]

[199] Kahane (1982, February), pp. 103-107; Severy, D. M., Brink, H. M., & Baird, J. D. (1968). *Backrest and head restraint design for rear-end collision protection*. (Paper No. 680079). New York: Society of Automotive Engineers; 49 CFR, Part 571.202.
[200] Kahane (1982, February), pp. 113-123 and 257-259; *Federal Register* 39 (March 19, 1974): 10268.

By the mid-1990s, the situation had deteriorated in some ways and improved in others. Just 12 percent of new cars had integral or fixed head restraints. On the other hand, occupants were now leaving only 50 percent of the adjustable restraints "down," and the median height of adjustable head restraints in the "down" position had improved to 27 inches – close to the FMVSS No. 202 requirement for the "up" position. Also, integral head restraints predominated in LTVs.[201]

Some questions about head restraints have been raised time and again during the past 30 years. (1) Are integral/fixed restraints more effective than adjustable head restraints, as used (often incorrectly adjusted), and if so, why do more cars not have integral or fixed restraints? (2) Should head restraints be increased in height (both in the "up" and the "down" positions) to protect taller-than-average occupants? How much? Would consumers accept them? (3) How important is it for the head restraint to be close to the head? Should head restraints be adjustable backwards and forwards, and/or should FMVSS No. 202 specify a maximum longitudinal distance from the head restraint to the head? (4) In combination with a head restraint, is a rigid seat back or a flexible seat back more desirable for mitigating whiplash? (5) Will head restraints be less effective in pickup trucks with conventional cabs than in other vehicles to the extent that the back wall of the cab, immediately behind the front seat, provides some degree of protection?[202]

Some passenger cars were equipped with head restraints as early as 1964, well before the January 1, 1969 effective date. However, only 3 percent of model year 1967 cars and 12 percent of model year 1968 cars had them. In model year 1969, as FMVSS No. 202 took effect in mid-year, 88 percent of cars were equipped with them. The extension of FMVSS No. 202 to LTVs was proposed in 1988 and took effect in September 1991. Most models of domestic pickup trucks were first equipped with head restraints between the proposal and the effective date (model years 1989-92). By contrast, the majority of vans and SUVs were already equipped with head restraints or high seat backs potentially meeting FMVSS No. 202 as early as model year 1983.[203]

Expected benefits: Drivers and RF passengers can expect to receive benefits primarily in rear-impact crashes, since other impacts are far less likely to propel occupants backwards, directly toward the head restraint. "Whiplash" is usually a complaint-of-pain injury, seldom life-threatening, but it can manifest itself in many body regions. A significant fatality reduction, or a significant reduction in lacerations or related injuries is not anticipated. There is likely to be a reduction of minor/moderate non-bleeding injuries to the neck, the head and quite possibly the arms and back, even in crashes of low severity (non-towaways).

Injury reduction – passenger cars: NHTSA's analysis, published in 1982, is based on 1972, 1974 and 1977 Texas data.[204] Texas files have records on every crash-involved driver, injured or not, and permit computation of the overall injury rate per 100 drivers in rear-impact crashes. Injury rates are compared for model year 1968, when only 6 percent of cars had adjustable and 6 percent had integral head restraints, and model year 1969, when 81 percent of cars had adjustable, and 7 percent had integral head restraints:

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[201] NHTSA. (1996). *Head restraints – Identification of issues relevant to regulation, design, and effectiveness*. Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.dot.gov/cars/rules/crashworthy/ headrest/status9/status9.html#28), pp. 19-23.

[202] Walz (2001, April), pp. 2-5.

[203] Kahane (1982, February), p. 104; Walz (2001, April), p. 2.

[204] Kahane (1982, February), pp. 181-197.

	N of Drivers	n Injured	Percent Injured
Model year 1968 (6% with adj. head restraints)	20,214	1,531	7.57
Model year 1969 (81% with adj. head restraints)	23,051	1,605	6.96

The injury rate is significantly lower in the 1969 cars. The arithmetic works out to a 10.4-percent injury reduction for adjustable head restraints relative to no head restraints. An identical estimate was obtained when the reduction in rear-impact injury rates was measured relative to a control group of side impacts, over a wider range of "before" and "after" model years.

Next, the analysis compared a group of 1970-to-1977 make-models equipped almost exclusively (96%) with integral restraints to another group of make-models equipped with 97 percent adjustable head restraints.[205] In Texas, the injury rates in rear impacts were:

	N of Drivers	n Injured	Percent Injured
Models with 97% adjustable head restraints	17,758	1,394	7.85
Models with 96% integral head restraints	21,205	1,552	7.32

The injury rate is significantly lower in the make-models with primarily integral head restraints. It works out to a 7.3-percent injury reduction for integral relative to adjustable head restraints. The injury reduction for integral head restraints relative to no head restraints at all is 16.9 percent – i.e., 1 - [(1 - .104)(1 - .073)]. Head restraints have significantly reduced the frequency of whiplash in crashes, but they have not nearly eliminated this type of injury.

Using 1979 as the "baseline" year, the evaluation estimated that an on-the-road fleet with 100 percent adjustable head restraints would prevent 52,000 injuries per year in passenger cars, but a fleet with 100 percent integral or fixed head restraints would prevent 85,000 injuries per year.[206]

Fatality reduction – passenger cars: In-depth investigations of fatal rear-impact crashes showed that most of the fatalities involved fire, occupant ejection or catastrophic intrusion: mechanisms unlikely to be influenced much, one way or the other, by head restraints. NHTSA analyzed 1975-80 FARS data by various techniques: rear-impact fatalities, before and after FMVSS No. 202, relative to control groups of fatalities in other crash modes; regression analyses; rear-impact fatality rates per million vehicle years. None of these analyses showed a statistically significant effect for head restraints.[207]

[205] *Ibid*., pp. 212-225.
[206] Ibid., pp. 237-245; 90 percent confidence bounds for effectiveness of adjustable head restraints: 4.0 to 16.8 percent, for integral head restraints: 9.1 to 24.7 percent; for benefits of adjustable head restraints: 17,000 to 87,000 injuries prevented, for integral head restraints: 40,000 to 130,000 injuries prevented per year.
[207] *Ibid*., pp. 91-95 and 161-177.

Injury reduction – LTVs: NHTSA's 2001 evaluation of head restraints for LTVs used CY 1993-to-1998 data from eight States: Florida, Indiana, Maryland, Missouri, North Carolina, Pennsylvania, Texas and Utah. Statistics were based on seven domestic make-models of pickup trucks that shifted during MY 1990-to-1992 from few or no head restraints in one model year to 100 percent or near-100 percent equipped with head restraints in the next year. Injury rates were compared for the first two model years with head restraints and the last two years before head restraints. Vans and SUVs were mostly equipped with head restraints from the start of production, precluding computation of "before" injury rates, and could not be included in the analyses. Injury rates were computed for drivers and RF passengers in rear-impact crashes and for a control group of frontal crash involvements.[208] Injury rates for the combined eight State date files were:

	N of Occupants	n Injured	Percent Injured
REAR IMPACTS			
Last 2 MY before head restraints	43,520	11,500	26.42
First 2 MY with head restraints	50,434	12,307	24.40
FRONTAL IMPACTS			
Last 2 MY before head restraints	98,541	23,581	23.93
First 2 MY with head restraints	106,417	24,631	23.15

Clearly, the injury reduction is greater in the rear impacts (where head restraints are effective) than in the frontal impacts (where head restraints ought to have no effect, and any difference between the "before" and "after" is due to various biases in the data). When the data is weighted by the number of registered pickup trucks in each State, rather than merely aggregated, and after corrections for the small percentages of trucks in the "before" group that already had head restraints and for those in the "after" group that still did not, this works out to a statistically significant 6.1-percent injury reduction for head restraints in rear impacts (relative to the control group). Using 1999 as the "baseline" year, the evaluation estimated that when all LTVs on the road (pickups, vans and SUVs) are equipped with head restraints, they will prevent 14,900 injuries per year.[209]

It is unknown why head restraints are more effective in passenger cars (10.4 – 16.9%) than in LTVs (6.1%). Perhaps the large mass and extensive rear structure of LTVs, especially pickup trucks, offers a degree of protection in rear impacts that makes it less necessary to have head restraints. Also, this evaluation did not show a significant difference in the effectiveness of adjustable versus integral head restraints in pickup trucks.[210]

[208] Walz (2001, April), pp. 9-27 and 41-46.
[209] *Ibid*., pp. 65-68; 90 percent confidence bounds for effectiveness: 3.5 to 8.7 percent; for benefits: 8,300 to 21,700 injuries prevented, per year.
[210] *Ibid*., pp. 58-63 and 68-69.

Fatality reduction – LTVs: NHTSA's 2001 evaluation does not analyze fatal crashes separately. However, it is reasonable to infer that, just as in passenger cars, head restraints have little or no effect on fatalities in LTVs.

2010-2012 head restraint upgrade (not yet evaluated)

Biomechanics research during the 1990s, statistical analyses, and observational studies suggested that head restraints could be more effective if they were (1) high, even in their lowest position, and stay locked in position and (2) close to the occupant's head. On December 14, 2004, NHTSA amended FMVSS No. 202 to raise the outboard front seat's height requirement in the head restraint's highest position from 700 mm (27.5 inches) to 800 mm (31.5 inches) and to add a new requirement that the restraint must be at least 750 mm (29.5 inches) high in its lowest position; also that the restraint should stay locked in position and cannot be lowered simply by pushing down on it. The rearward distance from the back of the head to the restraint ("backset") has to be less than 55 mm. As an alternative to the preceding height requirements, the head restraint (adjusted to its mid-height position) and seat assembly may demonstrate acceptable performance on a 17.3 km/h rear-impact sled test, as evidenced by HIC no more than 500 and angular rotation of the dummy head no more than 12°. The new requirements were phased in during MY 2010 to 2011 at the outboard front seats.[211] The Insurance Institute for Highway Safety has rated head restraints since 1995, based on their geometry and the dummy's kinematics and neck forces in a rear impact with a 10 mph velocity change.[212]

By 2000, manufacturers were equipping rear seats with head restraints on many vehicles. The upgraded standard does not mandate head restraints for the outboard rear seats, but if they are so equipped they must be at least 750 mm high in their lowest position or meet the dynamic performance requirements. The rear seat requirements phased in during MY 2011 to 2012. Active head restraints that move closer to the backs of occupants' heads in rear-end crashes are another technology that is now standard equipment on many vehicles.

The goals of the upgrade are to provide whiplash protection for tall occupants, safeguard people of average height even if they leave adjustable restraints in the "down" position, and protect rear seat passengers. NHTSA plans to evaluate the upgrade by statistical analyses of crash data from States that identify the body region of the injury as well as the MY, make, and model of the vehicle and the impact location. These files can be used to compute neck injury rates per 100 occupants involved in rear impacts:

- Before and after the upgrade of head restraints in the front seat;
- Before and after the installation of head restraints in the rear seat; and
- With and without active head restraints.

[211] *Federal Register* 69 (December 14, 2004): 74848; *Federal Register* 72 (May 4, 2007): 25514.
[212] www.iihs.org/iihs/ratings/ratings-info/rear-head-restraints-test.

FMVSS No. 203, "Impact protection for the driver from the steering control system"

FMVSS No. 204, "Steering control rearward displacement"

These two standards regulate one safety technology:

- **Energy-absorbing and telescoping steering assembly**

It is a basic protection for drivers in frontal crashes, designed to cushion their impact into the steering assembly. It was introduced in passenger cars from MY 1967 to 1968 and in LTVs over a longer period, extending approximately from 1970 to 1982.

The first paragraph of FMVSS No. 203 states, "This standard specifies requirements for steering control systems that will minimize chest, neck, and facial injuries to the driver as a result of impact." FMVSS No. 204 "specifies requirements limiting the rearward displacement of the steering control into the passenger compartment to reduce the likelihood of chest, neck or head injury."[213]

Regulatory history: FMVSS Nos. 203 and 204, applying at first only to passenger cars, were among NHTSA's initial safety standards, with a NPRM in December 1966, a final rule in February 1967 and an effective date of January 1, 1968. They basically incorporate General Services Administration Standard 515/4a, effective October 1967, for Federally purchased vehicles, and draw on SAE Recommended Practices J850 and J944. FMVSS Nos. 203 and 204 were extended to LTVs with GVWR up to 10,000 pounds, effective September 1, 1981.[214]

How it works: Before FMVSS Nos. 203 and 204, the steering assembly was by far the most common source of fatal or serious injuries for drivers in frontal crashes. The pre-standard steering column was essentially a rigid pole attached to the vehicle's front structure. When drivers' forward momentum propelled them into the column, it did not "give." Even worse, when the front structure deformed rearwards in a frontal impact, it pushed the column upwards and backwards toward the driver.[215]

The safety technology associated with FMVSS Nos. 203 and 204 consists of devices that arrest, absorb or deflect the rearward motion of the column in crashes and that deform at a safe level of force upon impact by the driver. The single, rigid column was replaced by assemblies of concentric tubes. The inner tube slides within the outer tube (telescopes) to make the assembly shorter in case of impact. Usually there are two telescoping sections, each about eight inches long: one in the engine compartment to prevent frontal damage to the vehicle from translating into rearward displacement of the steering wheel, and one in the passenger compartment to allow the driver to compress the steering assembly forward. The telescoping section in the passenger com-

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213 49 CFR, Parts 571.203 and 571.204.

214 Kahane, C. J. (1981, January); *Federal Register* 31 (March 8, 1966): 4091, 31 (July 15, 1966): 9631, 31 (December 3, 1966): 15212, 32 (February 3, 1967): 2414, 44 (November 29, 1979): 68470; SAE. (1968). *1968 SAE Handbook*. New York: Society of Automotive Engineers, pp. 915-916 and 923-925.

215 Kahane (1981, January), pp. 67-80; Huelke, D. F., & Gikas, P. W. (1968). How do they die? Medical engineering data from on-scene investigation of fatal automobile accidents. *Highway Vehicle Safety*. New York: Society of Automotive Engineers; Voight, G., & Wilfert, K. (1969). *Mechanisms of injury to unrestrained drivers in head-on collisions*. (Paper No. 690811). New York: Society of Automotive Engineers.

partment, however, does not slide freely but contains retardant devices such as crushable mesh that collapse at a safe, controlled force level, absorbing the energy of the driver's impact. The manufacturers developed about five distinct types of energy-absorbing devices.[216]

The shear capsule, which brackets the column to the instrument panel, is a one-way gate that resists the rearward movement of the column due to vehicle damage but freely allows the forward movement of the column upon driver impact. The assembly may contain universal joints to give it a flexible Z-shape, further isolating the steering-wheel area from damages within the engine compartment. Some vehicles may have a deformable canister in the steering wheel instead of/in addition to a telescoping column in the passenger compartment. Steering wheel rims and spokes may also be deformable. Manufacturers padded steering-wheel hubs and removed hazardous appurtenances such as horn rings.

In the test for FMVSS No. 203, a body block simulating an adult torso (the "black tuffy"), moving straight ahead, impacts a steering assembly mounted at the manufacturer's installation angle. The steering assembly is intact and has been removed from the vehicle. At an impact speed of 22 feet per second, the force on the body block may not exceed 2,500 pounds. The test approach and the design of most columns have raised several issues over the years: (1) Columns are well-designed to compress under axial (straight-ahead) impacts, but there are questions about their performance in off-center impacts; (2) The driver might have an easier time compressing an intact column (as in the test) than one that has been damaged or displaced during the vehicle impact phase; (3) A force level of 2,500 pounds may be acceptable for the healthy adult torso but excessive for older adults or when the head or abdomen contacts the steering wheel; a 1970 proposal for a more stringent requirement was not adopted; (4) It was difficult for some full-sized vans to meet FMVSS No. 203 since their steering columns were nearly vertical, perpendicular to the motion of the body block; the lead-time allowed for extending FMVSS No. 203 to LTVs essentially permitted the phase-out of vans with near-vertical columns.[217]

FMVSS No. 204 is tested in the 30 mph or 35 mph, full-vehicle impact with a frontal barrier that simultaneously tests FMVSS Nos. 208, 219 and 301 as well. The steering assembly is not allowed to intrude more than 5 inches rearward, into the passenger compartment in a 30 mph test; if the barrier test is conducted at 35 mph and intrusion does not exceed 5 inches that, too, demonstrates compliance with FMVSS No. 204. Vertical or sideways motion is permitted and has been substantial in a few test vehicles. That has also raised questions about the ability of these displaced or damaged columns to compress upon impact by the driver.

Vehicles equipped with dual or driver-only frontal air bags – specifically, at this time, vehicles required to meet S5.1 of FMVSS No. 208 by means other than a seat belt (the unbelted test specified by S5.1.2), which currently includes all new cars and LTVs up to 8,500 pounds GVWR – are exempt from the FMVSS No. 203 test. However, they continue to have energy-absorbing

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[216] Kahane (1981, January), pp. 87-93; Marquis, D.P. (1967). *The General Motors energy absorbing column*. (Paper No. 670039). New York: Society of Automotive Engineers; Huelke, D. F. (1969). *Accident investigations of performance characteristics of energy absorbing steering columns*. (Paper No. 690184). New York: Society of Automotive Engineers.

[217] Kahane (1981, January), pp. 93-99; Hill, A. (1978). *Steering wheel oscillations and vertical movements in 30 mph barrier impacts*. (Report No. DOT HS 803 606). Washington, DC: National Highway Traffic Safety Administration.

steering columns that, in combination with air bags, are still important for providing "crush space" and cushioning the driver's impact. The FMVSS No. 208 test, which measures the driver's injury risk in a 30 mph or 35 mph crash, implicitly tests the performance of the energy-absorbing steering assembly as part of the overall safety system.

The manufacturers were developing energy-absorbing and telescoping steering assemblies before NHTSA existed. All MY 1967 GM, Chrysler and American Motors cars built in the United States or Canada were equipped with them. All MY 1968 passenger cars had them, even though the standards did not take effect until mid-model year (January 1, 1968). Implementation in LTVs took place over a longer period and is not as clearly documented: the Volkswagen "bus" apparently had them in 1970, all Jeep and GM LTVs in 1973, and other LTVs in later years, some not until the effective date, September 1, 1981.[218]

Expected benefits: Only drivers can expect to receive benefits, since passengers rarely make significant contact with the steering assembly. Benefits are primarily in frontal crashes, since other impacts rarely propel the driver into the steering assembly directly and with enough force to compress the column. The principal benefit would be expected for injuries caused by driver contact with the steering assembly. The largest reductions are expected for chest injuries, although head, neck and abdominal injuries could be mitigated as a result of less steering-column intrusion, more deformable steering wheels, and removal of hazardous appurtenances. The largest reductions are expected for unbelted drivers, since belts absorb much of the driver's momentum prior to contact with the steering assembly.

Fatality reduction – passenger cars: NHTSA's analysis, published in 1981, was its first comprehensive evaluation of a FMVSS. It is based on 1975-to-1979 FARS data.[219] Since FARS data does not indicate the source or body region of fatal injuries, or provide information on nonfatal crashes to allow computation of fatality rates, they are best suited for comparing overall fatality risk of drivers in frontal crashes, before and after FMVSS Nos. 203/204, relative to a control group. One possible control group is the passenger fatalities in these same frontal crashes. The 1975-to-1979 FARS statistics are:

1975-to-1979 FARS	Driver Frontals	Passenger Frontals	Risk Ratio
Model year 1966 ("before")	2,119	1,048	2.022
Model year 1968 ("after")	2,573	1,463	1.759

[218] Kahane (1981, January), p. 92; NHTSA. (1977). *Multidisciplinary accident investigation data file, editing manual and reference information*, Vol. 2. (Report No. DOT HS 802 412). Washington, DC: National Highway Traffic Safety Administration; Motor Vehicle Manufacturers Association. (1978). *1978 model year passenger car and truck accident investigator's manual*. Detroit: Author; Ludtke, N. F. (1980). 1980 and 1979 Ford F-150 weight and cost analysis. *Third Automotive Fuel Economy Research Contractors' Coordination Meeting – Summary Report*. (Report No. DOT HS 805 875). Washington, DC: National Highway Traffic Safety Administration; NHTSA. (1978). *Preliminary evaluation of the proposed extension of standards no. 201, 203 and 204 to light trucks, buses, and multipurpose vehicles*, Washington, DC: National Highway Traffic Safety Administration, Office of Plans and Policy.
[219] Kahane (1981, January), pp. 197-203.

This is a statistically significant 13-percent fatality reduction for the drivers, relative to the passengers, in MY 1968: 1 – [(2,573/2,119) / (1,463/1,048)] = .13.

Another control group is driver fatalities in side or rear impacts. The 1975-to-1979 FARS statistics are:

1975-to-1979 FARS	Driver Frontals	Driver Side/Rear	Risk Ratio
Model year 1966 ("before")	2,119	1,103	1.921
Model year 1968 ("after")	2,573	1,508	1.706

This is a statistically significant 11.1-percent fatality reduction in frontals, relative to side and rear impacts, in model year 1968: 1 – [(2,573/2,119) / (1,508/1,103)] = .111.

The average of these two estimates is a 12.1-percent fatality reduction for drivers in frontal crashes. Using 1978 as the "baseline" year, the evaluation estimated that energy-absorbing steering assemblies would eventually save 1,300 lives per year in passenger cars, when all cars on the road met FMVSS Nos. 203 and 204. Only seat belts and frontal air bags currently save more lives.[220]

These estimates of effectiveness and benefits can be taken literally for cars and LTVs without frontal air bags: it is the energy-absorbing steering assemblies that are saving the lives. Later on, when vehicles were equipped frontal air bags but also continued to have the energy-absorbing steering assemblies, the situation is not so clear. The combination of these technologies creates a system that provides ride-down for drivers and saves many lives, but it is difficult to tease out the relative contributions of the air bag and the energy-absorbing steering assembly. The "lives saved" model in Part 2 of this report, as explained in the "Summary of the Estimation Method" at the beginning of Part 2 simplifies the apportionment in this case, as well as in other cases involving combinations of technologies. The model first estimates the additional fatalities for "removing" the frontal air bags but leaving in place the earlier technology (the energy-absorbing steering assemblies); then it estimates another increment in fatalities for also "removing" the earlier technology. It attributes to air bags the additional reduction in fatality risk of a vehicle equipped with air bags plus energy-absorbing assemblies relative to a vehicle equipped with the energy-absorbing materials but not the air bags. It then continues to attribute the above-calculated 12.1-percent fatality reduction for drivers in frontal crashes to energy-absorbing steering assemblies.

Injury reduction – passenger cars: NHTSA's 1981 analysis uses data from NCSS, the predecessor of NASS. This data specifies, like NASS, the severity, body region and contact source of injuries. The injury rate – the number of fatal or hospitalizing injuries due to contact with the steering assembly per 100 drivers involved in frontal towaway crashes – was computed for cars with energy-absorbing steering assemblies and compared to the rate in cars without the assemblies. These injury rates were controlled for factors such as driver age and gender by multidi-

[220] 90 percent confidence bounds for effectiveness: 8.5 to 15.5 percent; for benefits: 900 to 1800 lives saved.

mensional contingency table analysis, a predecessor of the logistic regression method widely used today.[221]

The analysis showed a statistically significant 38.4-percent reduction of fatal or hospitalizing injuries due to contact with the steering assembly. Using 1978 as the "baseline" year, the evaluation estimated that energy-absorbing steering assemblies would prevent 23,000 nonfatal hospitalizations per year when all cars on the road met FMVSS Nos. 203 and 204.[222]

The NCSS data did not show any one of the five types of energy-absorbing columns to be significantly more effective, or less effective than the other types, nor did the data show a significant difference between energy-absorbing columns and energy-absorbing canisters in the steering wheel. In other words, the United States data did not duplicate the results of a British study finding much higher effectiveness for the canisters and much better performance under non-axial loading.[223]

NHTSA's evaluation and other analyses showed many frontal crashes in which compression of the column was slight or minimal, especially in the presence of non-axial forces. These results, however, tended to be inconclusive because of the difficulty of establishing cause-and-effect relationships. It is difficult to determine if columns were "binding" and causing injury to drivers, or if the compression of the column was slight because it was not strongly impacted by the driver. The effect, if any, of vehicle damage on the column's ability to compress in response to occupant loading is also unclear. In other words, the data did not point to an unequivocal need or method for strengthening the FMVSS No. 203 regulation, and the issue eventually became moot with the introduction of air bags and with higher use of seat belts.[224]

The NCSS data demonstrated the exceptional success of FMVSS No. 204. Intrusion of the steering column in any direction (rearward, upward or sideways) was reduced by 68 percent in frontal towaway crashes and rearward intrusion, in particular, was reduced by 81 percent.[225]

The introduction of energy-absorbing and telescoping steering assemblies, along with deformable steering wheels, padded hubs, and removal of hazardous appurtenances, reduced injuries to all body regions: chest, abdomen, and head/neck. It did not have any undesirable side effects, such as increased driver injuries due to contacts with other parts of the vehicle (windshield, instrument panel, etc.).[226]

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[221] *Ibid*., pp. 138-197; Kahane, Smith, & Tharp (1977).
[222] 90 percent confidence bounds for effectiveness: 28 to 48 percent; for benefits: 14,900 to 33,500 hospitalizations prevented.
[223] Kahane (1981, January), pp. 226-236; Gloyns, P. F., & Mackay, G. M. (1974). Impact performance of some designs of steering assembly in real accidents and under test conditions. *Proceedings of Eighteenth Stapp Car Crash Conference*. Warrendale, PA: Society of Automotive Engineers.
[224] Kahane (1981, January), pp. 249-269; Garrett, J. W., & Hendricks, D.L. (1975). Factors influencing the performance of the energy absorbing steering column in accidents. *Report on the Fifth International Technical Conference on Experimental Safety Vehicles*. Washington, DC: National Highway Traffic Safety Administration; Horsch, J. D., Petersen, K. R., & Viano, D. C. (1982). *Laboratory study of factors influencing the performance of energy absorbing steering systems*. (Paper No. 820475). Warrendale, PA: Society of Automotive Engineers.
[225] Kahane (1981, January), pp. 220-226.
[226] *Ibid*., pp. 239-248.

Fatality reduction – LTVs: NHTSA's 1988 evaluation of occupant protection in frontal interior impact addresses the effect of energy-absorbing steering assemblies in LTVs. Since there was uncertainty about exactly when these assemblies were first installed, a direct "before-after" comparison, as shown above for cars, seemed unsuitable. Instead, a more extended time-series analysis considered head-on collisions between early- and late-model vehicles. The analysis controlled for vehicle weight, driver age and gender. Who fared better: the driver of the late-model truck or the early-model truck? This analysis indicated a 16-percent reduction in fatality risk for unrestrained drivers in frontal crashes during the model years that energy-absorbing steering assemblies were primarily installed in LTVs (1973-80). The corresponding analysis for passenger cars showed a 12-percent reduction in fatality risk during the model years that those assemblies were installed in cars (1967-68). Since the results are quite similar (well within sampling-error bounds), NHTSA concludes that energy-absorbing steering assemblies are as effective in LTVs as in passenger cars – i.e., an estimated 12.1-percent fatality reduction for drivers in frontal crashes.[227]

Injury reduction – LTVs: NHTSA's crash files, at the time of the 1988 evaluation, did not have enough data for a statistically meaningful analysis of the injury-reducing effectiveness of energy-absorbing steering assemblies in LTVs.[228]

[227] Kahane (1988, January), pp. xxx-xxxii, xxxiv and 192-194.
[228] *Ibid*., pp. 165-173.

FMVSS No. 205, “Glazing materials”

This standard regulates automotive glazing. NHTSA has evaluated two innovative safety technologies for glazing:

- **High penetration resistant (HPR) windshields**
- **Glass-plastic windshields**

HPR windshields, an essential protection against facial lacerations, have been standard equipment in motor vehicles since MY 1966. Glass-plastic windshields, although originally envisioned as even better protection against lacerations, were only installed on a few make-models of passenger cars during 1985 to 1987 and then discontinued.

FMVSS No. 205 states, “The purpose of this standard is to reduce injuries resulting from impact to glazing surfaces, to ensure a necessary degree of transparency in motor vehicle windows for driver visibility, and to minimize the possibility of occupants being thrown through the vehicle windows in collisions.”[229] FMVSS No. 205 regulates all automotive glazing, including windshields, side and rear windows, etc. However, during the 1965-to-2012 timeframe the only prominent innovations NHTSA evaluated pertained to windshields. These two evaluations will now be discussed, one-by-one.

High penetration resistant (HPR) windshields

Regulatory history: FMVSS No. 205 applies to all motor vehicles. The first version of FMVSS No. 205 was one of NHTSA’s initial safety standards, with a NPRM issued in December 1966, a final rule issued in February 1967 and an effective date of January 1, 1968. It primarily incorporated the American National Standards Institute (ANSI) Safety Code Z26.1 (July 1966) and SAE Standard J938, (October 1965). ANSI has periodically updated Code Z26.1 and NHTSA has amended FMVSS No. 205 on several occasions to incorporate updated codes. Currently, based on a final rule the agency issued in July 2003, FMVSS No. 205 incorporates the 1996 edition of Code Z26.1. However, in July 2005, NHTSA also issued FMVSS No. 205(a), based on the 1977 and 1980 editions of Code Z26.1; at this time, replacement glazing for vehicles built before November 1, 2006, may conform to either FMVSS No. 205 or FMVSS No. 205(a), but glazing for vehicles built after that date must conform to FMVSS No. 205. [230]

How HPR windshields work: Laminated “safety” windshields, comprised of a thin sheet of plastic sandwiched between two layers of glass, date back to 1927 in the United States. Nevertheless, the pre-HPR laminated windshield caused large numbers of facial lacerations requiring surgical care. The glass layers readily broke and tore through the plastic layer in moderately severe frontal crashes with head-impact speeds around 13 mph. The HPR windshield incorporated

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[229] 49 CFR, Part 571.205.

[230] Kahane, C. J. (1985, February). *An evaluation of windshield glazing and installation methods for passenger cars*. (Report No. DOT HS 806 693, pp. 1-2). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/806693.PDF; *Federal Register* 31 (March 8, 1966): 4091, 31 (July 15, 1966): 9631, 31 (December 3, 1966): 15212, 32 (February 3, 1967): 2414, 68 (July 25, 2003): 43964, 70 (July 12, 2005): 39959; American National Standards Institute. (1966). *Safety code for safety glazing materials for glazing motor vehicles operating on land highways*, Standard Z26.1. New York: Author; *1968 SAE Handbook*.

two strategies to improve performance. (1) The plastic (polyvinyl butyral) layer was made twice as thick as in the pre-HPR windshield to increase its tear resistance and energy absorption. (2) Even more important, the bond between the glass and the plastic layers was loosened by adding moisture to the plastic; as a result, the plastic flexed away from the glass pane rather than being torn by the glass. This allowed the windshield to bulge without tearing, at a force level low enough to avoid serious blunt-impact trauma, upon head-impacts ranging up to 22-29 mph, a quite severe crash. A test specified in FMVSS No. 205 states that a 5-pound steel ball must not penetrate the windshield at 19 mph – i.e., fast enough that pre-HPR windshields fail but slow enough that HPR windshields succeed. The glass and auto manufacturers developed HPR windshields before NHTSA existed. All 1965 Ford Thunderbirds and all domestic passenger cars beginning in model year 1966 have HPR windshields.[231]

Expected benefits: Drivers and front seat passengers can expect to benefit in frontal crashes that propel them into the windshield. The zone of benefits is for head impacts between 13 and 22-29 mph, where the pre-HPR windshield tears but the HPR windshield remains intact while crumpling and bulging. The most common benefit ought to be a reduction of "non-minor" (AIS ≥ 2) facial lacerations from torn glass – injuries that cause disfigurement, extend into the subcutaneous tissue or require more than first aid or simple closure. There should be a large reduction in serious injuries to the eyes, lips or tongue that occur, in pre-HPR windshields, when the occupant's head rebounds through the break in the windshield. There may be a reduction in fractures to the nose or facial bones caused by edges of broken windshields. There would likely be a smaller reduction of minor lacerations, since they can occur even without tears in the windshield. Blunt impact trauma is less likely to be mitigated. Fatal head injuries are hardly ever due to windshield contact alone, and unlikely to be affected by the HPR windshield.[232]

Injury reduction – passenger cars: In 1985, NHTSA published a statistical evaluation of the effectiveness of HPR windshields. It uses data from NCSS, the predecessor of NASS. The data specify, like NASS, the severity (AIS), body region, lesion and contact source of injuries. The injury rate – the number of AIS ≥ 2 lacerations of the face or head due to contact with the windshield, per 1000 front seat occupants involved in frontal towaway crashes – was computed for cars of the first model years with HPR windshields and compared to the rate in cars of the last model years with pre-HPR windshields.[233] For example, a comparison of cars of the first five years with HPR windshields and the last five years without them showed a dramatic, statistically significant 74-percent injury reduction with HPR:

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[231] Kahane (1985, February), pp. 5-11; Patrick, L.M., & Daniel, B.P. (1966). Comparison of standard and experimental windshields. *Eighth Stapp Car Crash and Field Demonstration Conference*. Detroit: Wayne State University Press; Rieser, R.G., & Michaels, G.E. (1966). Factors in the development and evaluation of safer glazing. *Ninth Stapp Car Crash Conference*. Minneapolis: University of Minnesota; Widman, J.C. (1965). *Recent developments in penetration resistance of windshield glass*. (Paper No. 650474). New York: Society of Automotive Engineers.
[232] Kahane (1985, February), pp. 8-9.
[233] Kahane (1985, February), pp. 77-80; Kahane, Smith, & Tharp (1977).

	AIS ≥ 2 Lacerations	N of Occupants	Lacerations per 1000 Occupants
Model year 1961-65 (“before”)	38	4,958	7.66
Model year 1966-70 (“after”)	52	26,110	1.99

Nearly identical reductions were observed when the data was limited to four, three, two or just one model year before and after the shift to HPR. The 74-percent injury reduction is one of the highest ever observed for any of the FMVSS. After 1966, there was an almost miraculous reduction of disfiguring facial injuries in motor vehicle crashes.[234] Using 1982 as the “baseline” year, the evaluation estimated that HPR windshields would prevent 39,000 AIS ≥ 2 lacerations per year when all cars on the road were equipped with them.[235]

HPR windshields reduce facial fractures involving windshield contact by 56 percent, preventing 8,000 fractures per year. In all, the windshields prevent 47,000 AIS 2-4 injuries per year[236] (39,000 lacerations plus 8,000 fractures). Many of these injuries involved the eyes, nose or mouth. HPR windshields reduced injuries to the eyes, nose or mouth involving contact with windshields by 72 percent, preventing 19,000 such injuries per year.[237]

HPR windshields were also effective in preventing minor (AIS 1) facial lacerations due to windshield contact, reducing them by a statistically significant 25 percent. However, HPR windshields had little or no observed effect on concussions, contusions or complaints of pain.[238]

NHTSA also analyzed 1974 New York State crash data to corroborate the NCSS results. These data indicate the body region and lesion of an occupant’s most severe injury, but not the contact source. Severity of nonfatal injuries is indicated by a three-letter severity scale (A, B, C; assigned by investigating officers, based on a list written criteria) but not the AIS. Facial injuries with level A (severe) bleeding in frontal crashes [from any contact source] were reduced by approximately 50 percent with HPR windshields; facial fractures by 25-30 percent. In other words, the New York results support the NCSS findings.[239]

Fatality reduction – passenger cars: NHTSA’s 1985 analysis is based on 1975-to-1982 FARS data. Since FARS does not indicate the source or body region of fatal injuries, or provide information on nonfatal crashes to allow computation of fatality rates, it is best suited for comparing overall fatality risk of front seat occupants in frontal crashes before and after HPR windshields, relative to a control group of non-frontal fatalities. Since energy-absorbing steering columns were introduced in some cars in MY 1967 and in all by 1968, 1 or 2 years after the HPR windshield, the analysis must either be limited to MY 1966 and earlier, or it must somehow control

[234] Huelke, D. F., Grabb, W.C., Dingman, R.O., & Oneal, R.M. (1968, June). The new automotive windshield and its effectiveness in reducing facial lacerations. *Plastic and Reconstructive Surgery*, *41*.
[235] 90 percent confidence bounds for effectiveness: 65 to 83 percent; for benefits: 25,000 to 53,000 lacerations prevented. See Kahane (1985, February), pp. 127-128 and 225-235.
[236] 90 percent confidence bounds: 31,000 to 62,000 injuries.
[237] 90 percent confidence bounds: 9,700 to 29,000 injuries.
[238] *Ibid*., pp. 77-95 and 225-235.
[239] *Ibid*., pp. 101-116.

for the energy-absorbing column. NHTSA used a log-linear regression of the frontal/non-frontal fatality ratio, by calendar year and model year, with independent variables: HPR windshield, energy-absorbing column, vehicle age, and calendar year. The effect attributed to the HPR windshield was negligible, and it was not statistically significant. The evaluation concluded that the HPR windshield, although highly effective in reducing nonfatal injuries, has little effect on fatalities.[240]

Injury and fatality reduction – LTVs NHTSA's 1985 evaluation only addressed the performance of windshields in passenger cars. However, since the mechanisms of injuries involving windshield contact are presumably similar in cars and LTVs, the effectiveness estimates for cars are probably appropriate for LTVs as well.

Glass-plastic windshields

Since facial lacerations are so often due to contact with shattered, torn or crumpled glass, it would seem preferable to line the interior surface of the windshield with shatterproof, energy-absorbing plastic. However, glass is scratch-resistant and its long-term optical qualities are far superior to most plastics, making it essential for windshields and other windows that drivers must look through. Circa 1980, glass manufacturers developed a polyurethane sheet that was transparent and durable enough for use as a windshield's inner lining. In 1983, NHTSA amended FMVSS No. 205 to permit the use of glass-plastic glazing at the option of the motor vehicle manufacturer. The amendment includes numerous tests to assure that the plastic would resist scratching, clouding and corrosion by chemicals.[241]

It was hoped that glass-plastic windshields, by largely eliminating any exposure of occupants to glass surfaces in frontal crashes, would substantially reduce laceration injuries relative to the conventional HPR windshield, especially the minor (AIS 1) lacerations where the HPR windshield did not have as large an effect as it did on AIS ≥ 2 lacerations.

Glass-plastic windshields were standard equipment in Cadillac Seville from MY 1985 to 1987 and in Cadillac Eldorado, Buick Riviera, and Oldsmobile Toronado in MY 1986 and 1987 as well as in substantial test fleets of several manufacturers: over 200,000 cars in all. The inner lining was applied to the HPR laminated windshield and made the glass-plastic windshield a four-ply material. However, the manufacturers discontinued installing glass-plastic windshields after 1987, largely because of durability problems in day-to-day use and high replacement costs. An additional consideration at that time, perhaps, was that increased use of seat belts and installation of air bags would soon be reducing the frequency of occupant contacts with the windshield, anyway.[242]

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[240] *Ibid*., pp. 122-127.
[241] Parsons, G. G. (1993, November). *An evaluation of the effects of glass-plastic windshield glazing in passenger cars*. (Report No. DOT HS 808 062, Chapter 1). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/808062.PDF; *Federal Register* 48 (November 16, 1983): 52065; 49 CFR, Part 571.205; NHTSA. (1983, September). *Final regulatory evaluation, anti-lacerative glazing, FMVSS 205*. Washington, DC: National Highway Traffic Safety Administration, Office of Plans and Policy.
[242] Parsons (1993, November), Chapters 3 and 4.

Injury reduction: NHTSA's evaluation was published in 1993. It is based on crash data from New York (1986-88), Pennsylvania (1985-88) and Indiana (1985-89). These State files distinguish between injuries with bleeding (primarily lacerations), injuries without bleeding (e.g., contusions or complaints of pain) and uninjured occupants. They identify the vehicle's make-model or VIN. However, not all of these files identify the impact location (frontal, side, etc.) or details about an injury's body region, severity or specific lesion**.** The rate of injuries with bleeding per 100 crash-involved front seat occupants was computed for the four make-models that had glass-plastic windshields as standard equipment and compared to the rate in three "control-group" make-models that had conventional HPR windshields: 1985-to-1987 Cadillac Deville, 1986-to-1987 Buick Electra, and 1986-to-1987 Oldsmobile 98 – i.e., full-sized cars of the same nameplates (Cadillac, Buick, or Oldsmobile) and model years as the cars with glass-plastic windshields.[243] For example, the injury rates for drivers in the combined New York and Pennsylvania data were as follows:

	Injuries with Bleeding	N of Drivers	Injuries with Bleeding per 100 Occupants
Control group	295	7,843	3.76
Glass-plastic windshields	85	1,942	4.38

Since the observed injury rate is actually slightly higher in the cars with glass-plastic windshields than in the control-group make-models, this data, as well as the other tables in the evaluation report, do not suggest that glass-plastic windshields reduced the overall rate of injuries with bleeding. (It is unknown whether or not they reduced the average severity of the injuries.)

More detailed (but less numerous) crash data from the operators of the test fleets during the 1980s are consistent with the statistical finding. They suggest that glass-plastic windshields were quite successful in keeping occupants away from contact with glass, but occupants nevertheless sustained lacerations due to skin tissue "splitting" or "tearing" from blunt impact with the plastic surface, or from sliding of the head or face against the plastic inner layer.[244]

Potential future applications Although the glass-plastic windshields actually installed during the 1980s were not successful in terms of durability or in reducing the overall frequency of lacerations, NHTSA continues to believe that glass-plastic glazing could have potential benefits in other applications. Specifically, side windows of motor vehicles are currently made of tempered glass. The entire pane breaks into many small pieces upon impact. Although that has the advantage of preventing serious lacerations, it results in wide-open windows that become portals for occupant ejection. In the final rule for FMVSS No. 226, "Ejection mitigation" NHTSA suggested that an inner layer of plastic with appropriate strength, durability and optical qualities could become one component in a system that would keep the occupant inside the vehicle.[245]

[243] *Ibid*., Chapter 2.
[244] *Ibid*., p. 2-32.
[245] *Federal Register* 76 (January 19, 2011): 3212 (see especially p. 3296).

FMVSS No. 206, "Door locks and door retention components"

This standard regulates one safety technology that has been evaluated by NHTSA:

- **Stronger locks, latches and hinges for side doors**

The first paragraph of FMVSS No. 206 states unequivocally that its purpose is to prevent occupant ejections: "This standard specifies requirements for door locks and door retention components including latches, hinges and other supporting means, to minimize the likelihood of occupants being thrown from the vehicle as a result of impact."[246] FMVSS No. 206 took effect for doors on the side of passenger cars on January 1, 1968, multipurpose passenger vehicles on January 1, 1970, and other LTVs on January 1, 1972.[247] Extensions of FMVSS No. 206 to back doors of vehicles (effective MY 1998) and to sliding doors (effective MY 2011) have not yet been evaluated by NHTSA.

Regulatory history: Self-regulation of side door locks, latches and hinges by the industry began in November 1962, well before NHTSA existed, with SAE Standard J839, "Passenger Car Side Door Latch Systems." In 1965, SAE substantially upgraded J839 to J839b, nearly doubling the strength requirements, and introduced another standard, J934, "Vehicle Passenger Door Hinge Systems." J839b and J934 were essentially incorporated into FMVSS No. 206, one of NHTSA's initial safety standards, with a NPRM in December 1966, a final rule in February 1967 and an effective date of January 1, 1968.[248]

What happened: Safety researchers in the 1950s learned that car doors were forced open in many crashes, especially rollovers; that occupants were often ejected via the opened doors; and that being "thrown clear" in a crash was not an advantage but a terrible risk, especially in rollovers, where an occupant could be wedged between the car and the ground. Safety door latches were introduced in the 1955 and 1956 domestic cars to assure that doors would not pop open when occupants on the inside, or objects/ground on the outside brushed against door handles during crashes. During about 1962 to 1968, the manufacturers began an almost continuous process of strengthening latches and hinges in their various make-models. Doors can open in crashes if latches or hinges are pulled apart by impact damage, or if latches and hinges are pulled loose from their supporting structures. The net effect of these cumulative improvements was a dramatic reduction of door-opening, as seen in Automotive Crash Injury Research (ACIR), a crash data file of the 1950s and 60s:[249]

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[246] 49 CFR, Part 571.206.

[247] *Federal Register* 32 (February 3, 1967): 2414, 34 (January 24, 1969): 1150.

[248] Kahane, C. J. (1989, November). *An evaluation of door locks and roof crush resistance of passenger cars – Federal Motor Vehicle Safety Standards 206 and 216*. (Report No. DOT HS 807 489, pp. 2-4). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807489.PDF; SAE. (1965). *1965 SAE Handbook.* New York: Society of Automotive Engineers, p. 893; SAE. (1967). *1967 SAE Handbook*, pp. 904-906; *Federal Register* 31 (March 8, 1966): 4091, 31 (July 15, 1966): 9631, 31 (December 3, 1966): 15212, 32 (February 3, 1967): 2414.

[249] Kahane (1989, November), pp. 27-30; Garrett, J. W. (1964). *The safety performance of 1962-63 automobile door latches and comparison with earlier latch designs*. (Report No. VJ-1823-R7). Buffalo: Cornell Aeronautical Laboratory; Garrett, J. W. (1969). *Comparison of door opening frequency in 1967-68 cars with earlier model U.S. cars*. (Report No. DOT HS 800 231). Washington, DC: National Highway Traffic Safety Administration.

Model Year	Percentage of ACIR Crashes Where Door Opened
Pre-1956	43
1956-1961	28
1962-1963	23
1964-1966	17
1967-1968	12

Expected benefits: The fewer doors open in crashes, the fewer ejections via that portal, especially in rollovers. Since it is safer to stay inside a vehicle than be ejected, there ought to be a significant fatality reduction, especially in rollovers. This should benefit all occupants who are at risk of being ejected via a side door, drivers and passengers, in the front seat or in rear seats.

Fatality reduction – passenger cars: Frankly, it is difficult to compute the benefits of this technology. Since improvements entered gradually over several years (and NHTSA does not know exactly when on what models), a diffuse time-series approach must replace the customary "just before-just after" comparison. Moreover, door locks were just one influence on rollover fatalities in the 1960s: above all, car size changed from year to year, and when cars grow, rollover fatalities decrease. Nevertheless, there is no doubt that improved door locks have saved lives. The side door was the leading ejection portal in cars of the 1950s and early 1960s, but door ejections have decreased to the point that the side window became the leading portal in the 1970s. The problem is quantifying the benefit.

NHTSA's evaluation, published in 1989, computed several rollover-fatality risk indices that control for car size, using logistic regression.[250] For example, one analysis used 1975-to-1986 FARS data to calibrate the ratio of rollover fatalities to frontal-fixed-object fatalities, as a function of model year, track width and curb weight. This ratio was graphed, by model year, for cars with 55 inch track width and 3000 pound curb weight (median values for cars on the road in 1975-86), and then indexed relative to the average value for model years 1975-80. The averages of the two indices defined in the evaluation[251] were:

Model Year	Rollover Fatality Risk Index
1963-1964	123
1968-1970	107
1975-1980	100

The risk indices dropped substantially between 1963-1964 and 1968-1970, when door locks steadily improved. However, door locks were not the only factor that influenced rollover fatalities in those model years. The evaluation specifically estimated that the 1962-to-1968 improvements to door locks reduced fatalities involving occupant ejection in rollovers by 15 percent. Us-

[250] Kahane (1989, November), pp. 127-204.
[251] *Ibid*., p. 202, average of the indices NEWROLL2 and NEWROLL3.

ing 1982 as the "baseline" year, the evaluation estimated these improvements were saving approximately 400 lives per year.[252]

Injury reduction – passenger cars: NHTSA's evaluation does not include any analysis or estimate of the effect of door locks on nonfatal injuries. However, other studies such as NHTSA's 1985 evaluation of windshields suggest that occupant ejections cause similar numbers of serious nonfatal injuries (AIS 3-5) and fatalities.[253] It is likely that the improvements to door locks, latches and hinges are about as effective in reducing serious injuries as fatalities, and that they are preventing comparable numbers of AIS 3-5 injuries and fatalities.

Fatality and injury reduction – LTVs: NHTSA's 1989 evaluation only addressed the performance of door locks in passenger cars. Since FMVSS No. 206 was extended to LTVs a few years after it took effect for cars, and since the door components of trucks and cars are similar, it seems plausible that the gradual improvement of door locks in cars was matched by a comparable effort in LTVs, with a similar effectiveness in reducing fatalities associated with door ejections. However, National Crash Severity Study (NCSS) data show that, proportionately, the door is the ejection route in only 2/3 as often in LTV rollovers as in car rollovers. Thus, the overall reduction of ejection fatalities in rollovers, estimated to be 15 percent in cars, would be 10 percent in LTVs.[254]

FMVSS No. 206 extensions: On September 28, 1995, NHTSA issued a final rule, effective September 1, 1997, extending FMVSS No. 206 to hinged back doors of passenger cars and multipurpose vehicles, including hatchbacks, station wagons, SUVs, and passenger vans.[255] On February 6, 2007, NHTSA issued another final rule amending FMVSS No. 206 in order to add and update requirements and test procedures and to harmonize with the world's first global technical regulation (GTR) for motor vehicles. The final rule added a new full vehicle test procedure and performance requirements for sliding side and back doors, added secondary latched position requirements for doors other than hinged side doors and back doors, provided a new optional test procedure for assessing inertial forces, and extended the application of the standard to buses with GVWR of less than 10,000 pounds, including 12-to-15 passenger vans. The final rule also eliminated an exclusion from the requirements of the standard for doors equipped with wheelchair platform lifts. The upgrades became effective on September 1, 2010 (early compliance was permitted).[256] NHTSA has not yet evaluated these extensions of FMVSS No. 206.

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[252] *Ibid*., pp. xxix and 222-225.
[253] Kahane (1985, February), pp. 161-163.
[254] An analysis of MY 1990-2003 cars and LTVs in 1995-2003 NASS data confirms the dramatic, long-term reduction in ejections via the open door. In NCSS, the open door accounted for 32 percent of ejections in car rollovers, 20 percent in LTVs. In NASS, the open door accounted for just 8 percent of ejections in car rollovers, 7 percent in LTVs. Thus, our conclusions that FMVSS 206-related technology reduced overall rollover fatality risk by 15 percent in cars and 10 percent in LTVs may even be a little bit conservative if the long-term, continuing improvement of doors is taken into account.
[255] *Federal Register* 32 (February 3, 1967): 2414, 34 (January 24, 1969): 1150, 60 (September 28, 1995): 50124.
[256] *Federal Register* 72 (February 6, 2007): 5385, 74 (July 20, 2009): 35131.

FMVSS No. 207, "Seating systems"

"This standard establishes [a variety of strength] requirements for seats, their attachment assemblies, and their installation to minimize the possibility of their failure by forces acting on them as a result of vehicle impact."[257] It is, however, linked with just one tangible safety modification that has been evaluated by NHTSA:

- **Seat back locks for 2-door cars with folding front seat backs**

The locks are designed to mitigate injury risk in frontal impacts by keeping seat backs upright and in place during a crash. They are supposed to prevent seat backs from folding over and pushing on front seat occupants and to keep unrestrained rear seat occupants in the rear seat area. They were introduced in 2-door passenger cars primarily in MY 1967 and 1968.

Regulatory history: FMVSS No. 207, one of NHTSA's initial safety standards, took effect for passenger cars on January 1, 1968, and was later extended to trucks, buses and multipurpose vehicles, effective on January 1, 1972. Except for the seat-back-lock requirement, FMVSS No. 207 largely incorporated SAE Recommended Practice J879, which had been in place since November 1963. Thus, the locks were the only substantial modification in domestic cars during the time frame of the FMVSS No. 207 rulemaking.[258]

How seat back locks are supposed to work: Two-door cars generally need front seat backs that fold down and out of the way to give passengers room to get in and out of the rear seat. Without a locking system, these seat backs are likely to fold over in frontal crashes, even at low severities. That could potentially increase injury risk for front seat occupants in a frontal crash by adding some or all of the mass of the 25-to-35 pound seat backs to that of the occupants themselves, thereby increasing their momentum as they contact structures at the front of the passenger compartment. The locks could be even more beneficial if there are unrestrained rear seat occupants. In a car without the locks, the rear seat passenger could move forward with the seat back, adding even more mass to the front seat occupant. Additionally, the seat back can act as a ramp for the rear seat passenger as it folds over, causing the rear seat occupant to then vault head-first into the front seat compartment and contact the windshield or header or make head-to-head contact with the front seat occupants. With the locks, a seat back should remain upright and prevent these actions from the rear seat occupant.[259]

However, for seat back locks to be effective, they must be able to withstand the impact forces to which they are exposed in crashes. FMVSS No. 207 (which makes no explicit claim of effectiveness when rear seat passengers are present) requires the locks to withstand a forward load of

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[257] 49 CFR, Part 571.207.

[258] Kahane, C. J. (1987, February). *A preliminary evaluation of seat back locks*. (Report No. DOT HS 807 067, pp. 2-3). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807067.PDF; *Federal Register* 31 (December 3, 1966): 15212, 32 (February 3, 1967): 2414, 36 (December 2, 1971): 22902; *1968 SAE Handbook*, pp. 954-955.

[259] Kahane (1987, February), pp. 10-12; Severy, D. M., Brink, H.M., Baird, J. D., & Blaisdell, D. M. (1969). Safer seat designs. *Thirteenth Stapp Car Crash Conference*. New York: Society of Automotive Engineers, pp. 323-325.

20 times the weight of the seat back.[260] If the 150-pound weight of an unrestrained adult rear-seat passenger is added to the 25-to-35 pound weight of the seat back, even a crash with acceleration levels below 10 g's could produce loads exceeding the FMVSS No. 207 level. In the 1970s, approximately 99 percent of adult rear-seat passengers were unrestrained; in 2012, about 25 percent were unrestrained.[261]

Manufacturers have developed two types of seat back locks for production vehicles:

- Manual seat back locks: occupants disengage the lock by operating a lever or pressing a button (not necessarily in a convenient location) every time they need to move the seat out of the way.

- Automatic inertial seat back locks that allow free movement of the seat back during normal vehicle operation and only lock up during impacts, road bumps, or emergency braking. The technology is similar to inertial locking retractors for seat belts.

Volkswagen and Opel installed manual seat back locks in their MY 1966 cars; GM, Fiat, Renault and Datsun in 1967; and Ford and Chrysler in the full MY 1968 – all before the January 1, 1968, effective date. Automatic seat back locks are obviously more convenient for passengers and they have completely superseded the manual type in domestic cars since about 1980. In addition to being more convenient, automatic locks preclude an imaginable (but unsubstantiated) safety problem: during a fire, immersion or other emergency egress situation, rear seat passengers could be delayed while they locate and operate manual locks, but can exit immediately from cars with automatic locks that allow free movement of the seat back.[262]

Potential benefits: Drivers and RF passengers might experience a reduction of fatalities and/or injuries in frontal crashes, when the rear seat is unoccupied, provided that a locked seat back imposes a smaller load on them than a freely moving, pre-FMVSS No. 207 seat back. When the rear seat is occupied, both outboard front seat occupants and outboard rear seat occupants might experience a more substantial reduction of fatalities and injuries in frontal crashes, provided that the locks are able to withstand the impact force of the rear seat occupant. In addition, upright seat backs might help contain rear seat occupants within their seating area and reduce their risk of ejection from the car in a frontal crash.

Evaluation findings: NHTSA's study, published in 1987, includes statistical analyses of crash data comparing injury and fatality rates in 2-door cars just before and after the introduction of seat back locks; sled tests simulating frontal crashes of seat systems with and without the locks, to study the effect of the locks on occupant force levels and kinematics; and a review of in-depth

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[260] 49 CFR, Part 571.207 S4.3.2.1: "Once engaged, the restraining device for a forward-facing seat shall not release or fail when a forward longitudinal force, in newtons, equal to 20 times the mass of the hinged or folding portion of the seat in kilograms multiplied by 9.8 is applied through the center of gravity of that portion of the seat."

[261] Phillips (1980, May), pp. 47-50; Pickrell, T. M. (2014, January). *Occupant restraint use in 2012: Results from the National Occupant Protection Use Survey Controlled Intersection Study.* (Report No. DOT HS 811 872, pp 6-8). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811872.pdf.

[262] Kahane (1987, February), pp. 4-5 and 11-12.

crash investigations to determine the ability of seat back locks to endure impact forces, as a function of delta V.

Crash data analyses: Injury rates per 100 crash-involved occupants are computed for domestic 2-door cars of the model year(s) just before and just after the introduction of manual seat back locks (GM in 1967, Ford and Chrysler in 1968). Corresponding rates are computed for a control group of 4-door cars of these same model years (i.e., just before and after seat back locks were introduced in the 2-door cars made by that manufacturer). Four-door cars are a useful control group because they received all of the safety improvements that 2-door cars received during that time frame – except seat back locks. In other words, did the injury reduction in 2-door cars (after versus before seat back locks) surpass the corresponding reduction in 4-door cars? Injury rates were computed from 1973-to-1977 Washington State data, 1972-to-1974 Texas data and 1974 New York State data.[263] Similarly, fatality rates per million vehicle registration years are computed from 1975-to-1985 FARS data and R. L. Polk registration data (their "National Vehicle Population Profile").[264]

None of these analyses showed a statistically significant reduction of injury or fatality rates in 2-door cars above and beyond the corresponding reduction in 4-door cars. There was no observed benefit for front seat occupants, regardless of whether the seat behind them was unoccupied, occupied by an adult (unrestrained or belted), or occupied by a child. There was no reduction of injury or fatality rates, or of ejection, for rear seat occupants, adults or children.

Sled tests: NHTSA sponsored 28 sled tests involving 84 unrestrained, 50th percentile Part 572 dummies.[265] Fourteen of these tests used a sled buck that simulated the passenger compartment of a 1981 domestic sedan with operational seat back locks: speeds ranged from 15 to 30 mph, impacts were full-frontal or oblique-frontal; dummies occupied the outboard front seats in all tests and the outboard rear seats in eight tests. The other 14 tests exactly replicated the above series, except that the seat back locks were removed to allow the seat backs to pivot freely in the crash (as they would have in a pre-FMVSS No. 207 car). That provided 42 matched pairs of dummies tested under identical conditions, except one of them had the seat back lock and the other did not. HIC, chest g's, femur loads, mean strain criterion, total laceration index and other measures were computed for each dummy.

The statistical analysis of the 42 matched pairs considers the average difference of the injury criterion in the test with seat back locks and in the corresponding test without seat back locks. These average differences were not significantly different from zero for any of the injury criteria. In other words, the dummies had the same average injury severity with and without the seat back locks. When the matched pairs were divided into three principal subgroups – front seat occupants with nobody sitting behind them, front seat occupants with somebody sitting behind them, and rear seat occupants – there was no significant benefit for seat back locks in any subgroup.

[263] *Ibid*., pp. 55-96.
[264] *Ibid*., pp. 97-135.
[265] *Ibid*., pp. 21-54.

The films from the sled tests explain why seat back locks did not significantly reduce injury risk:

- Seat backs (with or without the locks) "follow" front seat occupants gradually in a frontal crash, barely touch occupants at the crucial moment when they first contact the steering assembly or instrument panel, and subsequently only apply force over an extended time period that hardly spikes up the injury criteria.
- At 26.5 mph the impact of a rear seat dummy sheared the seat back lock or tore the entire front seat out of its track in every test.
- At 22.5 mph, although seat back locks remained intact, rear seat dummies deflect the front seat back forward quite a bit and are not well contained in the back seat area.

In-depth crash investigations: NHTSA's MDAI File provides detailed information on the performance of the seat and seat back lock in 1968-to-1978 crashes, plus a description of the vehicle damage that allows a rough estimate of delta V in frontal crashes. "Seat separation" is defined to include breakage of seat back locks and/or (much less frequently): seats tearing loose from tracks, seat tracks tearing loose from floors, and/or seat backs tearing loose from seat cushions.[266] The MDAI data suggest front seat separation occurred quite frequently in frontal impacts of 2-door cars equipped with seat back locks, when there was a rear seat occupant weighing 100 pounds or more:

Delta V (mph)	Percentage of Front Seats Separated
10 – 14.9	30
15 – 19.9	37
20 – 29.9	51
30 +	85

This performance obviously limited any potential benefits for seat back locks when rear seat occupants were present.

Given the absence of statistically significant positive findings in the crash-data analyses, the negligible effect of seat back locks on dummy kinematics in sled tests, and the high rates of front seat separation when rear seat occupants were present, NHTSA's evaluation concluded that seat back locks do not have a measurable overall effect on fatalities and injuries. It is conceivable that the locks are effective in certain narrowly defined crash types, but not to the extent of producing a statistically discernable overall effect.

266 *Ibid*., pp. 146-152.

FMVSS No. 208, "Occupant crash protection"

FMVSS No. 209, "Seat belt assemblies"

FMVSS No. 210, "Seat belt assembly anchorages"

These three standards regulate seat belts. FMVSS No. 208 also regulates frontal crash protection in general and requires frontal air bags. Seat belts and frontal air bags are probably the two best-known systems to protect occupants from death and injury in crashes. Six somewhat distinct belt technologies and four air bag technologies have been evaluated by NHTSA.

SEAT BELTS

- **Lap belts for front seat occupants**
- **Lap belts for rear seat occupants**
- **Manual 3-point lap-shoulder belts for outboard front seat occupants**
- **3-point lap-shoulder belts for rear seat occupants**
- **Automatic seat belts**
- **Pretensioners and load limiters for seat belts** (not required by FMVSS No. 208)

FRONTAL AIR BAGS

- **Frontal air bags**
- **Manual on-off switches for passenger air bags in pickup trucks and other vehicles with small or no rear seats**
- **1998-1999 redesign of frontal air bag (sled-certification)**
- **Advanced frontal air bags (automatic suppression or low-risk deployment)**

Seat belts are the basic protection system for all occupants (except children in safety seats installed in the vehicle with tethers and anchors), in most types of crashes, designed to keep occupants within the vehicle and close to their original seating position, provide "ride-down" by gradually decelerating the occupant as the vehicle deforms and absorbs energy, and, if possible, prevent occupants from contacting harmful interior surfaces or one another. Lap belts for outboard front seat occupants were first offered as options in MY 1956 and have been standard on passenger cars since 1964. Shoulder harnesses were added in MY 1968 or 1969 in passenger cars; modern 3-point lap-shoulder belts became standard in MY 1974. Automatic belts that require no action by the occupant were furnished on many cars starting in MY 1987, but had been phased out by 1997.

Frontal air bags are an effective supplemental protection system for outboard front seat occupants in frontal and partially frontal crashes. They significantly added to the energy absorption and ride-down offered by previously existing structures (seat belts, energy-absorbing steering columns and deformable instrument panels). They may also help prevent head contacts with the windshield, windshield header, among other components.

FMVSS No. 208 "specifies performance requirements for the protection of vehicle occupants in crashes." FMVSS No. 209 "specifies requirements for seat belt assemblies." FMVSS No. 210 "establishes requirements for seat belt assembly anchorages to insure their proper location and to reduce the likelihood of their failure." The three standards work together as a single unit to protect occupants in crashes.[267]

Overview of regulatory history: Here are the highlights of the long regulatory history of FMVSS Nos. 208, 209 and 210 – the amendments most associated with tangible changes in occupant protection technology. In many cases, manufacturers implemented the new technologies a few years or even many years before the effective dates. Not included are: numerous primarily technical or interpretative amendments; proposals and rules that were cancelled or changed before they took effect.

FMVSS Nos. 208, 209 and 210 were among NHTSA's initial safety standards, with a NPRM in December 1966, a final rule in February 1967, and an effective date of January 1, 1968. FMVSS No. 208 originally required lap belts at each designated seating position in passenger cars only, plus shoulder belts at the outboard front seats if lap belts alone could not prevent dummies from contacting the windshield header in static tests. Most new passenger cars received shoulder belts at that time. FMVSS No. 209 specified performance requirements for the belts themselves, while FMVSS No. 210 specified requirements for the anchorages that secure the belt systems to the vehicle.[268]

NHTSA extended the original FMVSS No. 208 requirements to LTVs up to 10,000 pounds GVWR, effective July 1, 1971. The extension did not result in much immediate change, because most LTV make-models had been equipped with lap belts by 1968 or earlier and continued to have only lap belts up to the mid-1970s.[269]

Responding to (1) the inadequate restraint provided by lap belts alone for the head and torso, (2) the inadequate restraint provided by loosely worn belts and (3) low belt use, NHTSA amended FMVSS No. 208, effective January 1, 1972[270]:

- To require shoulder belts at the outboard front seats of all passenger cars (dropping the test of contact with the windshield header). Shoulder belts at that time could still be separate or integral with the lap belt.
- To require emergency-locking or automatic-locking retractors.
- To require a warning to sound when the lap belts at the outboard front seats were not buckled.
- To permit an automatic restraint system, such as air bags or automatic belts, as an alternative to the manual shoulder belt and the buzzer.
- To include, for the first time, a 30 mph frontal barrier test (on which manual belts must remain intact, and optional automatic systems must meet injury criteria on the dummies).

Responding to (1) very low use of the separate shoulder belt and (2) continued low use of lap belts, NHTSA amended FMVSS No. 208, effective September 1, 1973, to require[271]:

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[267] 49 CFR, Parts 571.208, 571.209 and 571.210.
[268] *Federal Register* 31 (December 3, 1966): 15212, 32 (February 3, 1967): 2414.
[269] *Federal Register* 35 (September 30, 1970): 15222.
[270] *Federal Register* 36 (March 10, 1971): 4600; 49 CFR, Part 571.208 S4.1.1.
[271] *Federal Register* 38 (June 20, 1973): 16072; 49 CFR, Part 571.208 S4.1.2.

- Integral, 3-point lap-shoulder belts at the outboard front seats of passenger cars (or, alternatively, automatic protection).
- Ignition interlocks whereby belts at the outboard front seats must be buckled before a car can be started.

NHTSA amended FMVSS No. 208, effective October 29, 1974, to delete the ignition-interlock requirement. Taking its place was a 4-to-8 second visible and audible warning if the driver was unbelted.[272]

As part of its effort to bring safety requirements for LTVs up to the same level as cars, NHTSA amended FMVSS No. 208 to require integral, 3-point lap-shoulder belts (or, alternatively, automatic protection) at the outboard front seats of most LTVs effective January 1, 1976, and all LTVs with GVWR up to 10,000 pounds effective September 1, 1981.[273]

Low use of manual belts continued into the early 1980s. On July 17, 1984, NHTSA amended FMVSS No. 208 to phase automatic protection, such as air bags or automatic belts, into the outboard front seats of passenger cars between September 1, 1986, and September 1, 1989. To encourage the development of air bags, NHTSA exempted the RF seat from the automatic protection requirement until August 31, 1993, in cars with driver air bags. NHTSA, the manufacturers and the safety community dedicated themselves to a successful effort to encourage buckle-up laws in the States. Comfort and convenience standards for belts were also added to FMVSS No. 208, effective September 1, 1986. During the implementation of automatic protection, automatic belts initially predominated, then driver air bags with manual 3-point belts, and, after September 1, 1993, dual air bags with manual 3-point belts.[274]

The superior protection of lap-shoulder belts, as compared to lap belts alone, was extended to the outboard rear seats. Cars had to have 3-point belts, effective December 11, 1989, and LTVs, starting September 1, 1991.[275] Lap-shoulder belts were extended to all rear designated seating positions for passenger cars and light trucks, including the rear middle seats, but excluding side-facing seats, effective September 1, 2005.[276] The center front seats may be equipped with lap belts or lap/shoulder belts.

Automatic protection was to be phased into the outboard front seats of LTVs with GVWR 8,500 pounds or less from September 1, 1994, to September 1, 1997. Manufacturers used air bags with manual belts in LTVs; none had automatic belts after September 1, 1994, and very few before.[277]

On-the-road experience and consumer reaction soon demonstrated that the combination of manual 3-point belts with air bags was the most effective and desirable system. All cars manufac-

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[272] *Federal Register* 39 (October 31, 1974): 38380, 39 (December 6, 1974): 42692.
[273] *Federal Register* 40 (July 9, 1975): 28805; 49 CFR, Part 571.208 S4.2.1.
[274] *Federal Register* 46 (January 8, 1981): 2064, 49 (July 17, 1984): 28962, 50 (August 23, 1985): 34152; 49 CFR, Parts 571.208 S4.1.3, 4.1.4 and S7.4
[275] From December 11, 1989 to August 31, 1990, cars were allowed separate lap and shoulder belts as an alternative to 3-point belts, but nobody exercised that option; *Federal Register* 54 (June 14, 1989): 25275, 54 (November 2, 1989): 46257; 49 CFR, Parts 571.208 S4.1.4.2 and S4.2.4. The requirement does not apply to some types of seats/vehicles.
[276] *Federal Register* 68 (December 8, 2004): 70904.
[277] *Federal Register* 56 (March 26, 1991): 12472; 49 CFR, Part 571.208 S4.2.5.

tured after September 1, 1997, and all LTVs after September 1, 1998, were required to have manual 3-point belts and air bags for the driver and the RF passenger. Automatic belts were phased out.[278]

Air bags of the early 1990s presented risks to infants, children under the age of 12, and certain other individuals. NHTSA urged that high-risk individuals travel in the rear seat when possible. The agency also amended FMVSS No. 208 with measures to reduce risk when these people must travel in the front seat:

- Effective June 22, 1995, NHTSA permitted manual on-off switches for the passenger air bag in pickup trucks without rear seats or other vehicles that cannot accommodate child safety seats in the rear seat. This facilitated the implementation of passenger air bags in pickup trucks. Effective January 19, 1998, NHTSA also enabled people who must transport high-risk individuals in the front seats of any vehicle to obtain aftermarket on-off switches at their own expense.[279]
- Effective March 19, 1997, the agency temporarily relaxed some aspects of the frontal impact test in order to facilitate the introduction of "redesigned" air bags that deploy less forcefully.[280]
- From September 1, 2003 to September 1, 2006, "advanced" air bags were phased in that do not deploy at all ("suppression") or deploy only at a low level of force ("low-risk deployment") if a small child is present or if an older child/small adult is out-of-position and close to the air bag.[281]

Lap belts for front seat occupants

History: Ford and Chrysler began to offer lap belts at the outboard front seats as an option on some of their 1956 models. Even before then, consumers were outfitting their vehicles with aftermarket lap belts; the American Medical Association and the National Safety Council, among others recommended belts in cars. In 1961, Wisconsin required lap belts at the outboard front seats in all new cars sold there; New York State required anchorages to allow installation of aftermarket belts. By 1964, about half of the States had such laws. During that time, SAE issued Recommended Practices J4 for belts and J787 for anchorages; they were the starting points for FMVSS Nos. 209 and 210. The domestic manufacturers phased in lap belts at the outboard front seating positions of all new cars by 1964 or 1965, extending to the center front seat by 1968. FMVSS No. 208 took effect in passenger cars on January 1, 1968, and in LTVs on July 1, 1971, requiring a shoulder belt on an outboard front seat if a dummy restrained by just a lap belt could reach the windshield header. Lap-shoulder belts superseded lap belts at the outboard front seats,

[278] *Federal Register* 58 (September 2, 1993): 46551; 49 CFR, Part 571.208 S4.1.5.3 and S4.2.6.2.
[279] *Federal Register* 60 (May 23, 1995): 27233, 62 (November 21, 1997): 62406; 49 CFR, Part 571.208 S4.5.4 and Part 595.
[280] *Federal Register* 62 (March 19, 1997): 12960; 49 CFR, Part 571.208 S13.
[281] *Federal Register* 65 (May 12, 2000): 30679; 49 CFR, Part 571.208 S14.

immediately in passenger cars during MY 1968, more gradually in LTVs during 1969-81. However, center front seats continue to be equipped with just lap belts.[282]

How lap belts work: The principal benefit of a lap belt is to reduce greatly the likelihood of total ejection of an occupant from the vehicle during a crash. Ejection increases fatality risk in a crash by a factor of nearly four, all else being equal, because the ground is a less forgiving surface than the vehicle interior, and because the occupant may be caught between his or her own vehicle, the ground, and/or other vehicles. During 1977 to 1999, 28 percent of unrestrained fatalities in cars, and 48 percent in LTVs were ejectees; the percentages may have been higher before improved door locks (FMVSS No. 206).[283]

There was also hope, initially, that lap belts would be valuable for preventing, or reducing the severity of contacts with the vehicle interior, or with other occupants. These hopes were only partially realized – e.g., in far-side or oblique frontal impacts, where the interior is furthest from the occupant. However, in direct frontal crashes, lap belts do not necessarily prevent head contacts with the interior. Furthermore, restraining the lower torso but not the thorax can have two effects that potentially increase rather than mitigate injury. Concentration of the occupant's force on the lap belt can result in abdominal injury, especially if the belt rides up from the pelvis to the waist ("submarining"). The head and chest can jackknife forwards and downwards at a high velocity.[284]

Expected benefits: Substantial fatality reduction should be expected in rollovers, where the majority of unrestrained fatalities are ejectees. Fatality and injury reduction may be expected in far-side and oblique frontal crashes, and in crashes with multiple harmful events, where occupants are ejected or tossed around within the vehicle. Possible adverse effects, especially in frontal crashes, could detract from overall effectiveness. Lap belts should be more effective in LTVs than in cars, since there are more rollovers, more ejections, and more space within the vehicle.

Early effectiveness studies: Early analyses were usually based on fatalities or injuries per 100 crash-involved occupants. For example, if 10 percent of unrestrained occupants were injured, and 5 percent of lap-belted occupants, the effectiveness estimate was 50 percent. These studies estimated reductions of fatalities and/or serious injuries ranging from 35 percent upwards to 78

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[282] (1986). *Performance of lap belts in 26 frontal crashes*. (Report No. NTSB/SS-86/03, pp. 225-230). Washington, DC: National Transportation Safety Board; *1965 SAE Handbook*, pp. 868-872; *Federal Register* 32 (February 3, 1967): 2414, 35 (September 30, 1970): 15222.
[283] Kahane (2000, December), pp. 31-33; Evans, L. (1991). *Traffic safety and the driver.* New York: Van Nostrand Reinhold, pp. 52-54; Sikora, J. J. (1986). *Relative risk of death for ejected occupants in fatal traffic accidents*. (Report No. DOT HS 807 096). Washington, DC: National Highway Traffic Safety Administration.
[284] *Performance of Lap Belts in 26 Frontal Crashes*; whereas that report focuses on rear seat occupants, the conclusions are also pertinent to front seat occupants.

percent. Researchers grasped that several factors were definitely or possibly inflating the effectiveness attributed to belts:[285]

- People who buckle up also tend to drive more carefully than those who do not. They have less severe crashes, thus, lower injury rates per 100 crash involvements.
- Additional bias in favor of belts may occur if uninjured, unrestrained people report themselves, or are reported as belt users. That would lower the injury rate in the "belted" population, and raise it for the "unrestrained."
- Statistically meaningful results on fatality reduction are difficult to achieve because there are relatively few fatality cases on individual State crash files.

NHTSA's Restraint Systems Evaluation Project of 1974 to 1975 addressed the first two factors. Multidisciplinary teams investigated a probability sample of towaway crashes involving 21,000 outboard front seat occupants. Detailed information about vehicle damage made it possible to adjust the injury rates for differences in crash severity, using multidimensional contingency table analysis. Investigators were trained to report belt use as accurately as possible, based on an extensive checklist of evidence from the vehicle, driver interviews, the police report, and medical information. RSEP estimated that lap belts reduce moderate (AIS $\geq$ 2) injuries by 31 percent and serious (AIS $\geq$ 3) injuries by 46 percent.[286]

In 1984, in support of the rulemaking on automatic protection, NHTSA supplemented the RSEP data with NCSS plus all available NASS data. The additional data permitted a more extensive and realistic adjustment for crash severity, producing somewhat lower, but statistically significant injury reductions. They remain NHTSA's most reliable statistical results, and they will be discussed below. Based on these analyses and other studies available at that time, NHTSA's best estimates were that lap belts reduce fatalities by 30 to 40 percent, AIS 2-to-5 (moderate to critical) injuries by 25 to 35 percent, and AIS 1 (minor) injuries by 10 percent, for front seat occupants of passenger cars.[287]

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[285] NHTSA. (1976). *Safety belt usage – A review of effectiveness studies – Suggestions for State programs*. (Report No. DOT HS 801 988). Washington, DC: National Highway Traffic Safety Administration; Tourin, B., & Garrett, J. W. (1960). *Safety belt effectiveness in rural California Automobile Accidents*. Buffalo: Cornell Aeronautical Laboratory; Levine, D. N., & Campbell, B. J. (1971). *Effectiveness of lap seat belts and the energy absorbing steering column in the reduction of injuries*. (HSL Publication No. 00221617). Chapel Hill, NC: Highway Safety Research Center, University of North Carolina; Kahane, C. J. (1974). *Usage and effectiveness of seat and shoulder belts in rural Pennsylvania accidents*. (Report No. DOT HS 801 398). Washington, DC: National Highway Traffic Safety Administration.

[286] Reinfurt, D. W., Silva, C. Z., & Seila, A. F. (1976, September). *A statistical analysis of seat belt effectiveness in 1973-75 model cars involved in towaway crashes, volume 1.* (Report No. DOT HS 802 035, pp. vii-viii). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS802035.PDF.

[287] Kahane, C. J. (1984b). *Addendum to "Seat belt effectiveness estimates using data adjusted for damage type."* (NHTSA Docket No. 74-14-N35-229-05). Washington, DC: National Highway Traffic Safety Administration; NHTSA. (1984). *Final regulatory impact analysis, amendment to Federal Motor Vehicle Safety Standard 208, passenger car front seat occupant protection*. (Report No. DOT HS 806 572, p. IV-2). Washington, DC: National Highway Traffic Safety Administration.

Fatality reduction – passenger cars: Double-pair comparison, as originally applied by Evans to study lap-shoulder belts, greatly facilitated the estimation of fatality reduction.[288] Double-pair comparison allows the direct use of FARS data that have a much higher N of fatalities than NASS or State files. It implicitly adjusts or controls for the differences in the severity of crashes involving belted and unrestrained occupants. Until 1985, before buckle-up laws, FARS data was accurate or at least unbiased in the reporting of belt use.

A double-pair analysis of lap-belt effectiveness uses the technique developed in NHTSA's evaluation of 3-point belts (and similar to Evans').[289] The analysis is based on MY 1956-to-1973 cars (before 3-point belts) in CY 1975-to-1985 FARS data. It is limited to cars with a driver and a RF passenger (and perhaps other passengers). The driver, or the RF passenger, or both were fatally injured. Lap-belted and unrestrained drivers and RF passengers age 14 to 97 are included. The 34,889 vehicle cases tabulate as follows:

Vehicles	Driver Died RF Survived	Driver Survived RF Died	Both Died
Both unrestrained	13,064	14,781	5,926
Driver unrestrained, RF lap-belted	111	93	32
Driver lap-belted, RF unrestrained	104	201	73
Both lap-belted	178	261	65

This can be tabulated as fatality cases rather than vehicle cases, by adding the "both died" column to each of the preceding columns:

Fatalities	Driver Fatalities	RF Fatalities	Driver/RF Risk Ratio
Both unrestrained	18,990	20,707	0.917
Driver unrestrained, RF lap-belted	143	125	1.144
Driver lap-belted, RF unrestrained	177	274	0.646
Both lap-belted	243	326	0.745

It is clear that (1) the overwhelming majority of people killed in CY 1975-to-1985 crashes were unrestrained; (2) in these older cars, unrestrained drivers are at slightly lower risk than their RF passengers; and (3) people who buckled up with lap belts reduced their risk. The four rows of data allow a total of four double-pair comparisons, two for computing the effectiveness of belts for drivers, and two for RF passengers. The first comparison for the driver is based on the first and third rows of data:

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[288] Evans, L. (1986a). Double pair comparison - A new method to determine how occupant characteristics affect fatality risk in traffic crashes. *Accident Analysis and Prevention*, *18*, pp. 217-227; Evans, L. (1986b). The effectiveness of safety belts in preventing fatalities. *Accident Analysis and Prevention*, *18*, pp. 229-241.
[289] Kahane (2000, December), pp. 5-10.

		Driver Fatalities	RF Fatalities	Driver/RF Risk Ratio
Driver unrestrained	RF unrestrained	18,990	20,707	0.917
Driver lap-belted	RF unrestrained	177	274	0.646

In both pairs, the driver's fatality risk is compared to the same control group: the unrestrained RF passenger. The unrestrained driver has slightly lower fatality risk than the unrestrained RF passenger in the same crash, the lap-belted driver, substantially lower. The fatality reduction for lap belts is: 1 - (0.646/0.917) = 30 percent.

The other comparison for the driver is based on the second and fourth rows of data:

		Driver Fatalities	RF Fatalities	Driver/RF Risk Ratio
Driver unrestrained	RF lap-belted	143	125	1.144
Driver lap-belted	RF lap-belted	243	326	0.745

Here, the control group is the lap-belted RF passenger. The unrestrained driver has higher fatality risk than the lap-belted RF passenger in the same crash, the lap-belted driver, lower. The fatality reduction is: 1 - (0.745/1.144) = 35 percent. The effectiveness estimates for drivers are similar with the two control groups.

The first double-pair comparison to estimate belt effectiveness for the RF passenger is obtained by using the first two rows of data, reversing the order of the columns and computing the RF/Driver rather than the Driver/RF risk ratio:

		RF Fatalities	Driver Fatalities	RF/Driver Risk Ratio
RF unrestrained	Driver unrestrained	20,707	18,990	1.090
RF lap-belted	Driver unrestrained	125	143	0.874

The control group is the unrestrained driver. The fatality reduction for the lap-belted RF passenger is: 1 - (0.874/1.090) = 20 percent. The second estimate uses the last two rows of data:

		RF Fatalities	Driver Fatalities	RF/Driver Risk Ratio
RF unrestrained	Driver lap-belted	274	177	1.548
RF lap-belted	Driver lap-belted	326	243	1.342

The control group is the lap-belted driver. The fatality reduction for the lap-belted RF passenger is: 1 - (1.342/1.548) = 13 percent. Again, the two control groups produce similar estimates. Also, lap-belt effectiveness is lower for the RF passenger than for the driver.

NHTSA's 2000 evaluation of 3-point belts develops a weighting procedure that combines the two driver estimates and the two RF-passenger estimates into a single number, the overall, average fatality reduction for front-seat lap belts in passenger cars: 27 percent.

By crash mode, the estimated fatality reduction for lap belts is: 43 percent in rollovers, 22 percent in frontals, and 21 percent in side impacts, rear impacts and other crashes.

Fatality reduction – LTVs: Based on a similar double-pair comparison analysis for LTVs, the fatality reduction by lap belts for front seat occupants averaged 48 percent. There were not enough FARS cases for statistically meaningful separate analyses by crash mode. That is very close to a previous NHTSA estimate of 50-percent fatality reduction by lap belts in the center front seat of LTVs, not obtained directly from crash data, but inferred by examining the relationships between other estimates: lap-belt versus 3-point-belt effectiveness in cars and 3-point belt effectiveness in LTVs versus cars.[290]

Injury reduction – passenger cars: As stated above, NHTSA analyzed a database in 1984 that combined the RSEP, the NCSS, plus all available NASS cases. Injury rates were computed per 100 towaway-involved occupants: unrestrained, lap-belted, and lap-shoulder belted. The rates were adjusted for differences in impact location (front, side, rollover) and damage severity (CDC extent zone), using a Mantel-Haenszel model, a simpler approach than the logistic regression method widely used today. Lap belts reduced the adjusted overall (AIS ≥ 1) injury rate by 8 percent, moderate (AIS ≥ 2) injuries by 22 percent and severe (AIS ≥ 3) injuries by 33 percent.[291]

Injury reduction – LTVs: NHTSA has not analyzed the injury reduction for lap belts for outboard front seat occupants of LTVs. However, the agency estimated that lap belts in the center front seat of LTVs reduce AIS 2-5 injuries by 55 percent and AIS 1 injuries by 10 percent. The estimate was not obtained directly from crash data, but inferred by examining the relationships between other estimates: lap-belt versus 3-point-belt effectiveness in cars, 3-point belt effectiveness in LTVs versus cars, and fatality reduction versus injury reduction.[292]

Lap belts for rear seat occupants

History: The domestic manufacturers were providing lap belts at the outboard rear seating positions by MY 1967. FMVSS No. 208 required seat belts at all rear seats, including the center rear seat and the third row of seats in a station wagon, effective January 1, 1968, in passenger cars and July 1, 1971 in LTVs. As late as MY 1987, over 90 percent of new cars and LTVs had lap

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[290] NHTSA. (1990). *Final regulatory impact analysis, extension of the automatic restraint requirements of FMVSS 208 to trucks, buses and multi-purpose passenger vehicles*. (NHTSA Docket No. 74-14-N70-001, p. 23). Washington, DC: National Highway Traffic Safety Administration.
[291] Kahane (1984b); 90 percent confidence bounds for effectiveness: AIS ≥ 1 injuries, 6 to 13 percent; AIS ≥ 2 injuries, 13 to 42 percent; AIS ≥ 3 injuries, 20 to 76 percent.
[292] *Final regulatory impact analysis, extension of the automatic restraint requirements of FMVSS 208 to trucks, buses and multi-purpose passenger vehicles*, p. 23.

belts, not 3-point belts at the outboard rear seats. In cars, over 90 percent of center rear seats had lap belts (not 3-point belts) as late as 1996.[293]

How lap belts work: Here, too, the principal benefit of a lap belt is to reduce greatly the likelihood of total ejection. Lap belts may also prevent, or reduce the severity of some interior contacts – e.g., in far-side or oblique frontal impacts. There was, perhaps, some optimism that, in direct frontal crashes, lap belts would have fewer shortcomings in the rear seat than in the front seat. Rear seat occupants would hit the front seat back with their heads and chests. It is a well-padded surface, more benign than anything front seat occupants might contact. However, the National Transportation Safety Board's 1986 study indicated that lap-belted rear seat occupants had a high risk of abdominal injuries and head injuries in frontal crashes. These occupants experienced a concentrated force of the lap belt on their abdomens and their upper bodies jackknifed over the belt at a high velocity.[294]

Fatality reduction – passenger cars: NHTSA's evaluation, published in 1999, is based on double-pair comparison analysis of CY 1988-to-1997 FARS data.[295] Front seat occupants (drivers and RF passengers) were the control groups used to compare the relative fatality risk of lap-belted versus unrestrained outboard rear seat occupants, as, for example, in the following table:

Rear Seat Belt Use	Front Seat Belt Use	Rear Seat Fatalities	Front Seat Fatalities	Back/Front Risk Ratio
Unrestrained	3-point belts	3,028	2,098	1.443
Lap belts	3-point belts	1,135	1,079	1.052

In this example, unrestrained rear seat occupants had considerably higher fatality risk than front seat occupants protected by 3-point belts. However, lap-belted rear seat occupants had only slightly higher risk than 3-point-belted front seat occupants of the same cars: the greater safety of the rear seat nearly offsets the superior restraint system in the front seat.

The overall, average fatality reduction for lap belts at the outboard rear seats of passenger cars was 32 percent.[296] However, the effectiveness of lap belts varies greatly by crash mode. The estimated fatality reduction is 76 percent in rollovers and 39 percent in side impacts, but it is zero in frontals, rear impacts and other crashes.

A supplement to FARS called the Multiple Cause of Death (MCOD) file gleans injury information from death certificates. These data show why lap belts have no net benefit in frontal crashes. The rate of life-threatening abdominal injuries is three times as high for a lap-belted occupant as for an unrestrained occupant. That offsets any benefits of lap belts in frontals, such as a reduction of ejections or head injuries. In frontal crashes, occupants age 55 or older actually have

[293] *Performance of lap belts in 26 frontal crashes*, pp. 225-230.
[294] *Ibid.,* pp. 1-11.
[295] Morgan, C. (1999, June). *Effectiveness of lap/shoulder belts in the back outboard seating positions*. (Report No. DOT HS 808 945). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/808945.PDF.
[296] *Ibid*., pp. x and 13-30; 90 percent confidence bounds, 23 to 40 percent.

higher fatality risk with lap belts than unrestrained; they have exceptionally high risk of abdominal injury with lap belts.[297]

Fatality reduction – LTVs: NHTSA's 1999 evaluation similarly analyzes vans and SUVs. The fatality reduction by lap belts for rear seat occupants averaged 63 percent.[298] By crash mode, the estimated fatality reduction for lap belts is: 80 percent in rollovers, 44 percent in frontals, and 64 percent in side impacts, rear impacts and other crashes. A high percentage of rear seat passenger fatalities in LTVs are ejectees, even in frontals.

Injury reduction – passenger cars: A 1987 NHTSA report estimated the effectiveness of lap belts in reducing nonfatal injuries, based on double-pair comparison analyses of CY 1982-to-1985 Pennsylvania crash data. Compared to unrestrained rear seat occupants, lap belts reduced fatal-and-serious (K + A) injury risk by 37 percent, moderate-to-fatal (K + A + B) injury risk by 33 percent, and overall (K + A + B + C) injury risk by 11 percent.[299]

Injury reduction – LTVs: The agency has not analyzed crash data to estimate the injury reduction for lap belts in LTVs. However, a NHTSA Regulatory Impact Analysis in 1990 projected that lap belts in rear seats of LTVs could reduce AIS 2-to-5 injuries by 35.5 percent and AIS 1 injuries by 5.5 percent. Here, the agency assumed the same effectiveness in cars and LTVs; in retrospect, the AIS 2-to-5 effectiveness (35.5%) would appear to be an underestimate for the LTVs.[300]

Manual 3-point lap-shoulder belts for outboard front seat occupants

History: Volvo introduced 3-point lap-shoulder belts as standard equipment at the outboard front seats in Sweden in 1959 and in the United States in 1963. In 1968, Volkswagen and, apparently, Audi, BMW and Mercedes made 3-point belts standard. At that time, the domestic and, apparently, the Japanese manufacturers installed separate lap and shoulder belts in all new cars. Retractor systems were required effective January 1, 1972, and had been phased in by MY 1972. Effective January 1, 1968, FMVSS No. 208 originally required shoulder belts at the outboard front seats only if lap belts alone could not prevent contact with the windshield header. Effective January 1, 1972, FMVSS No. 208 required shoulder belts on all passenger cars, and effective September 1, 1973, shoulder belts had to be integral with the lap belt. Thus, from model year 1974 onwards, all passenger cars, except those with automatic belts, have had the modern system of integral 3-point belts with automatic locking retractors at the outboard front seats.[301]

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[297] *Ibid*., pp. xi-xiii, 47-52 and 99-111.
[298] *Ibid*., pp. xii and 83-97; 90 percent confidence bounds, 52 to 71 percent.
[299] Kahane, C. J. (1987b). Fatality and injury reducing effectiveness of lap belts for back seat occupants. *Restraint technologies: Rear seat occupant protection*. (Paper No. 870486, Publication No. SP-691, pp. 45-52). Warrendale, PA: Society of Automotive Engineers; 90 percent confidence bounds for effectiveness: K + A injuries, 23 to 51 percent; K + A + B injuries, 26 to 40 percent; all injuries, 7 to 15 percent.
[300] *Final regulatory impact analysis, extension of the automatic restraint requirements of FMVSS 208 to trucks, buses and multi-purpose passenger vehicles*, p. 23; NHTSA. (1989). *Final regulatory evaluation, rear seat lap shoulder belts in passenger cars*. (NHTSA Docket No. 87-08-N03-001, p. IV-1). Washington, DC: National Highway Traffic Safety Administration.
[301] *Performance of lap belts in 26 frontal crashes*, pp. 225-230; *Federal Register* 32 (February 3, 1967): 2414, 36 (March 10, 1971): 4600, 38 (June 20, 1973): 16072; 49 CFR, Part 571.208 S4.1.1 and S4.1.2.

LTVs were equipped with 3-point belts later than cars, but they went directly from lap belts to 3-point belts, skipping separate lap and shoulder belts. FMVSS No. 208 required 3-point belts at outboard front seats effective January 1, 1976, for all LTVs with GVWR up to 10,000 pounds except forward-control vehicles and some other types, and effective September 1, 1981, on the forward-control vehicles. However, Volkswagen had introduced 3-point belts by 1969. NCSS and NASS data indicate that other manufacturers began to phase them in during 1972, 1973 or 1974. The phase-in was completed in pickup trucks and SUVs by January 1, 1976, and in vans by MY 1980.[302]

How 3-point belts work: The combination of a lap and shoulder belt furnishes at least as much protection against ejection as a lap belt alone, and possibly more, because the shoulder strap might sometimes prevent partial ejection through the side window. But lap-shoulder belts also significantly reduce the injury severity of occupants who remain within the vehicle and they avoid most of the additional injury risks associated with lap belts. The lap-shoulder belt is the basic protection system for most outboard front seat occupants in most types of crashes.[303] Ideally, belts provide "ride-down" by linking the occupant to the vehicle structure. They gradually decelerate the occupant as the vehicle deforms and absorbs energy and as the belts themselves "give" a little – but not so much as to allow forceful contacts with interior surfaces. Lap-shoulder belts, especially in combination with frontal air bags, can keep the occupant in an upright, seated position and reduce the risk of flexion/tension injuries. Lap-shoulder belts often accomplish these missions, especially in directly frontal, large-overlap impacts with in-position occupants who are not exceptionally vulnerable due to their age or other factors. However, the belts cannot always prevent head contacts with interior surfaces, such as in oblique impacts; may sometimes place large force on the occupant in severe crashes; and are less effective if the passenger compartment is damaged, as in a near-side impact or a small-overlap frontal impact.

Separate shoulder belts were uncomfortable and inconvenient; only about 15 to 25 percent of the people who buckled the lap belt also fastened the separate shoulder harness. The most important feature of the integral 3-point belt is that everybody who buckled up received the protection of both the shoulder and the lap restraint, except for a small percentage of occupants who misused the shoulder belt by running it behind their backs or under their arms. Furthermore, the public did not consider the double belt excessively burdensome, because use of 3-point belts was as high as or higher than use of the lap belt alone.[304] Technological advances made the 3-point belt acceptable to the public. Most important was the locking retractor. Whereas "airline style" lap belts would be merely inconvenient in cars and LTVs, a shoulder belt that is not self-adjusting would be unacceptable because drivers must lean forward or sideways in the course of normal driving (and passengers also desire some flexibility). The locking retractor is a system that spools out more webbing when occupants wish to move around during normal driving, locks the spool when it senses a crash or other sudden decelerations (e.g., driving over potholes), and picks up excessive slack in the belt. Slack is comfortable, up to a point, in normal driving operations, but most undesirable in a crash because it defeats the early engagement of the occupant with the belts. The system had to be fine-tuned. Belts should never feel too tight or too loose, lock too

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[302] *Federal Register* 40 (July 9, 1975): 28805; 49 CFR, Part 571.208 S4.2.1.
[303] Even when children must ride in the front seat, their safety seats or booster seats are installed with the 3-point belt.
[304] Reinfurt, Silva, & Seila (1976, September), p. 18; Phillips (1980, May), pp. 4-5.

seldom or too often, or allow excessive slack. NHTSA's comfort and convenience standards for belts addressed these issues.[305]

Two problems with 3-point belts were excessive slack in some crashes, and large restraining force on some occupants in other crashes. Pretensioners and load-limiters, discussed later, address those shortcomings.

Belt use trends for outboard front seat occupants: Seat belt use in the United States has increased from about 11 percent in 1979-to-1982 to 86 percent in 2012. This has saved more lives than any other vehicle safety program. For many years, now, the vast majority of people are using the basic occupant protection that has been in their vehicles since the 1970s. The National Occupant Protection Use Surveys (NOPUS) of 1994, 1996, 1998, and every year since 2000, give unbiased estimates of belt use by outboard front seat occupants of cars and LTVs on the nation's streets, roads and highways during daylight hours, based on direct observation of a probability sample of vehicles and roadways. While unbiased, NOPUS results can have sampling error; 95 percent confidence bounds were initially $\pm$ 4 percent but in recent years have shrunk to less than $\pm$ 2 percent.[306]

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[305] *Federal Register* 46 (January 8, 1981): 2064, 50 (August 23, 1985): 34152; 49 CFR, Part 571.208 S7.4

[306] Bondy, N., & Utter, D. (1997, April). *Observed safety belt use in 1996*. Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/97820.PDF; Bondy, N., & Utter, D. (2001, February). *Observed safety belt use, fall 2000 National Occupant Protection Use Survey*. Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/01010.pdf; Glassbrenner, D. (2002, September). *Safety belt and helmet use in 2002 – Overall results*. (Report No. DOT HS 809 500). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809500.pdf; Glassbrenner, D. (2003, September). *Safety belt use in 2003.* (Report No. DOT HS 809 646). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809646.pdf; Glassbrenner, D. (2004, September). *Safety belt use in 2004 – Overall results.* (Report No. DOT HS 809 783). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809783.pdf; Glassbrenner, D. (2005, August). *Safety belt use in 2005 – Overall results.* (Report No. DOT HS 809 932). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809932.pdf; Glassbrenner, D., & Ye, J. Y. (2006, November). *Seat belt use in 2006 – Overall results.* (Report No. DOT HS 810 677). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810677.pdf; Glassbrenner, D., & Ye, J. Y. (2007, September). *Seat belt use in 2007 – Overall results.* (Report No. DOT HS 810 841). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810841.pdf; Pickrell, T. M., & Ye, J. Y. (2008, September). *Seat belt use in 2008 – Overall results.* (Report No. DOT HS 811 036). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811036.pdf Pickrell, T. M., & Ye, J. Y. (2009, September). *Seat belt use in 2009 – Overall results.* (Report No. DOT HS 811 200). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811200.pdf; Pickrell, T. M., & Ye, J. Y. (2010, September). *Seat belt use in 2010 – Overall results.* (Report No. DOT HS 811 378). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811378.pdf; Pickrell, T. M., & Ye, J. Y. (2011, November). *Seat belt use in 2011 – Overall results.* (Report No. DOT HS 811 544). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811544.pdf; Pickrell, T. M., & Ye, T. J. (2012, November). *Seat belt use in 2012 – Overall results*. (Report No. DOT HS 811 691). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811691.pdf.

From 1976 to 1991, NHTSA estimated national seat belt use by drivers in the 19-City Survey.[307] Unlike NOPUS, the basic estimate for the 19-City Survey is for drivers only and does not include RF passengers; a separate group of observations comprised passengers at the RF and other seating positions.

The point estimates generated by the 19-City Survey are not directly comparable to NOPUS, because of the different sampling frame (e.g., they do not include RF passengers) and also do not have estimates of sampling error because they are not a national probability sample.[308] The following table and graph track the 19-City estimates of belt use in the United States from 1976 to 1991 and the NOPUS estimates from 1994 to 2012.

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[307] Stowell, C., & Bryant, J. (1977, December). *Safety belt usage: Survey of the traffic population*. (Report No. DOT HS 803 354). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS803354.pdf (this initial survey encompassed only 15 of the 19 cities); Phillips (1980, May); Phillips, B. M. (1983, May). *Restraint system usage in the traffic population*. (Report No. DOT HS 806 424). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS806424.pdf; Perkins, D. D., Cynecki, M. J., & Goryl, M. E. (1984, July). *Restraint system usage in the traffic population*. (Report No. DOT HS 806 582). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS806582.pdf; Goryl, M. E., & Cynecki, M. J. (1985, March). *Restraint system usage in the traffic population*. (Report No. DOT HS 806 714). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS806714.pdf; Goryl, M. E. (1986, May). *Restraint system usage in the traffic population*. (Report No. DOT HS 806 987). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS806987.pdf; Goryl, M. E., & Bowman, B. L. (1987, March). *Restraint system usage in the traffic population*. (Report No. DOT HS 807 080). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807080.pdf; Bowman, B. L., & Rounds, D. A. (1988, August). *Restraint system usage in the traffic population 1987 annual report*. (Report No. DOT HS 807 342). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807342.pdf; Bowman, B. L., & Rounds, D. A. (1989, June). *Restraint system usage in the traffic population 1988 annual report*. (Report No. DOT HS 807 447). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807447.pdf; Datta, T.K., & Guzek, P. (1990, June). *Restraint system use in 19 U.S. cities 1989 annual report*. (Report No. DOT HS 807 595). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807595.pdf; Datta, T. K., & Guzek, P. (1991, July). *Restraint system use in 19 U.S. cities 1990 annual report*. (Report No. DOT HS 808 147). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/808147.pdf; Datta, T. K., & Guzek, P. (1992, March). *Restraint system use in 19 U.S. cities 1991 annual report*. (Report No. DOT HS 808 148). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/808148.pdf.

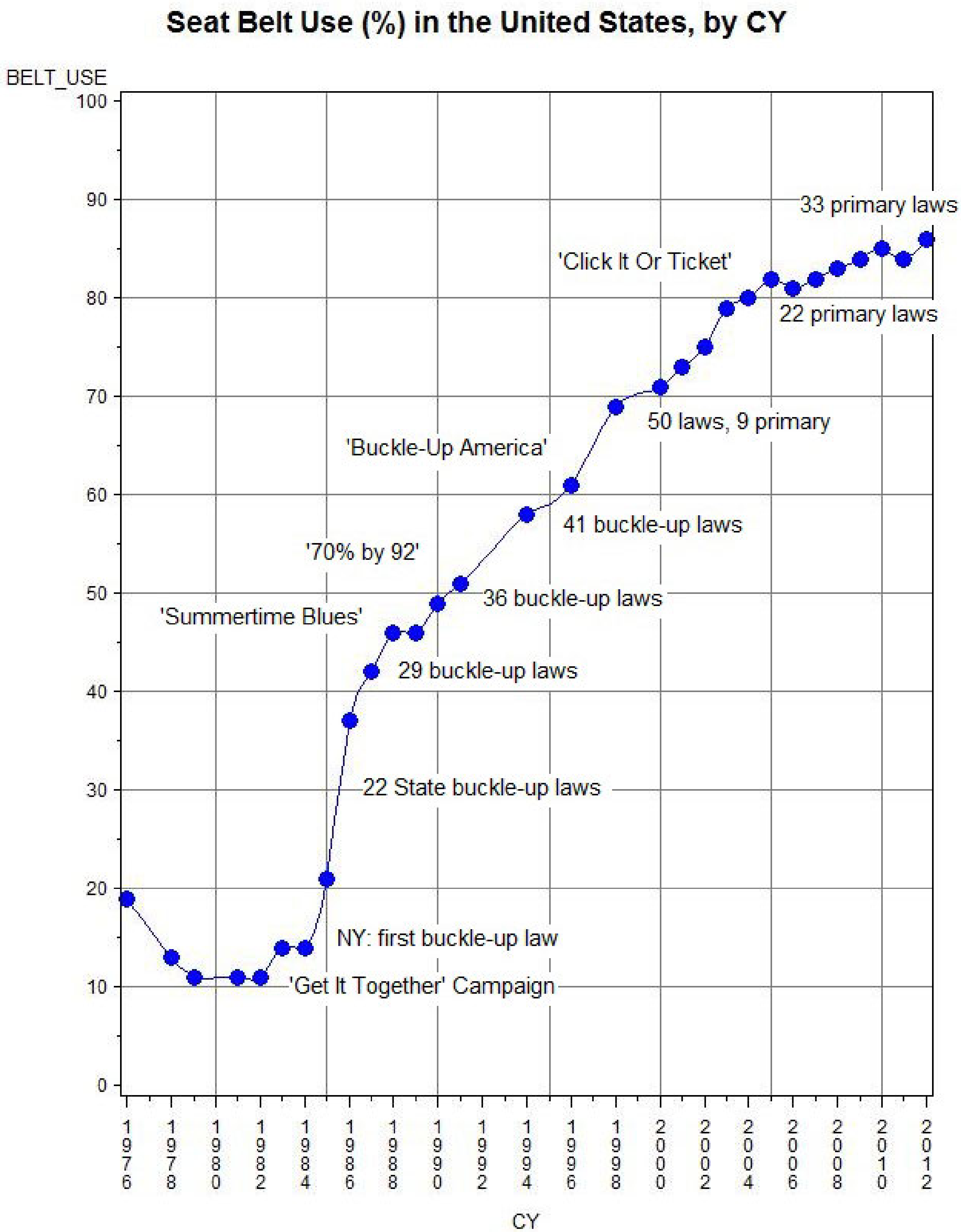
[308] NOPUS and the 19-City Survey never overlapped. However, both studies overlapped with a NHTSA computation of national averages based on individual State surveys during the 1990s. These averages cannot be considered unbiased estimates of the nation's belt use for various reasons – e.g., the exclusion of pickup trucks (which have lower belt use) in up to half the State surveys before 1997. In 1991, belt use was 51 percent in the 19-City Survey and averaged 58 percent in the State surveys; in 1994, belt use was 58 percent in NOPUS and averaged 66 percent in the State surveys. Thus, the State survey averages exceed the 19-city and NOPUS estimates by approximately the same amounts (7 or 8 percentage points) in 1991 and 1994, respectively. See also Kahane (2000, December), pp. 63 and 75-76.

Seat Belt Use in the United States, 1976-2012
(19-City Survey – Drivers Only, 1976-1991;
NOPUS – All Outboard Front Seat Occupants, 1994-2004)

1976	19 %	1989	46%	2002	75%
1977		1990	49	2003	79
1978	13	1991	51	2004	80
1979	11	1992		2005	82
1980		1993		2006	81
1981	11	1994	58	2007	82
1982	11	1995		2008	83
1983	14	1996	61	2009	84
1984	14	1997		2010	85
1985	21	1998	69	2011	84
1986	37	1999		2012	86
1987	42	2000	71		
1988	46	2001	73		

Seat belt use actually deteriorated from 19 percent in 1976 to 11 percent in 1979-82, prior to national buckle-up campaigns. NHTSA responded in the early 1980s with "Get It Together," its first national campaign for State, community, and private organizations to promote seat belts. Belt use has improved every year, or at least not significantly deteriorated from year to year, since 1982.[309]

[309] (1982). *Get it together*. (Report No. No. DOT HS 806 254). Washington, DC: National Highway Traffic Safety Administration; Stowell & Bryant (1977, December); Phillips (1980, May); Phillips (1983, May).


Seat Belt Use (%) in the United States, by CY
BELT_USE
100
90
80
70
60
50
40
30
20
10
0
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
CY
33 primary laws
'Click It Or Ticket'
22 primary laws
50 laws, 9 primary
'Buckle-Up America'
41 buckle-up laws
'70% by 92'
36 buckle-up laws
'Summertime Blues'
29 buckle-up laws
22 State buckle-up laws
NY: first buckle-up law
'Get It Together' Campaign

The greatest jump in belt use took place from 1984 to 1987 as buckle-up laws took effect in 29 States, including all ten most populous States. New York's law was the first, effective December 1, 1984, followed by New Jersey, Illinois and Michigan. Simultaneous with the July 1984 decision on automatic crash protection, NHTSA, the manufacturers – through their Automotive Coalition for Traffic Safety (ACTS) – and the safety community dedicated themselves to a successful effort to encourage buckle-up laws in the States. By 1995, 49 States, the District of Columbia, and Puerto Rico had buckle-up laws.[310]

Even though most of the States had buckle-up laws by 1990, belt use continued to increase from 49 percent in 1990 to 80 percent in 2004 to 86 percent in 2012. Sustained national campaigns, spearheaded by DOT/NHTSA and supported by States, communities and the private sector, have played an important role. They combine public information and education about the life-saving benefits of belts, law enforcement by States and communities, and additional information to make the public aware of the enforcement programs. Campaigns include "70% By 92" and "Avoid The Summertime Blues" in the early 1990s, "Buckle-Up America" starting in the late 1990s, and "Click It or Ticket" from 2003 onwards. There has also been a push for "primary" buckle-up laws that allow police to make a traffic stop solely upon observation of a belt law violation; 33 States and the District of Columbia had primary laws in 2012, up from 9 States in 1993 and 22 in 2004. After 30 years of cumulative and sustained education about seat belts, more and more Americans have been buckling up since childhood and view seat belts as a basic part of riding in vehicles.[311]

Early effectiveness studies: NHTSA's Restraint Systems Evaluation Project (RSEP) of 1974 and 1975 was the first statistical analysis in the United States with a large sample of crash-involved occupants who wore lap-shoulder belts. After controlling for damage location and severity, occupant age and vehicle weight, RSEP estimated that lap-shoulder belts reduce moderate

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[310] (1996). *Third report to Congress – Effectiveness of occupant protection systems and their use*. (Report No. DOT HS 808 537). Washington, DC: National Highway Traffic Safety Administration; NHTSA. (1999, May). *Fourth report to Congress – Effectiveness of occupant protection systems and their use*. (Report No. DOT HS 808 919). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/808-919.pdf.

[311] Hedlund, J., Gilbert, S. H., Ledingham, K., & Preusser D. (2008, August). *How States achieve high seat belt use rates*. Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810962.PDF; NHTSA. (1991). *Buckle up: Avoid the summertime blues*. (Report No. No. DOT HS 041 653). Washington, DC: National Highway Traffic Safety Administration; JAMA. (1992, July). 70 by 92: Increased safety-belt use. *Journal of the American Medical Association*, *268*, p. 318; NHTSA. (1997). *Buckle Up America*. (Report No. No. DOT HS 808 628). Washington, DC: National Highway Traffic Safety Administration; IIHS. (2001, November). 'Click It or Ticket' expands beyond North Carolina. *Status Report*, *36*, p. 4. Arlington, VA: Insurance Institute for Highway Safety; Eby, D.W., Vivoda, J. M., & Fordyce, T. A. (1999). *Direct observation of safety belt use in Michigan: Fall 1999*. (Report No. UMTRI-99-33). Ann Arbor, MI: University of Michigan Transportation Research Institute; *State seat belt laws.* Washington, DC: Governors Highway Safety Association. Available at www.ghsa.org/html/stateinfo/laws/seatbelt_laws.html; Pickrell & Ye (2012, November); for information about *Click It or Ticket* see also the NHTSA Web sites, www.nhtsa.gov/Driving+Safety/Occupant+Protection and www.nhtsa.gov/Driving+Safety/Research+&+Evaluation/Click+It+or+Ticket+Seat+Belt+Mobilization+Evaluation+Reports.

(AIS ≥ 2) and severe (AIS ≥ 3) injuries by 57 percent. RSEP hinted that fatality reduction might be close to 60 percent.[312]

By 1984, during the rulemaking on automatic protection, NHTSA realized that fatality reduction had to be somewhat lower than 60 percent. Buckle-up laws outside the United States were saving lives, but not as many as would be predicted based on 60 percent effectiveness. A review of 781 unrestrained fatalities in NCSS suggested that belts would have had little effect in nearly half of the cases. The agency performed two new analyses of belt effectiveness. RSEP data was supplemented with NCSS data plus all available NASS cases. The additional data permitted a more extensive adjustment for crash severity, and showed a statistically significant 49-percent reduction of fatalities and 45-percent reduction of serious (AIS ≥ 3) injuries. NHTSA compared the increase in belt use with the fatality reduction in 11 nations or Canadian Provinces that enacted buckle-up laws. The fatality reduction, on the average, suggested belts were 47 percent effective when used. In 1984, based on these analyses, NHTSA lowered its "best estimates" to 40-to-50 percent fatality reduction, 45-to-55 percent AIS 2-to-5 reduction, and 10 percent AIS 1 reduction.[313]

Expected benefits: Large fatality reductions should be expected in rollovers, where the majority of unrestrained fatalities are ejectees. Substantial fatality and injury reduction may be expected in direct-frontal, oblique-frontal and far-side crashes, except in impacts too severe for belts to effectively protect against contacts with interior surfaces. Effectiveness will be lowest in near-side impacts or other catastrophic crashes that reduce the space available to the occupant within the vehicle. Lap-shoulder belts should be more effective in LTVs than in cars, overall and specifically in side impacts, since there are more rollovers, more ejections, and fewer catastrophic damages.

Fatality reduction – passenger cars: Evans' double-pair comparison analyses of 1986 were an important advance in the estimation of fatality reduction. They confirmed NHTSA's estimate that effectiveness was in the 40's.[314] Double-pair comparison allows the direct use of FARS data. It implicitly controls for crash severity. Until 1985, before buckle-up laws, FARS data was accurate or at least unbiased in the reporting of belt use. NHTSA's current estimate of overall belt effectiveness, in its 2000 evaluation, is based on a double-pair analysis of MY 1975-to-1986 cars in CY 1977-to-1985 FARS data. It is limited to cars with a driver and an RF passenger (and perhaps other passengers). The driver, or the RF passenger, or both were fatally injured. Only 3-point-belted and unrestrained drivers and RF passengers, age 14-97, are included. This basic table demonstrates the life-saving benefit of 3-point belts.[315]

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[312] Reinfurt, Silva, & Seila (1976, September), pp. iv-viii; *Safety belt usage – A review of effectiveness studies – Suggestions for State programs*.
[313] *Final regulatory impact analysis, Amendment to Federal Motor Vehicle Safety Standard 208, passenger car front seat occupant protection*, pp. IV-2 – IV-16; Kahane, C. J. (1984a). *Estimates of fatality reduction for air bags and lap/shoulder belts based on case by case analysis of unrestrained fatalities*. (NHTSA Docket No. 74-14-N35-012) Washington, DC: National Highway Traffic Safety Administration; Kahane (1984b), 90 percent confidence bounds for effectiveness: fatalities, 37 to 68 percent; AIS ≥ 3 injuries, 38 to 55 percent.
[314] Evans (1986a); Evans (1986b).
[315] Kahane (2000, December), pp. 5-10.

	Driver Fatalities	RF Fatalities	Driver/RF Risk Ratio
Both unrestrained	16,503	16,786	0.983
Driver unrestrained, RF belted	374	226	1.655
Driver belted, RF unrestrained	288	589	0.489
Both belted	739	895	0.826

When the driver and RF passenger were both unrestrained, they had nearly equal risk. Unrestrained drivers had nearly double the risk of the belted RF passengers riding with them. Belted drivers had less than half the risk of unrestrained RF passengers. The evaluation report developed a procedure that combined these statistics into a single estimate of the overall fatality reduction for 3-point belts in passenger cars, 47.8 percent. This is very close to 45 percent, the midpoint of the agency's 1984 "best estimate" range of 40 to 50 percent and it essentially confirms that earlier estimate.

Immediately after 1985, double-pair comparison began producing inflated results. Whereas FARS apparently continued to report accurately the belt use of fatally injured outboard front seat occupants, buckle-up laws gave survivors a motive to declare they had been belted in some of the cases where they were actually unrestrained. In CY 1986, belt "effectiveness" jumped up over 60 percent, and it stayed there. However, numerous FARS analyses revealed that the degree of exaggeration in the effectiveness estimate varied little from year to year, State to State, by crash type, vehicle type or occupant characteristics. NHTSA developed an empirical tool called the "universal exaggeration factor" to adjust the biases out of double-pair comparison estimates based on 1986-to-1999 FARS data. That opened up the 1986-to-1999 FARS database, with its incomparably greater number of belted cases than the earlier FARS, permitting point-estimation of belt effectiveness by crash type, occupant age and gender, vehicle type, etc.[316]

[316] *Ibid*., pp. 10-43.

Fatality Reduction (%) by Manual 3-Point Belts in Passenger Cars
For Drivers and Right-Front Passengers

		Fatality Reduction (%)	Sampling Error Range[317]
IN ALL CRASHES		45	x
BY IMPACT TYPE:	Frontal impacts	50	x
	Side impacts	21	xx
	Near-side	10	xx
	Far-side	39	x
	Rollovers (primary)	74	x
	Rear impacts & other crashes	56	x
BY CRASH TYPE:	Single-vehicle	58	x
	Multivehicle	32	x
	With a car	41	x
	With a LTV	31	x
	With a heavy truck	25	xx
BY SEAT POSITION:	Driver	48	x
	RF passenger	37	x
BY OCCUPANT AGE:	5- 9 (RF passengers)	34	xxx
	10-14 (RF passengers)	35	xx
	15-29	50	x
	30-54	49	x
	55-69	43	x
	70-79	38	x
	80 and older	27	xx
BY GENDER:	Male	45	x
	Female	45	x
BY AIR BAG TYPE:	No air bags.	45	x
	MY 1975-79	47	x
	MY 1980-85	46	x
	Dual frontal air bags.	48	x
BY CURB WEIGHT:	2499 pounds or lighter	48	x
	2500-3149 pounds	44	x
	3150 pounds or heavier	41	x

[317] Minimum sampling error range: "x" denotes 2-sigma sampling error at least in the ± 4-10 percentage point range (plus possible, additional, unknown non-sampling error); "xx" = at least ± 10-20 percentage points; "xxx" = at least ± 20-50 percentage points.

Three-point belts are most effective in rollovers (74%), but they are also highly effective in frontals (50%), far-side impacts (39%) and all crash types except near-side impacts (10%). They are effective in single- and multivehicle crashes (but especially the single-vehicle crashes, where most of the rollovers are); slightly more effective for drivers (48%) than RF passengers (37%); beneficial for all age groups, but especially at 15 to 54; equally effective for males and females; consistently beneficial from MY 1975 onwards, including in cars without air bags and with air bags; and effective in cars of all sizes.

Fatality reduction – LTVs: In 1989 the agency concluded, based on double-pair comparison analyses by Partyka, that the overall fatality-reducing effectiveness of 3-point belts in LTVs was greater than in cars and that it was close to 60 percent.[318] NHTSA's 2000 evaluation reconfirms that estimate and provides more detailed estimates of belt effectiveness in LTVs by crash type, occupant age and gender, vehicle type, etc. Belts are exceedingly effective in rollovers (80%), but they are also very effective in all other types of crashes, including even near-side impacts (41%), because LTVs are better able than cars to resist catastrophic damage in side impacts. They are effective in single-vehicle crashes and multivehicle crashes (but least so in impacts with heavy trucks); beneficial for all age groups; consistently effective from MY 1980 onwards, including in LTVs without air bags and with air bags; and beneficial in pickup trucks, vans and SUVs:[319]

[318] *Final regulatory impact analysis, extension of the automatic restraint requirements of FMVSS 208 to trucks, buses and multi-purpose passenger vehicles*, p. 23; Partyka, S. C. (1988a). Belt Effectiveness in pickup trucks and passenger cars by crash direction and accident year (May 1988). *Papers on adult seat belts - Effectiveness and use*. (Report No. DOT HS 807 285, pp. 99-102). Washington, DC: National Highway Traffic Safety Administration.
[319] Kahane (2000, December), pp. 10-43.

Fatality Reduction (%) by Manual 3-Point Belts in LTVs
For Drivers and Right-Front Passengers

		Fatality Reduction (%)	Sampling Error Range[320]
IN ALL CRASHES		60	x
BY IMPACT TYPE:	Frontal impacts	53	x
	Side impacts	48	x
	Near-side	41	xx
	Far-side	58	x
	Rollovers (primary)	80	x
	Rear impacts & other crashes	81	x
BY CRASH TYPE:	Single-vehicle	70	x
	Multivehicle	43	x
	With a car	57	x
	With a LTV	45	xx
	With a heavy truck	28	xx
BY SEAT POSITION:	Driver	61	x
	RF passenger	58	x
BY OCCUPANT AGE:	5- 9 (RF passengers)	59	xxx
	10-14 (RF passengers)	63	xx
	15-29	63	x
	30-54	64	x
	55-69	53	xx
	70-79	42	xx
	80 and older	30	xxx
BY GENDER:	Male	60	x
	Female	62	x
BY AIR BAG TYPE:	No air bags.	60	x
	MY 1975-79	49	xx
	MY 1980-85	63	x
	Dual frontal air bags.	63	xx
BY TRUCK TYPE:	Pickup truck	58	x
	Van or SUV	63	x

[320] Minimum sampling error range: "x" denotes 2-sigma sampling error at least in the ± 4-10 percentage point range (plus possible, additional, unknown non-sampling error); "xx" = at least ± 10-20 percentage points; "xxx" = at least ± 20-50 percentage points.

Injury reduction – passenger cars: As stated above, NHTSA analyzed a database in 1984 that combined the RSEP, NCSS, plus all available NASS cases. Injury rates were computed per 100 towaway-involved occupants: unrestrained, lap-belted, and lap-shoulder belted. The rates were adjusted for differences in impact location (front, side, rollover) and damage severity (CDC extent zone), using a Mantel-Haenszel model, a simpler approach than the logistic regression method widely used today. Lap-shoulder belts reduced the adjusted overall (AIS ≥ 1) injury rate by 13 percent, moderate (AIS ≥ 2) injuries by 46 percent and severe (AIS ≥ 3) injuries by 45 percent.[321]

Injury reduction – LTVs: NHTSA has not statistically analyzed the injury reduction by 3-point belts for outboard front seat occupants of LTVs. However, the agency estimated that they reduce AIS 2-5 injuries by 65 percent and AIS 1 injuries by 10 percent. The estimate was inferred by examining the relationships between other estimates: 3-point belt fatality reduction in LTVs versus cars, and fatality reduction versus injury reduction in cars.[322]

3-point lap-shoulder belts for rear seat occupants

History: Volvo made 3-point belts standard at the outboard rear seating positions in MY 1971, and Mercedes made them standard in MY 1974. The 1982 Honda Accord was the first high-sales make-model equipped with 3-point belts. The majority of new cars had them at least one or two years before the December 11, 1989, effective date specified in FMVSS No. 208. The first LTVs with 3-point belts were some Isuzu Troopers in 1987, all Troopers and all full-sized GM vans in 1988. FMVSS No. 208 required them in all LTVs starting September 1, 1991. Retrofit kits could be purchased for many earlier vehicles equipped only with lap belts at the outboard rear seating positions.[323]

"Anton's Law," P.L. 107-318 (December 4, 2002) directed NHTSA to issue a regulation requiring 3-point belts for each rear seating position – i.e., including center rear seats – in passenger motor vehicles with a GVWR of 10,000 pounds or less. On December 8, 2004, NHTSA amended FMVSS No. 208 to require the phase-in of 3-point belts in center rear seats in all new passenger vehicles to start on September 1, 2005, and to be completed by September 1, 2007.[324] Manufacturers began installing 3-point belts at center rear seats well in advance of the new requirement, starting with Volvo and Saab in MY 1994 and extending to high-sales vehicles such as Ford Taurus and Toyota Camry by MY 1997. By 2001, the majority of new passenger cars had 3-point belts at the center rear seats; the majority of LTVs had them by 2003.

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[321] Kahane (1984b); 90 percent confidence bounds for effectiveness: AIS ≥ 1 injuries, 9 to 17 percent; AIS ≥ 2 injuries, 40 to 54 percent; AIS ≥ 3 injuries, 38 to 55 percent.

[322] *Final regulatory impact analysis, extension of the automatic restraint requirements of FMVSS 208 to trucks, buses and multi-purpose passenger vehicles*, p. 23.

[323] *Federal Register* 54 (June 14, 1989): 25275, 54 (November 2, 1989): 46257; 49 CFR, Parts 571.208 S4.1.4.2 and S4.2.4; from December 11, 1989 to August 31, 1990, cars were allowed separate lap and shoulder belts as an alternative to 3-point belts, but nobody exercised that option; NHTSA. (1992). *Lap/shoulder belt kits for rear seats*. (Report No. No. DOT HS 807 881). Washington, DC: National Highway Traffic Safety Administration; for additional information about retrofit kits see Document Nos. 001, 002, 003, 005, 016, 018-H and 035 in NHTSA Docket No. 89-01-N01 and Nos. 006, 007, 008, 009, 011, 012, 014, and 015 in NHTSA Docket No. 89-01-N03.

[324] *Federal Register* 69 (December 8, 2004): 70904; 49 CFR, Parts 571.208 S4.1.5.5 and S4.2.7.

How 3-point belts in rear seats work – expected benefits: As in the front seat, a lap and shoulder belt in the rear seat ought to provide excellent protection against ejection, provide "ride-down," keep occupants in an upright, seated position and reduce the severity of interior contacts. They should be effective in most crash modes, including frontals (but less so in severe near-side impacts or other catastrophic crashes). They should greatly alleviate the problem of abdominal injuries experienced with lap belts alone.

Fatality reduction – passenger cars: NHTSA's 1999 evaluation is based on double-pair comparison analysis of 1988-to-1997 FARS data. Front seat occupants (drivers and RF passengers) were the control groups used to compare the relative fatality risk of belted versus unrestrained outboard rear seat occupants in the following table:[325]

Rear Seat Belt Use	Front Seat Occupant Protection	Rear Seat Fatalities	Front Seat Fatalities	Rear/Front Risk Ratio
Unrestrained	Unrestrained	4,953	7,248	0.683
3-point belts	Unrestrained	119	344	0.346
Unrestrained	Frontal air bag	650	820	0.793
3-point belts	Frontal air bag	49	148	0.331
Unrestrained	3-point belts	3,028	2,098	1.443
3-point belts	3-point belts	807	880	0.917
Unrestrained	3-pt. + air bag	670	371	1.806
3-point belts	3-pt. + air bag	431	490	0.880

In each of these four comparisons with a control group, the rear seat occupants protected with 3-point belts had substantially lower risk than the unrestrained rear seat occupants. For example, relative to unrestrained front seat occupants, unrestrained rear seat occupants had a risk ratio of 0.683, belted rear seat occupants just 0.346. The overall, average fatality reduction for 3-point belts at the outboard rear seats of passenger cars was 44 percent.[326]

The preceding table also shows that the rear seat was a safer place to ride than the front seat of cars of the 1990s. Unrestrained rear seat occupants had 32 percent lower fatality risk than unrestrained front seat occupants of the same car, and they had lower fatality risk than unbelted front seat occupants in cars with air bags. Rear seat occupants using 3-point belts had lower fatality risk than front seat occupants using 3-point belts, even if the car was also equipped with an air bag in the front seat. (For additional discussion, see the FMVSS No. 213 chapter.)

Three-point belts are effective in all crash modes, including frontals. The estimated fatality reduction is: 77 percent in rollovers, 42 percent in side impacts, 29 percent in frontals, and 31 percent in rear impacts and other crashes.

[325] Morgan (1999, June), p. 19.
[326] *Ibid*., pp. x and 13-30; 90 percent confidence bounds, 38 to 50 percent.

Analyses of the FARS-MCOD file showed that 3-point belts reduce the risk of life-threatening abdominal injuries by 52 percent and head injuries by 47 percent relative to lap belts only, in frontal crashes. (Occupants wearing 3-point belts, however, still have higher risk of abdominal injury than unrestrained people, but their risk of head injury is 63% lower.) Three-point belts are beneficial for occupants of all age groups, including those 55 or older.[327]

Fatality reduction – LTVs: NHTSA's 1999 evaluation analyzes vans and SUVs. Three-point belts are highly effective: the fatality reduction for rear seat occupants averaged 73 percent.[328] By crash mode, the estimated fatality reduction is: 84 percent in rollovers, 50 percent in frontals, and 70 percent in side impacts, rear impacts and other crashes.

Injury reduction – passenger cars: NHTSA's 1999 study did not attempt to obtain point estimates of the effectiveness of 3-point belts in reducing nonfatal injuries, because belt use appeared to be substantially overreported in available State crash files. However, an "as-used" analysis of 1990-to-1996 Pennsylvania data showed outboard rear seat occupants of cars equipped with 3-point belts (regardless of whether or not these occupants wore the belts) had a statistically significant 12 percent fewer moderate-to-fatal (K + A + B) injury rate in frontal crashes than occupants of cars equipped with lap belts only. In 1990-to-1996 Florida data, the reduction was 6 percent, also statistically significant.[329] In 1989, the agency had projected that 3-point belts in rear seats of cars could reduce AIS 2-to-5 injuries by 45-55 percent and AIS 1 injuries by 10 percent. The estimate was not obtained directly from crash data, but inferred by examining the relationships between other estimates: lap-belt versus 3-point-belt effectiveness in the front seat of cars, lap belt effectiveness in the rear seat versus the front, and fatality reduction versus injury reduction.[330]

Injury reduction – LTVs: The agency has not analyzed crash data to estimate the injury reduction for 3-point belts in LTVs. NHTSA's Regulatory Impact Analysis in 1990 projected that 3-point belts in rear seats of LTVs could reduce AIS 2-to-5 injuries by 50 percent and AIS 1 injuries by 5.5 percent. Here, the agency assumed the same effectiveness in cars and LTVs; in retrospect, the AIS 2-to-5 number might be an underestimate for the LTVs.[331]

Automatic seat belts

Types of automatic belts – how they work: There have been two fundamentally different types of automatic seat belts for outboard front seat occupants of passenger cars: 2-point and 3-point. A 2-point automatic belt was a diagonal torso belt, running from the roof rail or the top of the door down to a floor anchor near the center of the car. An entirely separate manual lap belt and/or knee bolster had to be added for lower-torso restraint. Motorized 2-point belts were anchored to a track on the roof rail. A motor automatically rolled the anchor backward, moving the

[327] *Ibid*., pp. xi-xiii, 47-52 and 99-111.
[328] *Ibid*., pp. xii and 83-97; 90 percent confidence bounds, 64 to 79%.
[329] *Ibid*., pp. 75-82.
[330] *Final regulatory evaluation, rear seat lap shoulder belts in passenger cars*, pp. IV-1 – IV-26.
[331] *Final regulatory impact analysis, extension of the automatic restraint requirements of FMVSS 208 to trucks, buses and multi-purpose passenger vehicles*, p. 23; *Final regulatory evaluation, rear seat lap shoulder belts in passenger cars*, p. IV-1.

torso belt into place, when the ignition was turned on, and rolled it forward, away from the occupant, when he or she prepared to leave the car. All motorized belt systems came with a manual lap belt. Non-motorized 2-point belts were anchored to the door. They were designed to move into place when the door shut and away when it opened. Before 1990, some of the non-motorized systems did not come with a lap belt. All 2-point belts could be loosened for emergency egress, by a device that spools the belt out temporarily and/or by a buckle that could be permanently disconnected or reconnected as the occupant wished.

Automatic 3-point belts, when in use, closely resemble manual 3-point belts, but they are anchored to the door rather than the roof rail/B-pillar and fashioned so as to move into place around the occupant when the door shuts and move away when the door opens. They also have a buckle somewhere – e.g., close to the anchor point at the center of the car. If the occupant so chooses, he or she may unbuckle it and let the belts retract; thereafter, the belts may be manually buckled and unbuckled just like conventional, manual 3-point belts, each time he or she rides in the car.

To qualify as automatic crash protection under FMVSS No. 208, cars with automatic belts had to meet that standard's 30 mph frontal test requirement. Manual lap belts were not compulsory since the automatic belt, by itself, satisfied the FMVSS No. 208 requirement for a belt system.[332]

History: Twelve model years before FMVSS No. 208 required automatic protection on any vehicle, Volkswagen introduced non-motorized 2-point belts, with knee bolsters but no lap belt, as part of a popular option package on their MY 1975 Rabbit. From 1975 to 1984, approximately 30 percent of Rabbits were sold with automatic belts, comprising nearly 400,000 cars. Toyota made the motorized 2-point belt standard on all Cressidas, starting in 1981, accounting for over 200,000 cars in MY 1981 to 1986.[333]

The phase-in of automatic protection began on September 1, 1986. During model year 1987, the first year of the phase-in, 91 percent of the cars with automatic protection had automatic belts (only 9% had air bags), and in MY 1988, 93 percent. Starting in 1989, sales of cars with air bags steadily gained relative to automatic belts. Nevertheless, in MY 1990, the first year after FMVSS No. 208 was fully phased in, over 70 percent of the cars had automatic belts, comprising over 6 million cars. Sales of cars with automatic belts decreased each year after 1990. By 1997, one year before FMVSS No. 208 required it, all new cars had dual air bags and manual 3-point belts – but not before 31 million cars with automatic belts were sold. Close to 20 million of them were still on the road as of CY 2003 and over 7 million as late as CY 2011. Over the years, sales of automatic 2-point belts (17 million cars) slightly outnumbered automatic 3-point belts (14 million cars). LTVs were not equipped with automatic belts.

Automatic belt use: In 1983 and 1984, when NHTSA developed the automatic protection requirement of FMVSS No. 208, automatic belts were a promising alternative. Manual belt use was 14 percent, whereas automatic belt use was observed to be 96 percent in the Toyota Cressida (motorized) and 75 percent in the Volkswagen Rabbit (non-motorized 2-point) in the 19-City Study.[334] State buckle-up laws quickly narrowed the gap between manual and automatic belt use.

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[332] 49 CFR, Parts 571.208 S4.1.2.1 and S4.5.3.
[333] *Final regulatory impact analysis, amendment to Federal Motor Vehicle Safety Standard 208, passenger car front seat occupant protection*, pp. II-3 and IV-23.
[334] Perkins, Cynecki, & Goryl (1984, July), p. 16.

In the 19-city survey of 1991, manual belt use in MY 1987-to-1990 cars had risen to 56 percent, while automatic belt use was 91 to 97 percent in cars with motorized 2-point belts, 74 percent with non-motorized 2-point belts, and 64 percent with 3-point belts.[335] In the 1994 NOPUS, use of manual belts in late-model (MY 1989-to-1994) cars was up to 69 percent, exactly the same as 3-point automatic belts; use of 2-point automatic belts was not much higher: 78 percent for motorized, 75 percent for non-motorized.[336] NHTSA believes that, during most of the 1990s, use rates of manual and automatic 3-point belts were almost equal, increasing from year to year, while use of 2-point belts was close to 84 percent, changing little from year to year.[337]

In 1987, the Insurance Institute for Highway Safety observed 253 parked, unoccupied cars with 3-point automatic belts. Already at that early date, over 99 percent of them had been unbuckled and allowed to retract toward the door; functionally rendering them a manual belt system. It is little wonder, then, that automatic 3-point belts had the same use rates as manual within a few years after their introduction. By contrast, over 95 percent of the 753 2-point belts in their survey were still connected in the "automatic" mode (although that percentage must have decreased in later years).[338]

All of the preceding statistics for 2-point belts are use rates for the automatic shoulder belt. However, most of those cars, except for some early non-motorized systems, also had a manual lap belt. Lap belt use has been lower than shoulder belt use, but it is unclear by how much. (Lap belt use is, among other things, more difficult to observe than shoulder belts.) Lap belt use was only 29 percent in a 1989-90 North Carolina observational survey, 43 percent in a 1987 IIHS study, but 69 percent in 1992 Michigan observations. Shoulder belt use was over 90 percent in all three of these surveys.[339]

Expected benefits: Automatic 3-point belts closely resemble manual 3-point belts and may provide equally good protection. One caveat is that, being door-mounted, they might release in a crash that damages and opens the door, and allow more ejections than manual 3-point belts. Similarly, an automatic 2-point belt in combination with the manual lap belt may be functionally equivalent to a manual 3-point belt and equally effective. Without the lap belt, it stands to reason that 2-point belts would be less effective overall, but it is not clear where benefits would be reduced. Since the vehicle must meet the FMVSS No. 208 frontal barrier test without the lap belt, effectiveness could still be high in frontal crashes. However, without the lap belt, occupants might be more prone to slide beneath the shoulder belt (submarining) and they might not be as well protected from ejection.

[335] (1992). *Evaluation of the effectiveness of occupant protection, interim report*. (Report No. DOT HS 807 843, pp. 11-17). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807843.pdf.

[336] The 1994 NOPUS controlled-intersection survey was the only one to record license plates and obtain VINs from DMVs; NHTSA decoded the VINs to identify the model year and type of occupant protection.

[337] Kahane (2000, December), pp. 41 and 52-55.

[338] Williams, A. F., Wells, J. K., Lund, A. K., & Teed, N. (1989, October). Observed use of automatic seat belts in 1987 cars. *Accident Analysis and Prevention*, *21*, pp. 427-433.

[339] *Ibid*.; Hunter, W.W., et al. (1990). *Analysis of occupant restraint issues from state accident data*. (Report No. HSRC-TR75, Chapter 6). Chapel Hill, NC: Highway Safety Research Center, University of North Carolina; Streff, F. M., Molnar, L. J., & Christoff, C. (1994). Automatic safety belt use in Michigan: A two-year follow-up. *Journal of Safety Research*, *25*, pp. 215-219; Schmidt, R. A., Young, D. E., & Ayres, T. J. (1998, March). Automobile seat belts: Usage patterns in automatic belt systems. *Human Factors*, *40*, pp. 126-135.

Fatality reduction, automatic 3-point belts: NHTSA's 2000 evaluation estimated the fatality reduction for automatic 3-point belts, based on the same double-pair comparison analysis of 1986-to-1999 FARS data used for manual belts. Automatic and manual belts are equally effective: they reduce fatalities by 45 percent.[340] Furthermore, an analysis of 1986-to-1991 FARS data did not show any significant increases in occupant ejections as make-models shifted from manual belts to automatic 3-point belts during 1987 to 1989.[341] Automatic and manual 3-point belts appear to have essentially the same effectiveness and use rates.

Fatality reduction, automatic 2-point belts: The 2000 study estimated a 32 percent overall fatality reduction for automatic 2-point belts. That is significantly less than the 45 percent effectiveness of manual 3-point belts. However, this 32 percent effect is an average, comprising people who did not buckle the manual lap belt as well as those who did. (FARS data cannot be relied on to identify use of the lap belt.) If lap belt use has been as low as suggested by the North Carolina survey – less than one-third of shoulder belt use – it is easy to see how net effectiveness could drop to 32 percent. But if lap belt use were as high as the Michigan survey – over two-thirds of shoulder belt use – it would imply: (a) these systems are not very effective without the lap belt and/or (b) these systems, even with the lap belt, are not as effective as 3-point belts.[342] In any case, given recent use rates for manual belts, such as 86 percent in 2012, the combination of manual belts with air bags is clearly more beneficial than any automatic belt system.

Pretensioners and load limiters for seat belts

Pretensioners and load limiters are technologies designed to make seat belts more effective. Pretensioners retract the seat belt to remove excess slack almost instantly upon sensing the vehicle has crashed, typically by firing a pyrotechnic device. When forces on the shoulder belt rise above a predetermined level, load limiters allow the belt to give or yield while controlling the tension in the belt, typically by spooling it out of the retractor, to avoid concentrating too much force on the occupant's chest.

History: NHTSA has never required installation of these technologies, but encouraged it by listing the makes and models of vehicles that offer them in its annual *Buying a Safer Car* brochures from 1997[343] and, subsequently, on the Internet at www.safercar.gov. Furthermore, addition of these technologies usually improved vehicles' performance on NHTSA's NCAP tests (see below). Mercedes-Benz introduced pretensioners in the front seats of their S-class cars in 1981. Volvo introduced load limiters on its 850 series in 1995. The introduction of pretensioners was spread over many years, although most models received them sometime between 1998 and 2006. Load limiters mostly entered the new-vehicle fleet between 1997 and 2002. By MY 2002, approximately 63 percent of new cars and LTVs were already being equipped with pretensioners and 84 percent with load limiters. All new cars were equipped with pretensioners by MY 2006

[340] Kahane (2000, December), pp. 40-41; the point estimate for the 3-point automatic belts was actually 48 percent; since it was not significantly different from the 45 percent estimate for manual belts, the two systems may be considered equally effective, since they essentially work the same way.
[341] *Evaluation of the effectiveness of occupant protection, interim report*, pp. 43-46.
[342] Kahane (2000, December), pp. 40-41.
[343] Available for 2000 to 2005 at icsw.nhtsa.gov/safe_car_new/ (click on SaferCar2000, SaferCar2001, BASC2002, BASC2003, BASC2004, or BASC2005) and for 2006 to 2010 at www.safercar.gov/Vehicle+Shoppers/Resources/Buying+a+Safer+Car+brochures.

and load limiters by MY 2007 at outboard front seats. All new LTVs were equipped with pretensioners and load limiters by MY 2008 at the outboard front seating positions. Before 2007, a moderate number of vehicles were equipped with load limiters, but not pretensioners – or vice-versa – but no such vehicles were produced in MY 2007 or later.[344]

How pretensioners and load limiters work: In a crash, a seat belt needs to firmly engage the occupant's pelvis, clavicle, and rib cage to restrict occupant motion within the vehicle such that injurious contacts with other interior components are minimized. This process needs to occur early in the crash in order to couple the occupant to the decelerating vehicle and provide the most controlled ride-down. Any slack in the seat belt works against this process. Pretensioners are typically pyrotechnic devices in the belt-buckle assemblies triggered by the same crash sensors that control deployment of the vehicle's air bags. Gas produced by the pyrotechnic device may propel a piston that pulls down on the buckle or drive a turbine that rewinds the retractor, thus removing slack in the seat belt before any significant occupant motion begins. In minor collisions, the seat belt pretensioners may be fired without the air bags being deployed. In more serious crashes, both the pretensioners and the air bags will be deployed.

A load limiter is designed to allow the seat belt force applied to the chest to rise to a pre-determined point where the injury risk is still relatively low. The seat belt is then allowed to spool out of the retractor in a controlled manner, maintaining a constant restraining force as it absorbs energy. In a severe impact, where the extension of the belt could be substantial, a frontal, side, or curtain air bag would in many cases work in conjunction with the belt and arrest the occupant's motion. Load limiters in recent vehicles typically use a torsion bar built into the seat belt retractor. The torsion bar is a metal rod that will twist when sufficient torque is applied. In minor collisions, the torsion bar will hold its shape and the seat belt retractor will lock normally. But, when the force applied by the webbing reaches the design limit, the torsion bar twists and allows the webbing to spool out of the retractor.[345]

Pretensioners and load limiters ought to work best together. The belt engages the occupant as soon as possible, but forces do not reach a dangerous level, allowing a long, gradual ride-down. Removing the slack early with a pretensioner allows more room for belt extension with the load limiter.

Test performance: NHTSA may have indirectly encouraged the installation of pretensioners and load limiters through its frontal NCAP test, a 35 mph impact into a rigid barrier with belted dummies. It soon became apparent that vehicles could improve their test results by adding pretensioners and load limiters to their belt systems. In 2003, NHTSA published a statistical analysis tracking the improvements in NCAP results for various makes and models over the preceding five model years. In the models that added pretensioners and load limiters, HIC was reduced (i.e., improved) by an average of 232 units, chest acceleration by 6.6 g's, and chest deflection by 10.6 mm, for drivers and RF passengers. Each of these reductions was statistically significant. This was already a promising indication that pretensioners and load limiters make belts more ef-

[344] Kahane, C. J. (2013, November). *Effectiveness of pretensioners and load limiters for enhancing fatality reduction by seat belts*. (Report No. DOT HS 811 835, pp. 1-3). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811835.PDF.

[345] *Ibid*., pp. 1-3.

fective in at least one type of crash: collinear full-frontal impacts.[346] However, excessive slack or excessive belt forces would likely be harmful in other types of impacts, too; pulling in slack and limiting belt forces could have benefits in a variety of crash types.

Fatality reduction: Pretensioners and load limiters are only effective if people buckle up. They have no effect on unrestrained occupants. If these technologies save lives, they would only save lives of belted occupants. In other words, the observed fatality reduction for belt users (relative to the unrestrained occupants) ought to be higher in vehicles equipped with pretensioners and load limiters than in comparable vehicles with neither. Fatality reduction is estimated by double-pair comparison analyses, as in the earlier sections of this chapter, based on crash cases of vehicles with a driver and a RF passenger, at least one or possibly both fatally injured. Much data is needed, because the objective here is not merely to show that belts save lives but to detect a difference in the results for two separate effectiveness analyses: one for vehicles with pretensioners and load limiters, the other for comparison vehicles with neither. FARS data for 1986 to 2011 has enough applicable crash cases: 16,642 FARS vehicles equipped with both technologies and 27,389 comparison vehicles equipped with dual frontal air bags, but neither pretensioners nor load limiters. NHTSA's evaluation, issued in 2013, performs two separate double-pair comparisons, one on the 16,642 cases another on the 27,389 comparison vehicles. Subsequently, a procedure in SAS called CATMOD[347] statistically tests whether the observed belt-effectiveness estimates with pretensioners and load limiters are "approximately the same" as the estimates for belts equipped with neither or whether 3-point belts are significantly more effective when they are equipped with pretensioners and load limiters.

The analyses show that the combination of pretensioners and load limiters has significantly enhanced belt effectiveness in passenger cars, CUVs and minivans. Specifically, the estimated fatality reduction by belts for drivers is 53 percent if the belts have pretensioners and load limiters, 45 percent if not; for RF passengers, 51 percent and 39 percent, respectively. What this means is that a belted driver or RF passenger has, on the average, an estimated 12.8 percent lower fatality risk if the belt is equipped with a pretensioner and a load limiter than if it is not equipped with either (95% confidence bounds: 2.6% to 23.0%). The analyses of the currently available data do not yet show a significant effect for pretensioners and load limiters in truck-based LTVs (pickup trucks, SUVs with body-and-frame construction, and full-sized vans). Although there is enough data for statistically significant results for cars, CUVs, and minivans, the relatively wide confidence bounds demonstrate that effectiveness of pretensioners and load limiters cannot yet be estimated precisely; it may be advisable to rerun the analyses in about 4 or 5 years when more data will be available. Pretensioners and load limiters are definitely beneficial in frontal impacts of cars, CUVs and minivans, as evidenced by statistically significant results if the preceding analysis is limited to frontal impacts. It is also possible that they have some benefits in side impacts and rollovers; however, separate, individual analyses of side impacts or rollovers do not yield statistically significant results as in the frontals.[348]

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[346] Walz, M. C. (2003, March). *NCAP test improvements with pretensioners and load limiters*. (Report No. DOT HS 809 562). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809562.PDF.

[347] CATMOD is a logistic regression that may include categorical independent variables and it tests each variable (and their interactions') contributions to the dependent variable.

[348] Kahane (2013, November), pp. iv, 11-21, and 26-31.

Injury reduction: NHTSA has not statistically analyzed the effect of pretensioners and load limiters on nonfatal injuries.

Frontal air bags

From 1985 to 2012, there have essentially been three generations of frontal air bags. First, there were **barrier-certified** air bags through MY 1997 (1998 or even 1999 in a few make-models), so called because FMVSS No. 208 included a 30 mph crash test with unrestrained dummies into a rigid barrier. Next, manufacturers **sled-certified** their air bags after NHTSA allowed the option of a 30 mph sled test with unrestrained dummies rather than the barrier test, starting March 19, 1997 (and implemented in MY 1998 or shortly thereafter); the parameters selected for the sled test resulted in lower deceleration than the typical barrier test, facilitating the introduction of "**redesigned**" air bags that deploy less forcefully, with less risk for child passengers.[349] **Advanced** frontal air bags phased in from September 1, 2003 to September 1, 2006. They do not deploy at all for children ("suppression") or deploy only at a low level of force ("low-risk deployment"). The descriptions of frontal air bags in this section generally apply to all three generations although some focus on the barrier-certified type. The statistical analyses, however, are primarily based on barrier-certified air bags of MY 1985 to 1997; the next two sections analyze the differences between barrier-certified and more recent air bags.

How frontal air bags work: A system of dual frontal air bags – one for the driver and one for the RF passenger – includes sensors at various locations in the vehicle that send an electrical signal if they experience a substantial deceleration and velocity change from a frontal direction. A control module commands the air bags to deploy if these signals imply that the vehicle has been in a relatively severe frontal impact. Early air bag assemblies included an inflator with a prescribed amount of sodium azide propellant that generated nitrogen gas upon ignition of a squib. Other systems may have had a cylinder of compressed argon gas or mixture of inert gases that expanded under heat generated by the ignited squib to inflate a bag made of coated nylon fabric. Current inflator technology includes compressed gas and/or organic propellant that has all but replaced the older inflator systems with sodium azide. All bags have vents to release the gas gradually after a deployment as the occupant interacts with the bag. Many have tethers (internal straps) that limit how far the bag can deploy toward the occupant and make it spread outward, over a larger area. These assemblies are located in the steering wheel hub for the driver and in the instrument panel for the passenger. A driver-only air bag system has all of these components except the passenger bag assembly.

In a severe frontal crash such as a 30 mph or 35 mph barrier impact, even while the front bumper comes to an immediate stop against the barrier and the sheet metal deforms, the occupants remain in their seats for about the first 50 milliseconds, and the compartment interior continues forward at close to 30 mph as if nothing had happened yet. In the next 50-75 milliseconds, the compartment is slowed to a stop. Belted occupants load the seat belt, but unrestrained occupants would continue to move forward at close to 30 to 35 mph, fly out of their seats, and strike the steering assembly, instrument panel and other structures at a high relative speed.

[349] *Federal Register* 62 (March 19, 1997): 12960; 49 CFR, Part 571.208 S13.

The technological marvel of the air bag is that it has fully deployed during those first 50 milliseconds, just before a correctly positioned occupant makes initial contact with it. In that time, the sensors detect the crash, the control module sends signals to fire the propellant or open the cylinders, and gas is generated or released at high enough pressure for the bags to burst through "doors" in the steering wheel hub and instrument panel, and to fill up entirely. As the occupant begins to move forward, he or she will almost immediately contact an energy-absorbing surface that is ideally "tuned": soft enough to cushion the head and neck without serious injury, yet rigid enough to absorb, in combination with the seat belt, much of the torso's kinetic energy.

The air bag is one key component in a chain of deformable devices that allow the occupant to "ride down" from 35 mph to 0 mph as gradually as possible, remaining in an upright position. The other components are: the continuing crumple of the sheet metal in the front of the vehicle even after the occupant moves out of the seat; the compression of the energy-absorbing steering assembly, facilitated by transmission of force through the air bag; deformation of the instrument panel by the knees; and the "give" in the seat belt system (especially with load limiters) and the seat structure.

Air bags usually deploy rapidly and with great force in order to get their job done in less than 50 milliseconds – although many advanced frontal air bags now have a capability for low-risk deployment when the control system senses that a full deployment is not warranted. For adequate gas pressure (energy-absorbing capability) in the fully deployed bag, there must be much higher gas pressure and temperature as the bag begins to deploy. Initial bag velocities of 200 mph or more were not unusual in the 1985-to-1997 generation of air bags. Whereas air bags are of great value to the correctly positioned occupant, they can increase risk for an out-of-position occupant who is close to the air bag module (e.g., within 4 inches) at the moment of deployment.

How do people get close to the air bag? Infants in rear-facing child safety seats would be close to the air bag module at all times, and must **never** be placed in the front seat of a vehicle with a passenger air bag that is "on." Other people may simply have been out of position pre-crash or they may have been jostled forward from their seats during hard braking, bumps on or off the road, and/or minor impacts before the one that deploys the bag. A correctly worn seat belt or forward-facing safety seat and/or the inertial weight of an adult reduce the tendency to slide forwards. Thus, unrestrained children 1 to 12 years old are especially vulnerable. Drivers of short stature are at higher risk of being out of position and in the path of a deploying air bag. Temporary proximity to the air bag can result from leaning forward to adjust the radio or other controls.

The only two guaranteed methods to stay away from an air bag are to ride in the rear seat or to turn the on-off switch "off," if one is available. NHTSA recommends that children up to age 12 ride in the rear seat if possible; it is the safest place in the vehicle for child passengers. Risk can be greatly reduced, although not totally eliminated, by using seat belts/forward-facing safety seats, moving the passenger seat rearward, and moving adjustable pedals rearward if this feature is available. For the overwhelming majority of occupants 13 or older who wear seat belts, the risk of serious injury from air bags is so negligible relative to their potential benefits that they should not even consider obtaining an aftermarket on-off switch.

Seat belts remain the primary occupant protection system and need to be worn in vehicles with air bags. In side impacts, rear impacts and first-event rollovers, frontal air bags generally do not deploy, and even if they do, they have limited benefits. Deployments of frontal air bags are, of course, beneficial in relatively severe frontal crashes, but there is no guarantee that an air bag will deploy in a particular crash. Air bags are designed to deploy in frontal impacts with force levels equivalent to a full-frontal barrier impact at 8-to-14 mph or more. However, deployments occasionally happen at lower speeds and sometimes do not take place at substantially higher delta V. This is not an evidence of malfunction; rather, the sensors take into account various aspects of the crash pulse and do not simply measure delta V. Frontal air bags do not prevent ejection and they may have limited benefits if a frontal impact is followed by a rollover, side impact, fire or immersion. They deflate rapidly after deploying and may not be as helpful in multiple impacts. Notwithstanding these caveats, air bag systems usually deploy when they are needed, do not deploy when they are not needed, and seldom malfunction. The manufacturers and NHTSA constantly review the performance of the systems and promptly correct problems that may develop over time.[350]

History: Air bags to cushion occupants in frontal crashes were conceptualized in the 1950s. Prototypes were built and tested in the early 1960s. NHTSA announced in 1969 it was considering air bags or other automatic protection, especially in view of low belt use, and issued its first NPRM for automatic protection in 1970. The original January 1, 1972, effective date was postponed or cancelled several times for reasons such as revision of the test requirements, alternative proposals for occupant protection, risk to children/out-of-position occupants and lack of industry/public support. However, NHTSA's July 17, 1984, rule to phase automatic protection into the outboard front seats passenger cars was successfully implemented from 1986 to 1989.[351]

On-the-road experience began in 1972 and 1973: 831 MY 1972 Mercury Montereys with frontal air bags for the RF passenger and 1000 MY 1973 Chevrolet Impalas with dual frontal air bags. These cars were driven by corporate personnel or leased to corporate fleets. In MY 1974 and 1975, the general public bought 10,281 full-size Buicks, Cadillacs, and Oldsmobiles with optional dual frontal air bags. No air bags were offered on new cars from MY 1976 to 1983. During MY 1985 (or possibly in late MY 1984), driver air bags of the next design generation (1984 to 1997) began to appear in some Mercedes models for sale to the public and in 5,000 Ford Tempos purchased by the Federal government. Driver air bags were standard on all 1986 Mercedes.[352]

[350] (1997). *Air bags & on-off switches: Information for an informed decision*. (Report No. DOT HS 808 629). Washington, DC: National Highway Traffic Safety Administration. Available at www.safercar.gov/Vehicle+Shoppers/Air+Bags/ON-OFF+Switch+FAQ; *Fifth/Sixth report to Congress – Effectiveness of occupant protection systems and their use*. (Report No. DOT HS 809 442, pp. 2-3). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809-442.pdf.

[351] Clark, C., Blechschmidt, C., & Gordon, F. (1966). Impact protection with the 'Airstop' restraint system. *Eighth Stapp Car Crash and Field Demonstration Conference*. Detroit: Wayne State University Press; *Federal Register* 34 (July 2, 1969): 11148, 35 (May 7, 1970): 7187, 42 (July 5, 1977): 34289, 46 (October 29, 1981): 53419, 49 (July 17, 1984): 28962; Air bag chronology. *USA Today*, July 13, 1999.

[352] *Final regulatory impact analysis, amendment to Federal Motor Vehicle Safety Standard 208, passenger car front seat occupant protection*, p. IV-40; Smith, R. A., & Kahane, C. J. (1975). *1974 accident experience with air cushion restraint systems*. (Paper No. 750190). Warrendale, PA: Society of Automotive Engineers; Bloch, B. (1998). Advanced designs for side impact and rollover protection. *Sixteenth International Technical Conference on the Enhanced Safety of Vehicles*. (Report No. DOT HS 808 759, p. 1780). Washington, DC: National Highway Traffic Safety Administration; NHTSA. (1986). *Recent air bag field performance*. Washington, DC: National Highway Traffic Safety Administration, National Center for Statistics and Analysis; Kahane (1996, August), p. 89.

The FMVSS No. 208 phase-in of automatic protection began on September 1, 1986. To help get frontal air bags into cars, recognizing that the development of passenger air bags was taking longer than driver air bags, NHTSA exempted the RF seat from the automatic protection requirement until August 31, 1993, in cars with driver air bags. During MY 1987 and 1988, fewer than 10 percent of cars with automatic protection had air bags, while over 90 percent had automatic belts. The public, however, soon expressed a preference for air bags. In mid-1988, Chrysler committed itself to shift from automatic belts to frontal air bags within the next few years. By 1990 to 1991 all domestic manufacturers made frontal air bags standard at the driver's seat on some models with high sales; in 1992 to 1993 driver air bags peaked at 49 percent of new car sales. Starting September 1, 1993, cars could not have just a driver air bag and manual belts, but they could have a driver air bag and an automatic belt for the RF passenger; in fact 25 percent of MY 1994 cars had that configuration.[353]

Dual frontal air bags were available on Porsche in 1987 to 1989 and standard in 1990. They became available on a few other models in 1990 or 1991, were in 5 percent of MY 1992 cars and 14 percent of MY 1993, including, for example, all the Chrysler LH cars. By MY 1994, the manufacturers placed dual air bags in 58 percent of their cars, and in 1995, 90 percent. All new cars had dual frontal air bags with manual 3-point belts from MY 1997 onward, one year in advance of the FMVSS No. 208 requirement.[354]

Chrysler equipped some MY 1991 and all 1992 minivans with driver air bags. Chrysler and Toyota minivans were the first with dual frontal air bags, in MY 1994. The FMVSS No. 208 phase-in of automatic protection into LTVs started on September 1, 1994. By then, the majority of LTVs at least had driver air bags and 16 percent had dual air bags. Most SUVs and vans had dual air bags by MY 1996 or 1997, two to three years in advance of the FMVSS No. 208 requirement. In pickup trucks without rear seats, and in other vehicles that could not accommodate a child restraint in the rear seat, however, passenger air bags would have posed a risk to children obligated to ride in the front seat. After NHTSA permitted on-off switches for the passenger air bag in such vehicles, effective June 22, 1995, dual air bags with the switches began to appear in 1996 Ford Rangers, and were standard in all pickup trucks with GVWR < 8,500, excluding crew-cab models, by MY 1998. LTVs with GVWR over 8,500 pounds are exempt from the automatic protection requirement and in some cases do not have air bags.[355]

Expected benefits: Based on the preceding descriptions of how frontal air bags work, here are some hypotheses of the types of crashes where statistical analyses would likely show benefits. Frontal air bags ought to be quite effective in frontal crashes, the closer to directly frontal, the more effective. They should substantially reduce life-threatening head and chest injuries in these crashes. They should be effective, but to a lesser extent, in oblique frontal crashes, because occupants are often injured by components off to the side, not in a trajectory to the air bag. Air bags ought to save lives of belted as well as unrestrained occupants, because seat belts alone cannot prevent all contacts with the compartment interior in frontal crashes.

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[353] *Federal Register* 49 (July 17, 1984): 28962, 55 (January 17, 1990): 1586; 49 CFR, Parts 571.208 S4.1.4; Kahane (1996, August), pp. 77-95.
[354] *Federal Register* 58 (September 2, 1993): 46551; 49 CFR, Part 571.208 S4.1.5.3; Kahane (1996, August), pp. 77-95.
[355] *Federal Register* 56 (March 26, 1991): 12472, 58 (September 2, 1993): 46551, 60 (May 23, 1995): 27233; 49 CFR, Part 571.208 S4.2.5, 4.2.6.2 and S4.5.4; Kahane (1996, August), pp. 97-101.

Frontal air bags will have no effect in crashes where they do not deploy, including most 90-degree side impacts, rear impacts and rollovers. Frontal air bags generally will not block occupant ejection from the vehicle, except possibly through the windshield portal. When frontal crashes are followed by other harmful events such as secondary impacts, rollovers or fires, the air bags might not prevent injuries associated with the subsequent events. Intuitively, air bags would be less effective in catastrophic crashes where the integrity of the occupant compartment is lost.

Frontal air bags for RF passengers would clearly be dangerous to infants in rear-facing safety seats in the front seat of a vehicle and they could also increase the net fatality risk for some other types of child passengers. As of January 1, 2009, NHTSA reported 29 confirmed cases of infants in rear-facing safety seats and 162 other children who received fatal injuries from air bag deployments in relatively low-speed crashes.[356] However, the latter is not necessarily the "net" increase, since air bags may have saved some children in other crashes.

Early predictions of fatality reduction: In 1974, NHTSA predicted that air bags would reduce overall fatality risk by 32 percent relative to an unrestrained occupant, and that air bags would save 9,000 lives per year. In 1977, after the energy crisis, 55 mph speed limit and other factors had dramatically reduced overall traffic fatalities, NHTSA upped the effectiveness estimate for air bags to 40 percent and still predicted they would save 9,000 lives per year. Because air bags protected dummies in 35 mph frontal barrier crashes, the analyses assumed that air bags would essentially eliminate fatalities in frontal crashes on the highway with delta V ≤ 35 mph (57 to 65 percent of all unrestrained frontal fatalities) – regardless of what contact points or injury mechanisms were actually causing the fatalities. The analyses also assumed air bags would have some benefits in side impacts, rear impacts and rollovers if these crashes included a secondary frontal impact or a frontal-force component in the main impact.[357]

During the 1984 rulemaking on automatic protection, NHTSA revisited air bag effectiveness, based on the agency's data systems created during 1977 to 1984. Two NHTSA analysts independently reviewed approximately 800 unrestrained outboard-front-seat fatality cases on the NCSS file (all types of crashes – not limited to frontal impacts). Both studies concluded that 72 to 77 percent of these crash fatalities would not likely have been mitigated, even if the vehicles had been equipped with frontal air bags, because the injuries were principally attributed to contacts with the vehicle's side interior or other non-frontal areas, ejection through side doors or windows, catastrophic damage to the vehicle interior, fire, or immersion. Thus, the overall fatality reduction for air bags could not exceed 23 to 28 percent and presumably would be some frac-

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[356] (2009, January). *Special crash investigations – Counts of frontal air bag related fatalities and seriously injured persons*. (Report No. DOT HS 811 104). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811104.pdf.

[357] *Final regulatory impact analysis, amendment to Federal Motor Vehicle Safety Standard 208, passenger car front seat occupant protection*, pp. IV-37 – IV-39; NHTSA. (1974). *Analysis of Effects of Proposed Changes to Passenger Car Requirements of FMVSS 208*. (NHTSA Docket No. 74-14-N01-104). Washington, DC: National Highway Traffic Safety Administration; NHTSA. (1977). *Standard No. 208 – Passive restraint amendment, explanation of rulemaking action*. (NHTSA Docket No. 74-14-N10-011; Report No. DOT HS 802 523). Washington, DC: National Highway Traffic Safety Administration.

tion of that. NHTSA at that time essentially halved its predictions, ranging them down to 20-percent fatality reduction and 4,570 lives saved per year.[358]

Fatality reduction – passenger cars – drivers: The four NHTSA analyses of the actual crash experience of cars equipped with air bags, in 1992, 1996, 1999 and 2001, have had remarkably consistent results. Frontal air bags reduced overall fatality risk by 12 percent, 11 percent, 11 percent and 12 percent, respectively. The last study is based on the most data and it is NHTSA's best estimate. In the crash databases, the frontal air bags were all barrier-certified air bags in the first two analyses and predominantly barrier-certified in the last two analyses. However, subsequent analyses of sled-certified and advanced frontal air bags showed little or no change in the overall effectiveness estimate (see below).[359]

Each of these studies estimated fatality reduction based on two double-pair comparison analyses and averaged the two results. The first analysis is feasible because a large number of make-models were initially equipped with only a driver air bag at some point before 1994. The driver's seats changed from no air bags to air bag-equipped, while the RF passenger seat stayed the same (no air bag). That allows double-pair comparison, with the RF passenger as the control group. NHTSA's 2001 study was based on CY 1986-to-2000 FARS data involving MY 1985-to-2000 cars equipped with 3-point belts and no air bags, or with 3-point belts and a driver-only air bag. It is limited to cases where the driver's and RF seats were both occupied; the RF passenger was at least 5 years old; and the driver, or the RF passenger, or possibly both died:

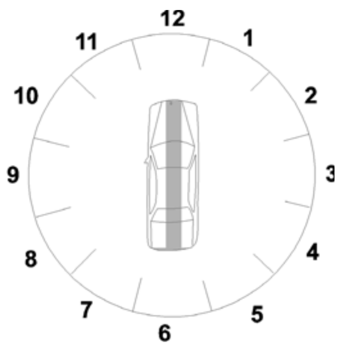
Driver's Seat	RF Passenger Seat	Driver Fatalities	RF Passenger Fatalities	Driver/RF Risk Ratio
No air bag	No air bag	22,535	24,168	0.932
Frontal air bag	No air bag	3,654	4,420	0.827

In cars with no air bags, drivers are nearly as much at risk as RF passengers. In cars with driver air bags, there are substantially fewer driver fatalities than passenger fatalities. Drivers experienced a statistically significant 11-percent fatality reduction with air bags:

$$1 - [(3{,}654/4{,}420) / (22{,}535/24{,}168)] = .113$$

This is called an "as used" analysis, because it includes all types of crashes and it is not limited to crashes in which the air bag deployed.

[358] *Final regulatory impact analysis, amendment to Federal Motor Vehicle Safety Standard 208, passenger car front seat occupant protection*, pp. 3 and IV-47 – IV-67 (analysis by S. C. Partyka); Kahane (1984a).
[359] *Evaluation of the effectiveness of occupant protection, interim report*, pp. 21-25; Kahane (1996, August), pp. 7-12; *Fourth report to Congress*, pp. 8-11; *Fifth/sixth report to Congress*, pp. 6-11.



The second analysis is based on another distinctive characteristic of frontal air bags: they are primarily designed for action in frontal crashes. With an inclusive definition of "frontal and partially frontal" crashes (initial or principal impact location between 10 o'clock and 2 o'clock), it can be assumed that air bags have little effect in the remaining "non-frontal" crashes. These non-frontal fatalities are a control group. NHTSA's 2001 study was based on CY 1986-to-2000 FARS data and limited to selected MY 1985-to-2000 make-models equipped with 3-point belts that shifted from no air bags to driver (or dual) air bags. Driver fatalities in cars of the last 3 model years before air bags were compared to fatalities in cars of the first 3 model years with driver (or dual) air bags. (In this analysis, it does not matter if the RF seat is occupied or unoccupied, or what sort of occupant protection it has.):

	Frontal (10-2 o'clock) Fatalities	Non-Frontal Fatalities	Frontal/Non-Frontal Risk Ratio
Driver seat without air bag	5,434	2,860	1.900
Driver seat with frontal air bag	3,360	2,223	1.511

Drivers of cars equipped with frontal air bags experienced a statistically significant 20-percent reduction of frontal fatalities:

$$1 - [(3{,}360/2{,}223) / (5{,}434/2{,}860)] = .204$$

Because 65 percent of fatalities were frontal (by this rather inclusive definition of "frontal"), that amounts to a 13 percent overall reduction of fatalities:

$$.204\ [5{,}434 / (5{,}434 + 2{,}860)] = .134$$

The two statistically significant estimates of overall fatality reduction (11 and 13%) average out to 12 percent.

Frontal air bags are most effective in "purely frontal" crashes where the principal impact is at a 12 o'clock location and it is also the most harmful event – i.e., the most harmful event is not a subsequent rollover, fire, or immersion. The first analysis method demonstrates the high effectiveness of air bags:

Purely Frontal Crashes

Driver's Seat	RF Passenger Seat	Driver Fatalities	RF Passenger Fatalities	Driver/RF Risk Ratio
No air bag	No air bag	7,597	8,241	0.922
Frontal air bag	No air bag	950	1,438	0.661

The average for the two analysis methods is a 29-percent fatality reduction in purely frontal crashes. Effectiveness drops off steeply as the impact moves away from purely frontal. When the principal impact is at an 11 o'clock or 1 o'clock location and is also the most harmful event, frontal air bags reduce fatality risk by 15 percent; when the principal impact/most harmful event is at a 10 o'clock or 2 o'clock location, fatality reduction for frontal air bags is 6 percent. When the principal impact is 3 o'clock to 9 o'clock or to the top of the car, or when the most harmful event is a rollover, fire, immersion or other non-collision, effectiveness is zero.

Enough data was available to obtain statistically significant estimates of fatality reduction for subpopulations of drivers:

Fatality Reduction (%) by Frontal Air Bags in Purely Frontal Crashes, Drivers of Passenger Cars

		Fatality Reduction (%)
IN ALL PURELY FRONTAL CRASHES		29
BY OCCUPANT AGE:	14-29	29
	30-55	30
	56-69	30
	70 and older	20
BY GENDER:	Male	29
	Female	29
BY BELT USE:	Belted	21
	Unbelted	34
BY CURB WEIGHT:	2,778 pounds or lighter	30
	2,779-3,119 pounds	28
	3,120 pounds or heavier	26

Air bags are about equally effective for young and middle-aged drivers (29 to 30%) and perhaps slightly less effective for drivers 70 or older (20%). As of January 1, 2009, NHTSA reported 92 confirmed cases of adult drivers, including 31 who were 70 or older, who had received fatal injuries from air bag deployments in relatively low-speed crashes – but, clearly, the lives saved by air bags in more severe crashes far exceed these losses, in all age groups.[360] Air bags are equally effective for male and female drivers, and about equally effective in cars of various sizes. They are quite effective for unrestrained drivers (34%), but also provide significant supplemental protection for belted drivers (21%). Since 3-point belts, by themselves, reduce fatality risk by 50 percent in frontal crashes (see above), the combination of 3-point belts with air bags reduces fatality risk by an estimated 61 percent in purely frontal crashes:

[360] *Special crash investigations – Counts of frontal air bag related fatalities.*

$$1 - [(1 - .50) / (1 - .21)] = .605$$

NHTSA was also able to estimate the fatality reduction in all crashes (not just purely frontal) separately for belted and unbelted drivers. Air bags reduced overall fatality risk by 11 percent for belted drivers and 14 percent for unbelted drivers. Since 3-point belts, by themselves, reduce fatality risk by 45 percent, the combination of 3-point belts with air bags reduces fatality risk by an estimated 51 percent:

$$1 - [(1 - .45) / (1 - .11)] = .5105$$

Fatality reduction – passenger cars – RF passengers 13 and older: Essentially the same two double-pair comparison analyses can be used to compute fatality reduction for RF passengers. Separate estimates are obtained for passengers 13 or older, who ought to benefit significantly from all types of frontal air bags, and children 12 or younger, who might experience increased fatality risk with barrier-certified air bags.

The first analysis method works because quite a few make-models had only driver air bags up to MY 1993 and were equipped with dual frontal air bags starting in MY 1994. The RF seats changed from no air bags to air bag-equipped, while the driver's seat stayed the same (air bag-equipped). That allows double-pair comparison, with the driver as the control group. The following example from NHTSA's 2001 study was based on purely frontal crashes where the driver's and RF seats were both occupied; the RF passenger was at least 13 years old; and the driver, or the RF passenger, or possibly both died:[361]

Purely Frontal Crashes

RF Passenger Seat	Driver's Seat	RF Passenger Fatalities	Driver Fatalities	RF/Driver Risk Ratio
No air bag	Frontal air bag	1,427	914	1.561
Frontal air bag	Frontal air bag	1,282	1,179	1.087

In these purely frontal crashes, when the driver had an air bag and the passenger did not, the fatality risk was substantially higher for the passenger. But with dual air bags, the fatality risk was about the same for drivers and passengers. The average for this analysis method and the other method (based on purely frontal versus non-frontal fatalities) is a statistically significant 32-percent fatality reduction in purely frontal crashes. In other words, air bags are just as effective, and perhaps a bit more effective for RF passengers 13 and older than they are for drivers (29% fatality reduction).

Effectiveness drops off to 24 percent in 11 o'clock or 1 o'clock principal impact/most harmful events, 4 percent in 10 o'clock or 2 o'clock impacts, and near zero in non-frontal crashes or when most harmful event is a rollover, fire, immersion or other non-collision. In all types of

[361] *Fifth/sixth report to Congress*, pp. 10-11.

crashes, frontal air bags reduce the fatality risk of RF passengers 13 and older by an average of 14 percent.

Frontal air bags are about equally effective for RF passengers 13 to 29, 30 to 55, 56 to 69, and 70+ years old.[362]

Fatality reduction – LTVs – drivers: NHTSA's 2001 study has enough FARS data for statistically significant estimates of the effect of air bags in pickup trucks, SUVs and vans, based on the same analysis methods as for cars. Driver air bags reduce fatality risk in purely frontal crashes by 29 percent and in all crashes by 12 percent. These estimates are exactly the same as the corresponding results for passenger cars, and they suggest that frontal air bags are about equally effective for LTV and car drivers.[363]

Fatality reduction – LTVs – RF passengers 13 and older: NHTSA's 2001 report has less data on LTV passengers than on drivers or car passengers, because most LTVs were not equipped with dual air bags until 1996 to 1998. Nevertheless, there is enough data for a statistically significant estimate that passenger air bags reduce fatality risk in purely frontal crashes by 32 percent. It is exactly the same as the corresponding result for car passengers, and it suggests that frontal air bags are about equally effective for LTV and car passengers 13 and older.[364]

Effect of barrier-certified air bags on fatalities of RF passengers 12 and younger: NHTSA has repeatedly advised the public about the hazards of frontal air bags to infants and children and until 2009 the agency periodically updated and issued a list of Special Crash Investigations (SCI) of children who received fatal injuries from air bags in relatively low-speed crashes.[365] NHTSA's 1996 evaluation recommends a double-pair comparison method for estimating the effect of air bags on child passenger fatalities.[366] When that analysis is updated with the FARS database of the 2001 report, it shows that, in all crashes, child passengers up to12 years old in the RF seating position have 22 percent higher fatality risk with barrier-certified air bags than without them. In crashes where the principal and/or initial impact is at 12 o'clock, risk is 42 percent higher with air bags. Both increases are statistically significant. However, the added risk is not at all uniform, but depends a lot on the age of the child and restraint use. For infants in rear-facing safety seats, barrier-certified air bags increase fatality risk in 12 o'clock impacts by an estimated factor of 5½. For unrestrained infants and children up to 5, barrier-certified air bags approximately double fatality risk in 12 o'clock impacts; for children 1 to 5 years old in safety seats or belts (not necessarily used correctly) and unrestrained children 6 to 10, they increase risk by 70 percent. Each of these three increases is statistically significant. They have smaller effects for these groups in oblique-frontal crashes (10 o'clock, 11 o'clock, 1 o'clock, or 2 o'clock). They do not significantly increase or decrease the net fatality risk of belted children 6 to 10 years old or of any 11- or 12-year-olds and, of course, they have little or no effect in non-frontal crashes.

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362 Kahane, C. J. (2013, May). *Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women*. (Report No. DOT HS 811 766, pp. 230-233). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811766.pdf.
363 *Fifth/sixth report to Congress*, p. 11.
364 *Ibid*., p. 11.
365 *Special crash investigations – Counts of frontal air bag related fatalities.*
366 Kahane (1996, August), pp. 48-49.

Based on these statistically derived effectiveness estimates, NHTSA calculates that barrier-certified air bags may have resulted in a **net** increase of 188 child passenger fatalities from 1993 to 2012, including 172 from 1993 through 2008.[367] The latter number is almost identical to the 171 confirmed SCI cases of infants and children with fatal injuries from barrier-certified air bags from 1993 to 2008 reported as of January 1, 2009.

Injury reduction: NHTSA's reports to the Congress estimated injury reduction based on injuries per 100-crash involved occupants in NASS-CDS data, with logistic regression to control for delta V and other variables. The estimates are biased upwards because:

- Belt use of uninjured occupants appears to be overreported.
- Vehicles equipped with frontal air bags are substantially newer than vehicles without air bags.

Neither bias is fully addressed by the logistic regression method. The effectiveness estimates increased with each successive report. Furthermore, the use of weighted NASS-CDS data increased sampling error. For example, the last report to the Congress estimated that air bags plus seat belts reduced AIS ≥ 3 injury risk by 67 percent relative to an unrestrained occupant, while seat belts alone reduced it by 69 percent. Both estimates are implausibly high and the latter ought not to have been higher than the former, since it implies that air bags increased the injury risk of a belted occupant.[368]

Less biased and more precise estimates can be obtained from unweighted 1989-to-2003 CDS casualty cases by using double-pair comparison analysis of frontal versus non-frontal casualties, almost exactly as with FARS. To maximize sample size, the analysis comprises fatality cases of drivers and RF passengers of cars as well as LTVs, belted as well as unrestrained. First, as a "calibration run," fatality reduction is estimated from NASS data; the overall fatality reduction is 12 percent, statistically significant and exactly the same as the fatality reduction in FARS. The same analysis estimates that frontal air bags reduce AIS ≥ 3 injury risk by 15 percent and AIS ≥ 2 injury risk by 11 percent, in all crashes. Both reductions are statistically significant.[369]

Effectiveness can be estimated separately for unrestrained and belted occupants.[370] For unrestrained occupants, air bags reduce both AIS ≥ 3 and AIS ≥ 2 injury risk by 21 percent, in all crashes. For occupants who buckle up, air bags reduce AIS ≥ 3 injuries by 12 percent and AIS ≥ 2 injuries by 4 percent. Since 3-point belts, by themselves, reduce AIS ≥ 3 injuries by 45 percent and AIS ≥ 2 by 46 percent in passenger cars (RSEP-NCSS-NASS estimates, see above), the injury reduction for the combination of 3-point belts with air bags can be estimated:

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[367] 188 is the sum of 183 in Table 2-51 of this report (estimated net fatality increase in vehicles without on-off switches) and 5 in Table 2-53 (estimated net increase in vehicles with switches that were left on).

[368] *Third report to Congress*, p. 20; *Fourth report to Congress*, p. 17; *Fifth/sixth report to Congress*, p. 13.

[369] Analysis of unweighted NASS data is unacceptable for estimating national totals or rates (the customary use of NASS), but may be empirically defensible for effectiveness analyses employing double-pair comparison, based entirely on fatal or non-minor injury cases. In this analysis, "frontal" crashes are those with GAD1 = F and/or DOF1 = 11, 12 or 1.

[370] Belt use is overreported by uninjured occupants in NASS, but can be assumed accurately reported for people with AIS ≥ 2 injuries; the double-pair comparison analysis is based entirely on the injury cases.

PASSENGER CARS ALL CRASHES	Fatality Reduction (%)	AIS ≥ 3 Reduction (%)	AIS ≥ 2 Reduction (%)
3-point belt plus frontal air bag	51	52	48
Frontal air bag alone	14	21	21
3-point belt alone	45	45	46

In purely frontal crashes,[371] frontal air bags reduced AIS ≥ 3 injuries by 32 percent and AIS ≥ 2 injuries by 23 percent. For unbelted occupants alone, these reductions are 39 percent and 38 percent, respectively. For occupants who buckle up, they are 27 percent and 10 percent, respectively. In other words, the AIS ≥ 3 and AIS ≥ 2 injury reductions for frontal air bags are generally similar (and sometimes even a little higher) than the fatality reductions, with the one exception that frontal air bags apparently do not have that large an effect on the AIS ≥ 2 injuries of belted occupants.

Manual on-off switches for passenger air bags in pickup trucks and other vehicles with small or no rear seats

History: NHTSA recognized that barrier-certified passenger air bags of the early 1990s were absolutely incompatible with rear-facing child safety seats and also presented risks to child passengers and certain other individuals. NHTSA urged that children and other high-risk passengers travel in the rear seat when possible. The agency also amended FMVSS No. 208 with measures to reduce risk when these people must travel in the front seat. Effective June 22, 1995, more than three years before the September 1, 1998, effective date for dual air bags in all LTVs, NHTSA permitted (but did not require) on-off switches for the passenger air bag in pickup trucks without rear seats or other vehicles that could not accommodate rear-facing child safety seats in the rear seat. This facilitated the implementation of passenger air bags in pickup trucks, beginning with some Ford Rangers in MY 1996 and extending to every make-model of pickup trucks with passenger air bags by 1998: excluding full crew cabs, but including all 2-door cabs and those 3-door and 4-door cabs with rear seats not designed to accommodate a rear-facing child safety seat. Other vehicles with on-off switches, because they have no rear seat or only a limited rear seat have included sporty cars such as Ford Thunderbird, Chevrolet Corvette, and Mazda Miata; sporty SUVs such as Jeep Wrangler; and cargo vans such as Dodge Ram. Effective January 19, 1998, NHTSA also enabled people who must transport high-risk individuals in the front seats of any vehicle to obtain aftermarket on-off switches at their own expense.[372]

Advanced frontal air bags, phased in by September 1, 2006, do not deploy or have low-risk deployments if the RF passenger weighs less than a certain amount. Essentially, they are automatic on-off switches that made the manual switches largely redundant, although FMVSS No. 208 retains the option of manual switches, even in vehicles with advanced air bags, until September 1,

[371] GAD1 = F, DOF1 = 12, and this event is a collision with another vehicle or a fixed object.
[372] *Federal Register* 60 (May 23, 1995): 27233, 62 (November 21, 1997): 62406; 49 CFR, Part 571.208 S4.5.4 and Part 595.

2015.[373] After the successful phase-in of advanced air bags, the manufacturers steadily phased out the manual switches – e.g., GM Silverado and Sierra pickup trucks in MY 2003, Ford F-150 and Nissan Frontier in 2005, and Chevrolet Corvette in 2006.

As of July 1, 2011, there were approximately 14,000,000 vehicles on the road with factory-equipped on-off switches, including 13,200,000 pickup trucks and 800,000 other vehicles without rear seats that accommodate rear-facing child safety seats. This number gradually decreased from a peak of 14,400,000 in 2005 and 2006, as existing vehicles were retired and ever fewer new vehicles had the switches.[374]

Aftermarket switches are much rarer – e.g., in August 2002, only 12,513 vehicles were known to have aftermarket switches.[375]

How switches work: A manual on-off switch is usually located on the driver's part of the instrument panel, but well over to the right where both the driver and the passenger can see it. A key (often the ignition key) or key-like object operates it. The switch has two settings, "air bag on" and "air bag off." It remains at its current setting until somebody uses the key to change it. When the switch is "off," a light on the dashboard advises "air bag off."

Public use and understanding of the switches: During July-November 2000, NHTSA sponsored a survey of 3,182 pickup trucks (including 617 with child passengers) at 79 sites in 4 States. "Since the recommended switch setting depends on who is in the front seat at the moment, the survey was performed while the vehicles were occupied." Investigators observed the actual setting of the switch and recorded the passenger's age. Then they interviewed the driver to find out his or her awareness of the switch and its current setting, and the driver's own criteria for turning the switch on or off.[376]

NHTSA recommends turning the switch "off" if there is a child passenger 12 or younger in the front seat. With very rare exceptions, it should be "on" if the passenger(s) are 13 or older. The principal finding of the survey was that many switches were "on" for child passengers in the RF seat, especially 7-to-12 year olds, while quite a few were "off" for passengers 13 or older (the percentage of switches at the recommended setting is shown in bold type)[377]:

[373] *Federal Register* 77 (August 30, 2012): 52619.
[374] Based on analyses of registration data for make-models known to be equipped with the switches.
[375] Morgan, C. (2003, November). *Results of the survey on the use of passenger air bag on-off switches*. (Report No. DOT HS 809 689, pp. v and 4-5) Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809689.PDF.
[376] *Ibid*., pp. 4-8.
[377] *Ibid*., pp. 13-15 and 22; the report's statistics for infants in rear-facing seats, forward-facing seats and unrestrained are combined here, but cases of infants in the center-front seat are not included in the table.

Age of the RF Passenger	Switch “On” (%)	Switch “Off” (%)
Less than 1 year[378]	14	**86**
1-6	26	**74**
7-8	41	**59**
9-10	53	**47**
11-12	70	**30**
13-15	**78**	22
16-19	**83**	17
20-59	**85**	15
60-79	**81**	19
70 and older	**44**	56

While 86 percent of switches are turned “off” for infants in the RF seat that percentage decreases to 74 at age 1 to 6 and to 30 by 12. The percentage of switches turned “on” for adults does not exceed 85 in any age group, and it drops to 44 at 70 years or older.

Interviews showed that these drivers were well informed in 2000 about some aspects of the switch: 98 percent knew their truck had a switch that could turn the air bag on or off, and 97 percent correctly identified its setting; 65 percent who had used the switch and even 35 percent of those who had never used it volunteered (i.e., without being given a list of choices) that the primary purpose of the switch was to prevent “children” from being exposed to a deployment. But they were not as well informed about what age children should not be exposed. Some thought that air bags were safe for 3- or 4-year-olds, while others worried they were unsafe for their 6’1” teen-aged children. Thus, the proportion of switches turned off declines gradually as the passengers get older, rather than dropping abruptly at age 13.[379]

Other factors that can result in switches being “off” for adults or “on” for children:[380]

- People who sometimes transport children may prefer to leave the switch “off” all the time, rather than try to change the setting each time an adult or child rides in the truck. They do not want to risk forgetting to turn it off for the child.
- Quite a few people turn the air bag off for older passengers. In fact, older passengers derive a significant net benefit from air bags (see above). The older occupant/air bag problem is short drivers who must sit close to the steering wheel, not passengers.
- Some adult passengers who “don’t like air bags” turn off the factory-equipped switches in pickup trucks, even though they would not incur the effort and expense to obtain aftermarket switches in other vehicles.
- With an adult in the RF seat and a child in the center-front seat, or vice-versa, the driver cannot optimally protect both.

[378] The survey included 29 RF passengers less than 1 year old and/or seated in a rear-facing child safety seat; 4 of the 29 switches were set “on.” In these four cases, the driver was not the owner of the truck, or mistakenly believed the switch was “off.” Not a single driver intentionally left the switch “on” in his or her own truck.
[379] *Ibid*., pp. vii, 10-13, 15-16 and 22-23.
[380] *Ibid*., pp. vi-vii, 10-13, and 20-21.

- People who borrow somebody else's truck may be unfamiliar with the switch or reluctant to change its setting.

Effect on fatalities: Manual on-off switches were a necessary and fairly successful interim measure that made it possible to offer life-saving passenger air bags in pickup trucks as early as 1996, while allowing the opportunity to protect infants and children from those air bags. Without the switches, passenger air bags might not have been feasible in pickup trucks or other vehicles without a full rear seat until the phase-in of automatic suppression or low-risk deployment technology in MY 2004 to 2007. Table 2-52 of this report estimates that the combination of passenger air bags and manual on-off switches in MY 1996-to-2011 pickup trucks had saved 453 adults by the end of CY 2012.

On the other hand, the combination of air bags and switches has not fully achieved the potential benefits it could accrue if they were always at the recommended setting. Table 2-52 estimates that 114 adults had died through 2012 because the switches were turned off.

Of course, the purpose of the switches is to protect infants and children from air bag deployments. On January 1, 2009, SCI had 6 cases of infants and children with fatal injuries from air bags in vehicles where the switch was left "on." Their ages ranged from 2 months to 8 years.[381] The statistical analysis of FARS data in Table 2-53, based on the estimated effects of air bags and the percentages of switches left "on," produces a similar estimate: it concludes that the combination of air bags and manual on-off switches may have resulted in a net increase of 8 child passenger fatalities from 1996 to 2012. Without the switches, air bags in these vehicles would have increased child passenger fatalities by a net 30; the public saved 22 of these potential fatalities by turning the switches "off." (As described in the preceding section, this statistical analysis, based primarily on crash data for vehicles with barrier-certified air bags, showed a significant increase in fatality risk for restrained children up to 5 years old and unrestrained children up to 10 years old and no significant effects for restrained children 6 to 12 years old or unrestrained children 11 to 12 years old.)

Thus, from 1996 to 2012, the combination of air bags and switches saved an estimated 453 adults in pickup trucks, with a net increase of 8 child passenger fatalities. Over the years, information and education campaigns have urged owners of pickup trucks to turn switches "off" for child passengers and leave them "on" for adults.

1998-99 redesign of frontal air bag (sled-certification)

History: Frontal air bags can harm occupants positioned near the air bag module at the time of deployment because the air bags reach peak force when they begin to deploy. Early designs of air bags involved a trade-off between supplying enough gas to absorb a substantial portion of the kinetic energy of a large, unrestrained person versus not exposing an out-of-position, nearby occupant to a highly forceful deployment. In the early 1980s, when belt use was less than 20 percent, the unrestrained occupant was a priority. FMVSS No. 208 included a 30 mph barrier-crash test with unrestrained dummies. By the mid-1990s, the majority of occupants were buckling up and injuries to out-of-position occupants had become an issue. NHTSA had long warned con-

[381] *Special crash investigations – Counts of frontal air bag related fatalities*.

sumers not to place an infant's rear-facing safety seat in the front seat of a vehicle equipped with passenger air bags, because the infant would be close to the air bag at all times. By late 1995, it was evident that not only infants, but also children and even some adults were injured by air bags. Statistical analyses showed a significant increase in overall fatality risk with air bags for children up to 12 years old. Children slid forward toward the air bag during pre-crash braking, especially if they were unrestrained or on the lap of another passenger. Short drivers often sat close to the air bag located in the steering wheel. Any occupant could approach an air bag by leaning forward, for instance, to adjust the radio or air-conditioning. By late 1995, NHTSA had identified 30 fatalities due to contact with barrier-certified air bags in otherwise survivable crashes (that number had grown to 264 fatalities due to contact with barrier-certified air bags by the beginning of 2009).[382]

In October 1995, NHTSA began a series of actions to reduce and eventually eliminate the adverse effect of air bags for infants, children and other high-risk occupants while retaining, to the largest extent possible, the great life-saving benefits of air bags for most people. Specifically, on March 19, 1997, NHTSA amended FMVSS No. 208, effective immediately (i.e., in time to allow implementation in MY 1998 or, at the latest MY 1999), relaxing some aspects of the frontal impact test for the unrestrained dummy in order to facilitate the introduction of "redesigned" air bags that deploy less forcefully. Instead of a barrier-crash test with an actual vehicle, manufacturers could use a sled test with a deceleration pulse stipulated in FMVSS No. 208, resembling the deceleration of a typical large passenger car in a barrier impact – i.e., relatively gradual.[383]

How air bags were redesigned: In approximately 84 percent of driver air bags and 70 percent of passenger bags, suppliers achieved less forceful deployments by literally "depowering" the air bags: removing some of the gas-generating propellant. Others replaced or supplemented the propellant with a cylinder of stored argon gas. The gas can be vented at different rates, depending on the occupant's belt use and the crash severity. The peak pressure and rise rate are two measures of how forcefully air bags deploy: upon sled certification, the peak pressure decreased by an average of 13 percent for both driver and passenger bags, while the rise rate decreased by an average of 24 percent on the driver's side and by 18 percent on the passenger side. The rearward extent of the deployment was abbreviated by reducing the volume of the air bag or by adding tethers to shackle its movement. Approximately 70 percent of new vehicles were sled-certified for the entire 1998 model year, and 99 percent by model year 1999.[384]

Effect on fatalities – drivers and RF passengers 13 and older: The second analysis in the section on frontal air bags compared the ratio of frontal-impact to non-frontal fatalities for drivers in vehicles equipped with barrier-certified air bags to drivers of vehicles without any air bags. The analysis found a statistically significant 20 percent risk reduction for barrier-certified air bags in the frontal impacts. The same method can be used to compare cars and LTVs of the first three

[382] *Ibid*.
[383] *Federal Register* 62 (March 19, 1997): 12960; *Code of Federal Regulations*, Title 49, Part 571.208 S13.
[384] Kahane, C. J. (2006, August). *An evaluation of the 1998-1999 redesign of frontal air bags*. (Report No. DOT HS 810 685, pp. 1-3 and 11-18). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810685.PDF.

sled-certified MY to the last three MY before sled-certification, based on FARS data from CY 1997 to 2004:[385]

Drivers of Cars and LTVs	Frontal (11-1 o'clock) Fatalities	Non-Frontal Fatalities	Frontal/Non-Frontal Risk Ratio
Barrier-certified	9,273	7,169	1.293
Sled-certified	7,629	5,911	1.291

Here, the frontal/non-frontal risk ratio for drivers is almost identical (0.2% difference) with barrier-certified and sled-certified air bags. For belted drivers, the risk ratio is 5 percent lower with sled-certified than with barrier-certified air bags; for unrestrained drivers, 5 percent higher. However, neither of these changes is statistically significant. For all RF passengers 13 and older the risk-ratio is 5 percent lower with sled-certified than with barrier-certified air bags; for belted RF passengers, 5 percent lower; for unrestrained passengers, 7 percent lower. None of these changes is statistically significant, either. In other words, sled-certified air bags preserved the life-saving benefits of barrier-certified air bags for drivers and for RF passengers 13 years and older.[386]

Effect on fatalities of RF passengers 12 and younger: The 191 confirmed SCI cases, reported as of January 1, 2009, of infants and children with fatal injuries from air bags in relatively low-speed crashes include 171 with barrier-certified passenger air bags, 20 with sled-certified air bags, and none with advanced air bags.[387] However, to quantify the effect of redesigning air bags, it is appropriate to compare fatality rates per million registration years for the same time period, specifically SCI-case fatalities per billion vehicle registration years of cars and LTVs in CY 1998 to 2003:

Calendar Years	Cars and LTVs	SCI Fatalities < 13 Years Old	Vehicle Years	SCI Fatalities per Billion Years
1998-2003	Barrier-certified	75	213,481,330	353.0
1998-2003	Sled-certified	15	243,523,549	61.6

This is an 83-percent reduction in child passengers' risk of sustaining fatal injuries from air bags. In other words, the redesign of frontal air bag did not completely eliminate such risk but reduced it dramatically. Because there is still some risk, NHTSA continued to recommend that children ride in the rear seat, if possible, until they turn 13 years old.[388]

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385 *Ibid*., p. 41.
386 *Ibid*., pp. xiii and 45-68.
387 *Special crash investigations – Counts of frontal air bag related fatalities.*
388 Kahane (2006, August), pp. 27-29.

The preceding analysis focused on SCI cases. A more general analysis is based on CY 1986-to-2011 FARS data and uses double-pair comparison, with driver fatalities as the control group. Child passengers' overall fatality risk was not significantly different between sled-certified air bags and no air bags in any of the three groups of vulnerable child passengers. That is quite a contrast to barrier-certified air bags, where fatality risk was significantly higher, sometimes much higher than with no air bags, for all three groups.

Tables 2-51, 2-53 and 2-54 of this report show that sled-certified air bags may have contributed to 32 child-passenger fatalities, but that number could have increased to 221 with barrier-certified air bags – i.e., redesigned air bags saved an estimated 189 child passengers.

Advanced frontal air bags (automatic suppression or low-risk deployment)

History and technology: On May 12, 2000, the agency added a section S14 to FMVSS No. 208 to phase in "advanced" frontal air bags from September 1, 2003, to September 1, 2006. GM full-size pickup trucks and SUVs, Honda Odyssey, and Acura MDX already certified to advanced air bags in MY 2003, one year before the phase-in. The options for advanced air bags are: that they do not deploy at all for children ("suppression"), deploy only at a low level of force ("low-risk deployment"), or track an occupant's motion and suppress the air bag if they are too close ("dynamic automatic suppression"). However, as of 2013, no vehicle employed dynamic automatic suppression. The predominant option is suppression, based on a weight sensor in the RF seat that automatically switches off the air bag unless it detects a mass greater than a predetermined threshold. Some manufacturers use weight sensors with two thresholds: suppression upon sensing low mass, low-risk deployment for an intermediate range of mass (e.g., a range that includes the average weight of a 6-year-old child), and normal deployment above that range. Air bags certified to comply with the S14 requirements of FMVSS No. 208 are formally called "certified-advanced compliant" air bags or, simply, "advanced" air bags.

During this timeframe, NHTSA also modified and in some cases strengthened selected performance requirements in FMVSS No. 208. The agency reinstated a barrier crash test with an unbelted 50th percentile adult male ATD (dummy), in place of the sled test; however, the maximum speed for that test is now in a range of 20 to 25 mph (as compared to the range of 0 to 30 mph in the original barrier test and the sled test with a 28-to-30 mph velocity change). NHTSA may conduct the test with a barrier that is perpendicular to the vehicle's line of travel or tilted at any angle up to 30° in either direction to simulate an oblique crash. For the first time, the standard tests performance for small-stature adults represented by a belted 5th percentile female Hybrid III ATD in a 30 mph perpendicular-barrier test. The test with the belted 50th percentile male ATD was upgraded from 30 mph to 35 mph, phasing in from September 1, 2007, to September 1, 2010. On August 31, 2006, the agency amended FMVSS No. 208 to likewise upgrade the test with the belted 5th percentile female from 30 mph to 35 mph, phasing in from September 1, 2009, to September 1, 2012. During the 2000s, in addition to designing to the amended regulations, manufacturers also introduced features to tailor deployments to the needs of the occupant. The features include multistage inflators to allow various alternative force levels for deployments, seat-belt use sensors that can influence whether or how forcefully the air bag should deploy, and seat-track sensors that can detect if an occupant is sitting close to the air bag.[389]

Effect on fatalities – drivers and RF passengers 13 and older: The analysis in the preceding section can be moved forward in time to compare cars and LTVs of the first three MY with advanced air bags to the last three MY that these make-models had sled-certified, but not yet certified-advanced compliant air bags. The data is FARS from CY 2003 to 2011. One change from the earlier analyses is that non-occupant fatalities (pedestrians and bicyclists struck and fatally injured by the vehicles in question) form the control group rather than non-frontal fatalities. This control group is preferable here, because many cars and LTVs were, at approximately the same time, receiving curtain or side air bags that reduce risk in non-frontal crashes, making those crashes not a true control group. The table here includes both drivers and RF passengers 13 and older:[390]

Drivers & RF Passengers of Cars and LTVs	Frontal (11-1 o'clock) Fatalities	Non-Occupant Fatalities	Frontal/Non-Frontal Risk Ratio
Sled-certified	3,004	1,348	2.229
Advanced frontal air bags	2,573	1,186	2.170

The frontal/non-occupant risk ratio is 2.7 percent lower with advanced air bags than with sled-certified air bags. It is not a statistically significant difference. That estimate comprises all drivers and RF passengers of cars and LTVs. The corresponding estimates for subgroups of the data are: cars, 6.7-percent fatality reduction with advanced air bags; LTVs, 2.5 percent increase; drivers, 3.6-percent reduction; RF passengers, 1.8-percent increase. None of those effects are statistically significant, either. In other words, advanced air bags preserved the life-saving benefits of sled-certified (and barrier-certified air bags) for drivers and for RF passengers 13 years and older.[391]

Effect on fatalities of RF passengers 12 and younger: As stated above, there is not a single SCI case of an infant or a child with fatal injuries from advanced frontal air bags in a relatively low-speed crash. This is evidence that the suppression and/or low-risk deployment features of advanced air bags have been highly effective for children, with one possible caveat: SCI investigations are triggered if a police agency or other person notifies NHTSA that a crash of interest has occurred. Child passenger fatalities involving air bags have become such rare events (thanks to the unprecedented educational effort to have children 12 and younger ride in the rear seats, as well as to sled-certified and advanced air bags) that the issue may have largely faded from public

[389] 49 CFR, Part 572.208 S14; *Federal Register* 65 (May 12, 2000): 30679, 71 (August 31, 2006): 57168; Greenwell, N. K. (2013, July). *Evaluation of the certified-advanced air bags*. (Report No. DOT HS 811 834, pp. 1-4). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811834.pdf; Bean, J.D., Kahane, C. J., Mynatt, M., Rudd, R.W., Rush, C.J., & Wiacek, C. (2009, September). *Fatalities in frontal crashes despite seat belts and air bags*. (Report No. DOT HS 811 202, p. 7). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/pubs/811102.pdf
[390] Greenwell (2013, July), p. 8.
[391] *Ibid*., pp. 9-16.

awareness. Reporting to SCI may have become less complete because the events have become so rare.

A more general analysis considers all child fatalities who are RF passengers in frontal impacts in CY 2004-to-2011 FARS – regardless of the source of the injuries (not specified in FARS), the severity of the impact, or whether the air bag deployed. There are 15 such fatality cases with sled-certified air bags, 12 with advanced air bags. The fatality rate per billion vehicle registration years is 218 with the sled-certified air bags, 207 with the advanced air bags. That is not a statistically significant difference. However, both of these rates are much lower than the 992 fatalities per billion registration years in CY 1998 to 2004 with barrier-certified air bags.[392] NHTSA continues to recommend that children up to age 12 ride in the rear seat if possible.

Table 2-54 of this report shows that advanced frontal air bags directly saved lives two ways: (1) If the child passengers in the crashes had instead been exposed to barrier-certified air bags there would have been an estimated 24 child-passenger fatalities; (2) By allowing the phase-out of manual on-off switches, advanced air bags have eliminated situations where the air bag was turned off for adult passengers, which could have resulted in 16 additional fatalities.

[392] Greenwell (2013, July), pp. 16-17; Kahane (2006, August), pp. 80-81.

FMVSS No. 212, "Windshield mounting"

This standard is associated with one safety technology that has been evaluated by NHTSA:

- **Adhesive windshield bonding**

FMVSS No. 212 is a performance standard requiring vehicles to retain not less than 75 percent of the windshield periphery (50 percent in vehicles with automatic occupant protection) after a 30 mph frontal barrier collision test.[393] The purpose of windshield retention is to prevent occupant ejection. FMVSS No. 212 took effect for passenger cars on January 1, 1970, two years after NHTSA's initial group of safety standards and it was extended to most LTVs, vans and multipurpose vehicles up to 10,000 pounds GVWR, effective September 1, 1978.[394]

Bonding of the windshield directly to its frame with adhesives gradually (1963 to 1983) superseded the earlier method of first enclosing the windshield in a rubber gasket and then attaching the gasket to the frame. Thus, the shift to adhesive bonding began in some vehicles well before anybody anticipated FMVSS No. 212, but rubber gaskets persisted in other make-models for quite a few years after the standard. Although rubber gaskets are generally a looser installation than adhesive bonding, they can be designed to meet FMVSS No. 212, as evidenced by the use of rubber gaskets in some post-standard vehicles well after 1970. However, NHTSA's evaluation estimates the effects and benefits of the shift from rubber gaskets to adhesive bonding in all make-models of passenger cars, regardless of whether the shift took place in that make-model before, on, or after the effective date of FMVSS No. 212.

How adhesive bonding works: Before 1963, windshields were sealed inside a rubber gasket or molding that, in turn, was attached and sealed to the frame. It was a relatively loose attachment. In low-speed impacts, the rubber gasket had some energy-absorbing "give." At higher speeds, the gasket could partly or completely tear away from the frame, beginning during the initial vehicle collision and deformation, and continuing as occupants impact the windshield. The advantages of gaskets are their durability, water- and sound-proofing, and perhaps, with pre-HPR windshields[395] (pre-1966), hope that windshields that "give" or "pop out" would be less prone to lacerate occupants. However, the important disadvantage of too loose an installation is that occupants are more likely to be ejected via the then-open windshield portal. Such ejections almost always follow partial or complete separation of the windshield bond. Hardly ever are occupants ejected through the glazing while the bond remains intact.[396]

In the early 1960s, General Motors found that butyl rubber tape could be used to attach windshields directly to the frame, making a firmer bond than rubber gaskets, apparently at lower cost, with acceptable durability, water- and sound-proofing. GM began using the tape on some 1963 Buick Specials and Oldsmobile F-85's and on all their domestic passenger cars by 1968, well before the FMVSS No. 212 effective date. In 1973, GM shifted from butyl tape to a polyurethane sealant, perhaps an even stronger adhesive bond. Ford began adhesive bonding in 1965 on full-

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[393] 49 CFR, Part 571.212.
[394] Kahane (2005, February), p. 3; *Federal Register* 33 (August 16, 1968): 11652, 41 (August 30, 1976): 36493, 42 (July 5, 1977): 34288.
[395] Please see the chapter on FMVSS 205, earlier in this report.
[396] Kahane (2005, February), pp. 8 and 11-17.

sized cars but continued using rubber gaskets on some car models through 1977; Chrysler started in 1969 but continued gaskets on some models through 1976. Obviously, the cars with rubber gaskets from 1970 onwards could and did meet FMVSS No. 212: the American rubber-gasket installation was hardly a "pop-out" windshield.[397]

Overseas manufacturers mostly continued to use rubber gaskets until the late 1970s. However, Volkswagen (and perhaps other German manufacturers) had loose enough bonds that specific actions were needed to comply with FMVSS No. 212. VW began to install continuous plastic clips between the gasket and the frame's pinchweld flange in 1970. It appears that Japanese manufacturers had shifted to adhesive bonding, or to a rubber gasket installation as tight as adhesive bonding by MY 1980, and European manufacturers at most a few years after that.[398]

Pickup trucks, vans and SUVs also kept rubber gaskets during most of the 1970s, and in many cases after FMVSS No. 212 was extended to LTVs (September 1, 1978). Manufacturers may have been especially concerned that operation on rough roads could accelerate deterioration of adhesive bonds, as compared to rubber gaskets.[399] Adhesive bonding was gradually phased in during approximately 1978 to 1985.[400] The final transition to adhesive bonding may have been spurred by anticipation of safety benefits, cost advantages with the second-generation sealants, and a 1976 rule allowing NHTSA to conduct the FMVSS No. 212 test in a wider range of temperatures, from 15 to 110° Fahrenheit: the performance of rubber gaskets can vary widely with temperature, adhesive bonding, less so.[401]

Expected benefits; concerns about a possible increase in lacerations: Windshields installed in domestic cars with adhesive bonding are expected to have a lower percentage of bond separation, in frontal crashes, at any speed, than windshields mounted with rubber gaskets in those domestic make-models. Similarly, German cars meeting FMVSS No. 212, with plastic clips between the rubber gasket and the frame, are expected to have less bond separation than pre-FMVSS No. 212 German cars also with rubber gaskets, but without the clips.

As a consequence, front seat occupants (drivers, RF passengers, and center front passengers) should have a significantly lower risk of ejection via the windshield portal – in domestic cars after the switch to adhesive bonding and in German cars after the addition of plastic clips to the rubber gaskets. Since an ejected occupant has substantially higher risk of fatality and serious in-

[397] Manuals published by National Auto Glass Specifications, Inc., are the definitive source of information on when make-models shifted to adhesive bonding; however, they do not list all make-models (*Ibid*., pp. 13-14). That necessitates assigning approximate dates for other make-models, based on more tentative sources.
[398] Mazda and Volvo used adhesive bonding from 1970 (*Ibid*., p. 14); Ebay offers extensive "windshield seals," "windshield gaskets," "windshield rubber" or "windshield weatherstrips" for domestic cars in model years when they had rubber gaskets, and for imported cars in the 1970s, but few after 1980; an analysis of NCSS data suggests that Japanese cars of the 1970s with rubber gaskets had about the same probability of ≥ 25% bond separation in frontal crashes as domestic cars with adhesive bonding.
[399] *Ibid*., p. 15.
[400] Richard Humphrey, while manager of GM's Washington Liaison Office for Safety Regulations, informed the author that GM phased adhesive bonding into their LTVs specifically during MY 1978 to 1985; Ebay offers rubber gaskets for a wide variety of LTVs up to approximately MY 1985, but after that only for SUVs with removable windshields (such as Jeep Wrangler).
[401] *Federal Register* 41 (August 30, 1976): 36493.

jury than a non-ejected occupant under the same crash conditions, that should result in a reduction of fatalities and serious injuries.[402]

Conversely, if adhesive bonding makes windshields less prone to "give" or "pop out" from occupants' head impacts by occupants, it is conceivable that facial lacerations could increase. Specifically, a 1968 statistical study by Fargo of cars with pre-HPR windshields showed significantly higher laceration rates with adhesive bonding than with rubber gaskets.[403] At that time, there were insufficient crash cases of cars with HPR windshields to compare laceration rates with rubber gaskets versus adhesive bonding.

Effect on windshield bond separation in crashes: NHTSA's 1985 analysis uses data from NCSS, a predecessor of NASS.[404] Investigators measured the percentage of bond separation and computed the delta V in actual towaway crashes. Linear regression calibrated the average percentage of bond separation in frontal impacts, as a function of delta V, by windshield installation method. For example, in frontal crashes with delta V = 30 mph, the average percentage of bond separation was:

Manufacturer	Windshield Installation Method	Pre or Post FMVSS No. 212?	Average Bond Separation at ΔV 30 mph (%)
U.S.-based[405]	rubber gasket	pre	22
		post	23
	butyl tape	pre	16
		post	15
	polyurethane	post	14
Germany[406]	rubber gasket	pre	59
		post	37

For cars manufactured in North America by U.S.-based companies, both types of adhesive bonding substantially reduced bond separation at 30 mph, relative to rubber gaskets. Within each method, separation rates were about the same before and after FMVSS No. 212. In German cars, the plastic clips added to the rubber gaskets in response to FMVSS No. 212 greatly reduced bond separation, although to a level that was still higher than pre-standard domestic cars. Similarly, at all other speeds, adhesive bonding reduced the percentage of bond separation in domestic cars, and the plastic clips reduced it in German cars.

[402] Sikora (1986).
[403] Fargo, R. B. (1968). *Windshield glazing as an injury factor in automobile accidents*. Buffalo: Cornell Aeronautical Laboratory.
[404] Kahane (1985, February), pp. 143-154; Kahane, Smith, & Tharp (1977).
[405] I.e., GM, Ford, Chrysler, or AMC (at the time of NCSS).
[406] I.e., cars manufactured in Germany for sale in the United States.

Effect on occupant ejection via the windshield portal: Combining the 1977-to-1979 NCSS data with the earlier 1968-to-1978 MDAI data generates a large file with information on the windshield installation method for each case vehicle. It specifies whether occupants were ejected and, if so, via what portal. For cars manufactured by U.S.-based companies, the rate of ejection via the windshield portal per 100 crash-involved front seat occupants was 68 percent lower with adhesive bonding than with rubber gaskets. However, after examining ejections via the windshield portal relative to a control group of ejections via other portals, the evaluation concluded that, more realistically, a 50-percent reduction of ejection via the windshield portal could be attributed to adhesive bonding. Similarly, for cars built in Germany for sale in the United States, the installation of plastic clips within the rubber gaskets reduced ejection via the windshield portal by an estimated 50 percent.[407]

Fatality reduction – passenger cars: The great advantage of preventing ejection is that, all else being equal, an occupant is safer remaining inside the vehicle than being ejected from it. Yet, not every ejection prevented is a life saved. A portion of ejectees would have sustained fatal injuries from interior components even if they had stayed within the car.[408] This is especially true of the windshield portal, where an estimated 70 percent of the fatally injured ejectees in the NCSS and MDAI data had already received mortal wounds from the steering assembly, instrument panel, windshield header and/or other components before the ejection, and would likely have died even if they had not been ejected. In other words, reducing ejection-fatality cases by 100 means saving 30 lives (the other 70 would still not survive). The 50-percent reduction of ejection attributed to adhesive bonding in cars built by U.S.-based companies and to plastic clips in German cars corresponds to saving 15 percent of the fatalities who were ejected via the windshield portal before these safety improvements. Using 1982 as the "baseline" year, the evaluation estimated that adhesive bonding would be saving 105 lives per year in cars built by U.S.-based companies and plastic clips, 7 lives per year in German cars by the time all cars built before these safety improvements had been phased out.[409]

Serious injury reduction – passenger cars: Likewise, 30 percent of the people ejected via the windshield portal who survived but sustained one or more serious, nonfatal AIS 3-to-5 injuries received all of these injuries after exiting the vehicle, while 70 percent suffered at least one such injury prior to the ejection. Thus, as above, a 50-percent reduction of ejection corresponds to a 15-percent injury reduction. Again using 1982 as the "baseline" year, the evaluation estimated that adhesive bonding would eventually save 160 people from AIS 3-to-5 injury per year in cars built by U.S.-based companies and plastic clips, 11 AIS 3-to-5 casualties per year in German cars.

Effect on lacerations – passenger cars: As stated above, if adhesive-bonded windshields "gave" less upon head impacts by occupants, facial lacerations could have increased. Fargo's 1968 study of pre-HPR windshields showed significantly higher laceration rates with adhesive bonding than with rubber gaskets and raised a worry this could persist with HPR windshields (1966 and later). NHTSA extensively analyzed crash data from NCSS, New York (1974) and Texas (1972 to 1974) on cars equipped with HPR windshields. Cars with adhesive bonding and

[407] Kahane (1985 Windshields), pp. 154-161.
[408] Sikora (1986).
[409] *Ibid*., pp. 161-163, 179-182 and 236-243; 90 percent confidence bounds for life-saving effectiveness: 7 to 22 percent; for lives saved in domestic cars: 35 to 175.

rubber gaskets had equally low rates of facial lacerations and other type of minor-moderate injuries involving windshield contact. Windshield penetration by occupant impact was no more common with adhesive bonding than with rubber gaskets. NHTSA concluded that adhesive bonding does not have any side effect of increasing minor-moderate injuries in cars with HPR windshields. Incidentally, the NHTSA analysis confirmed Fargo's finding that adhesive bonding was associated with higher injury rates in cars with pre-HPR windshields, now phased out except for occasional "historic" vehicles.[410]

Effectiveness – LTVs: NHTSA's 1985 evaluation only addressed the performance of windshield bonding in passenger cars. However, if the kinematics of occupant ejection via the windshield portal were similar in cars and LTVs, the estimated reduction (50%) for this type of ejection from cars might be appropriate for LTVs as well.

[410] *Ibid*., pp. 185-220.

FMVSS No. 213, "Child restraint systems"

FMVSS No. 225, "Child restraint anchorage systems"

These two standards work together to protect child passengers. FMVSS No. 213 regulates child safety seats, safety equipment that is not part of the vehicle. FMVSS No. 225 regulates vehicles, specifically the anchors whereby safety seats are secured in the vehicle. FMVSS No. 213 took effect on April 1, 1971, but FMVSS No. 225 did not begin to phase in until September 1, 1999. Four technologies to advance child passenger safety – by reducing fatality and injury risk and/or by making child passenger protection easier and more convenient – have been evaluated, or will be evaluated by NHTSA. A fifth "technology" that has always been available – riding in the rear seat – is not related to any particular FMVSS but will be discussed here because it has important benefits for child passengers:

- **Rear-facing and forward-facing child safety seats**
- **Upper tethers and anchorages (not yet fully evaluated)**
- **LATCH (lower anchors and tethers for children – not yet fully evaluated)**
- **Booster seats (not yet fully evaluated)**
- **Riding in the rear seat**

Child safety seats and booster seats are the basic protection systems for passengers who are too small to obtain full benefits from seat belts. Newborns start with rear-facing seats, graduate to forward-facing seats, booster seats and, finally, seat belts. Rear-facing and forward-facing child safety seats originally were secured in a vehicle at one place by a lap belt (or the lap and shoulder belt going through the same slot). The vehicle's lower anchors now offer a harder-to-misuse alternative to the vehicle's belts as a method of securing rear- and forward-facing seats in the vehicle. Forward-facing seats now have an upper tether, which can be used whether the child safety seat is installed with the vehicle belt or lower anchors, securing the top of the child safety seat at a second place, significantly reducing the tendency of these seats to move or rotate in crashes. Booster seats are typically secured by the lap and shoulder belt going around the child while seated and securing the child to the booster seat while at the same time securing the child and booster seat to the vehicle. The rear seat is intrinsically safer than the front seat, given equal safety equipment, because severe frontal impacts are more common than severe rear impacts and it is safer to sit further away from the point of impact.

FMVSS No. 213 "specifies requirements for child restraint systems … to reduce the number of children killed or injured." FMVSS No. 225 "establishes requirements for child restraint anchorage systems to ensure their proper location and strength for the effective securing of child restraints, to reduce the likelihood of the anchorage systems' failure, and to increase the likelihood that child restraints are properly secured and thus more fully achieve their potential effectiveness."[411]

[411] 49 CFR, Parts 571.213 and 571.225.

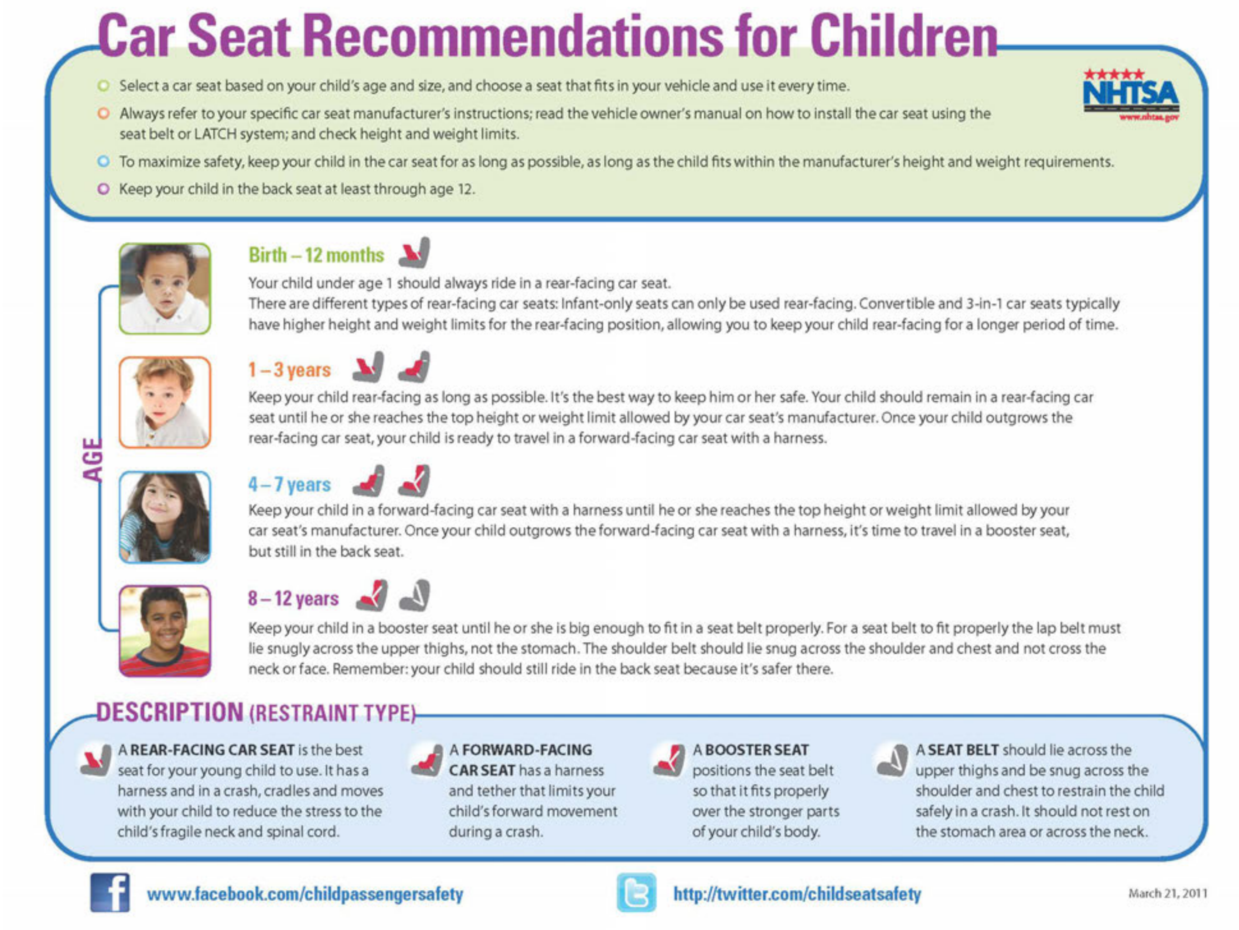
Rear-facing and forward-facing child safety seats

History: Early child seats and car beds, dating back to 1933, were designed for comfortable transportation, not crash protection. The first safety seats include the Ford Astro-Guard (1965) and Tot-Guard (1967) and the GM "Love" infant and child seats (1970). NHTSA issued FMVSS No. 213, effective April 1, 1971, to establish performance criteria for any device marketed as a "safety car seat," and to discourage the marketing of non-safety devices for use in vehicles. This version of FMVSS No. 213 required that safety seats be designed for attachment within a car by the car's seat belts, and it set limits for forward motion under a static load, but it did not include a dynamic test simulating a crash. By the mid-1970s, frontal 30 mph sled testing by the Consumers Union and others demonstrated that some seats offered substantially less protection than others. NHTSA revised FMVSS No. 213, effective January 1, 1981, incorporating the 30 mph test. The seat must remain structurally intact during the test, limit the forward motion of the dummy, and also limit the head injury criterion (HIC) to 1000 and chest acceleration to 60 g's on the 3-year-old dummy.[412]

How safety seats work: The goal of safety seats is to provide small children with the same protection, or better, that adults obtain from seat belts and the other safety equipment built into a vehicle. They are designed to keep children within the vehicle and close to their original seating position, prevent contacts with harmful interior surfaces or other occupants and provide "ride-down" by gradually decelerating the child as the vehicle deforms and absorbs energy. Key terminology is the "excursion" of the head and knee, the greatest distance that those parts of a dummy extend forward from the seat back at any time during the 30 mph test. Excursion is allowed by the looseness of the devices that secure the seat to the vehicle and the dummy within the seat, and by the tendency of seats to tilt or rotate during the test. Obviously, the less the excursion, the lower the probability of contacting any part of the vehicle interior.

There are three principal types of safety seats (or three modes of safety seat installation): rear-facing, forward-facing, and booster seats. The last type is discussed in a separate section of this chapter. It is important that the type of safety seat and its installation be appropriate for a child's weight and height. Children should not "graduate" to the next type of seat until their weight and/or height exceeds the limit specified by the seat manufacturer for that mode of use. Information on child safety seats is available at www.safercar.gov/parents/CarSeats.htm on NHTSA's web site. The following chart was available at www.nhtsa.gov/DOT/NHTSA/Traffic%20Injury%20Control/Articles/Associated%20Files/4StepsFlyer.pdf as of June 2014:

[412] Radovich, V. G. (1983). Development of infant and child restraint regulations and their application. *SAE Child Injury and Restraint Conference Proceedings*. (Paper No. 831655, Publication No. P-135, pp. 101-111). Warrendale, PA: Society of Automotive Engineers; Kahane, C. J. (1986, February). *An evaluation of child passenger safety: the effectiveness and benefits of safety seats*. (Report No. DOT HS 806 890, pp. 2-4). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/806890.PDF; *Federal Register* 35 (September 23, 1970): 14778, 44 (December 13, 1979): 72131; Consumer Reports.(1972, August). *Consumer Reports*, *37*, p. 484.



Rear-facing seats are recommended from birth until an infant or child reaches a manufacturer-specified weight or height limit for that child restraint. The safety seat is like a cushioned compartment that holds the passenger in a semi-recumbent position, with the head higher than the torso. Since the seat faces rearwards, the passenger's entire body presses into the cushion during a frontal crash, and rides down with the vehicle. That is the safest way to absorb the passenger's kinetic energy, since force is not concentrated on one part of the body. It minimizes the risk of neck injury, to which infants are especially vulnerable. In side impacts, the passenger presses against cushions on the side of the seat. A small harness keeps the passenger within the seat in rollovers, rear impacts or multiple impacts. A rear facing seat is secured to the vehicle by connecting the lower anchor attachments of the child safety seat to the vehicle's lower anchors at the seating position or, alternatively, by the vehicle's seat belt. A rear-facing seat must never be exposed to a deploying air bag, because the front of the seat is directly in the path of the deploying air bag. Rear-facing seats must be placed in the rear seat. If that is impossible but the vehicle has a manual on-off switch for the air bag, that switch must be turned off; if the vehicle has advanced frontal air bags, it will automatically suppress the deployment or keep it at a low-risk level of force.

Forward-facing child seats are recommended after a child exceeds the weight or height limit for the rear-facing seat he or she has been using and until he or she reaches the manufacturer-specified weight or height limit for that forward-facing seat. The safety seat is like an armchair. The child sits up in it; the child's head and torso are protected in back and, to some extent, on each side by the seat's shell and cushion; the child's legs hang down over the edge of the seat. Typically a 5-point harness, fitting over both shoulders, hips and abdomen, restrains the child in rollovers, frontals and side impacts, without concentrating force on one part of the body. The back of the seat and its cushion protect the child from whiplash in rear impacts.

Until August 31, 2002, the vehicle's lap belt secured the safety seat to the vehicle. Belts were routed through the frame of the child seat, as specified by the manufacturer, or less frequently around the seat and the child. Beginning September 1, 2002, child safety seats must have lower attachments for use in new vehicles equipped with LATCH anchorages, but must also be securable by lap belts in older vehicles. Effective January 1, 1981, FMVSS No. 213 limited forward head excursion to 32 inches and knee excursion to 36 inches on the 30 mph frontal test, measured from the seatback pivot point (at the lower-rear edge of the seatback). Those levels are sufficient to prevent contact with interior surfaces in an average-sized passenger car. As of September 1, 1999, FMVSS No. 213 has further limited head excursion to 720 mm (28.35 inches), providing an additional margin of safety. All forward facing child seats in the market are equipped with an upper tether to meet the limited head excursion requirement. Before that, some seats were equipped with upper tethers on a voluntary basis dating back to 1970. The advantage of the upper tether is that it reduces the tilting or rotation of the seat during a crash, because it is firmly attached to the vehicle at the top as well as the bottom.

FMVSS No. 213 also sets numerous other requirements for seats, including a limit of 1000 HIC and 60 chest g's on the 3-year-old dummy and maintenance of structural integrity in the 30 mph test, clear labeling of instructions for their use, convenient seat registration, and a requirement that the force needed to open harness buckles is in a range that adults can conveniently open them but small children cannot open them.[413]

Safety seat use trends: In 1979, NHTSA's first national survey indicated that 45 percent of infants less than 1 year old and 9 percent of toddlers 1 to 4 years old rode in some kind of child "seat." Half of these "seats" were not secured by the car's belt, hardly protecting the child (many of them were probably not safety seats designed to FMVSS No. 213). However, Tennessee had recently become the first State with a child passenger protection law, effective January 1, 1978. Rhode Island followed in 1980, West Virginia in 1981 and ten States in 1982. By June 1, 1985, every State and the District of Columbia had a law to protect child passengers. In NHTSA's 19-City Study, safety seat use rose quickly during the 1980s, exceeding 80 percent for infants and toddlers by the end of the decade. By 2002, NOPUS showed that 99 percent of infants less than a year old and 94 percent of toddlers 1 to 4 years old were in some kind of restraint (not necessarily age-appropriate or correctly used). In 2009, the corresponding rates were 98 percent of infants and 96 percent of toddlers 1 to 3 years old. Many of the laws initially allowed children to "graduate" too early from safety seats to the vehicle's belts, but as of 2011, 48 States and the District

[413] 49 CFR, Part 571.213 S5.1.3. and Figure 1B; Kahane (1986, February), p. 3.

of Columbia require children to be in a safety seat or booster seat at least up to their sixth birthday.[414]

Safety seat misuse: For full benefits, safety seats should be installed correctly in the vehicle and children properly harnessed within the seat. Misuse is a potential problem because there are many styles of seats, and the mode of use can also vary by the age of the child, the type of vehicle, or even by seating position within the same vehicle. NHTSA's evaluation of child passenger safety reviewed 957 observations during 1984 of children less than 5 years old riding in safety seats:[415]

- 40 percent of the seats were correctly used, exactly as recommended by the manufacturer or very close to that.
- 18 percent were "grossly" misused: the seat was not secured to the vehicle by a belt or tether and/or the seat's harness or shield was not used. In a crash, the child would immediately become a projectile and derive little or no protection from the seat.
- 42 percent were "partially" misused, substantively differing from the method recommended by the manufacturer. Depending on the type of misuse, effectiveness could be slightly or seriously degraded. Typical misuse modes include:
    - Incorrectly routing the lap belt through/around the frame, where the frame is weaker or where it will allow more excursion.
    - Using a seat in the forward facing mode for an infant who should be in a rear-facing seat.
    - Not attaching the upper tether, if one is available.

NHTSA, other government and private organizations and the safety-seat manufacturers have made an effort to design seats that are easy to install and use correctly, to provide clear instructions that are prominently displayed on the seat, and to establish a national network of instructors who can advise people about the type of seat they need for their child and their vehicle, and show them how to install it correctly. The public may find an instruction station close to their home at www.nhtsa.gov/apps/cps/index.htm.

A 2002 survey of safety seats in actual use by 5,527 child passengers showed that gross misuse of seats had greatly decreased since 1984, but misuse of safety seats remained a problem. Approximately 2 percent were not secured by the vehicle's belt and 3 percent did not have the safe-

[414] Lawless, E. W., & Siani, T. A. (1983). The state of the art of child passenger safety legislation in North America. *SAE Child Injury and Restraint Conference Proceedings*. (Paper No. 831650, Publication No. P-135, pp. 229-242). Warrendale, PA: Society of Automotive Engineers; Kahane (1986, February), pp. 4-5; Phillips (1980, May); Phillips (1983, May); Perkins, Cynecki, & Goryl (1984, July); Goryl & Cynecki (1985, March); Goryl (1986, May); Goryl & Bowman (1987, March); Bowman & Rounds (1988, August); Bowman & Rounds (1989, June); Datta & Guzek (1990, June); Datta & Guzek (1991, July); Datta & Guzek (1992, March); NHTSA. (2000). *Traffic safety facts 1999 – Children*. (Report No. DOT HS 809 087, p. 5). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/99Children.pdf; Glassbrenner, D. (2003, February). *The use of child restraints in 2002*. (Report No. DOT HS 809 555). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809-555.pdf; Pickrell, T. M., & Ye, J. Y. (2010a, September). *The 2009 National Survey of the Use of Booster Seats.* (Report No. DOT HS 811 377). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811377.pdf; *Traffic safety facts 2011*, pp. 186-193.

[415] Kahane (1986, February), pp. 30-47, especially p. 45.

ty seat's harness connected (a big reduction from 18 percent gross misuse in the earlier survey). Misrouting of the vehicle's belt, once quite common, had decreased to about 3 percent or less. On the other hand, the majority of seats showed some type(s) of misuse, especially loose or mis-positioned harnesses, loose belts, and/or use of the seat in a mode inappropriate to the age or size of the child (e.g., too-early graduation to the forward-facing mode).[416]

Initial results from NHTSA's 2011 national survey of safety seats in actual use by 4,167 child passengers suggest the four most frequent installation mistakes were: (1) Use of the wrong harness slot; (2) The harness retainer or chest clip incorrectly positioned or not used at all; (3) Loose safety-seat installation (more than two inches of side-to-side or front-to-back movement); (4) Loose harness strap (more than two inches of slack).[417]

Expected benefits: Here are hypotheses for what might be expected in statistical analyses of effectiveness. Qualitatively, correctly used safety seats ought to have the same types of benefits for child passengers that seat belts have for adults. Quantitatively, we might expect even higher effectiveness, because safety seats might do a better job preventing child passengers' contacts with the vehicle interior than seat belts do for adults, and because their typically 5-point harnesses will more evenly spread forces than a lap-shoulder belt. Conceptually, misuse of safety seats could diminish the observed, "as used" effectiveness in crash data – i.e., because the restrained population includes the actual mix of correctly-used and misused seats, effectiveness might be lower than if all children were correctly restrained. It is unclear how large a factor that might have been in recent years, when few seats were grossly misused. "As used" effectiveness can increase over time if the proportion of correctly used seats increases.

Fatality reduction – passenger cars: In 1984, at about the same time that Evans developed the "double-pair comparison" method to estimate belt effectiveness, Partyka at NHTSA independently developed essentially the same method to estimate safety seat effectiveness. NHTSA expanded and updated the analysis in its 1986 evaluation, in 1988, and finally in 1996. The last study provides NHTSA's current estimates of the "as used" fatality reduction by child safety seats. It is based on 1988-to-1994 FARS data. The analysis of safety seats resembles the procedures used to estimate the effectiveness of seat belts, especially rear seat belts (see the FMVSS No. 208 chapter). For example, in cars with unrestrained drivers, the fatality ratio of unrestrained children to their drivers is compared to the fatality ratio of children in safety seats to *their* drivers. "Safety seat users" include those that FARS reported in "child safety seats" or "child safety seats used improperly." Since the percentage of seats "used improperly" is far lower in FARS than in observational surveys, a substantial but unknown percentage of the children that FARS merely reported "in safety seats" were also in improperly used seats. Thus, the two groups have been combined to provide an overall, "as used" effectiveness estimate. For infants less than 1

[416] Decina, L. E., & Lococo, K. H. (2004, January) *Misuse of child restraints*. (Report No. DOT HS 809 671, pp. 33-34). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/Research/Human+Factors/Seatbelt+and+Child+Seat+Use.

[417] (2012, September). *Traffic safety facts research note: National child restraint use special study*. (Report No. DOT HS 811 679). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811679.pdf

year old, safety seats reduced overall fatality risk by a statistically significant 71 percent. For toddlers 1 to 4 years old, the seats reduced fatality risk by a statistically significant 54 percent.[418]

The preceding "as used" estimates include misused seats. In 1983, the Tennessee Highway Patrol estimated that correctly used safety seats could reduce fatality risk by 71 percent. The estimate was not based on statistical analysis comparing fatality rates of restrained and unrestrained children, but on a detailed case-by-case analysis of 51 unrestrained fatalities, judging what would have happened if the children had been protected by safety seats. This estimate is not used in the model to compute lives saved (Part 2 of this report), because it is not based on a statistical analysis and because the FARS data does not have detailed information on the correct use of safety seats. Nevertheless, it continues to appear plausible, especially given that the preceding "as used" estimates including misused seats are not much lower.[419]

Over the years, a modest proportion of toddlers 1 to 4 years old, especially at the higher ages have only been restrained by the vehicle's belts, not by a safety seat (e.g., 2% of toddlers in 1977 to 1979, 3% in 1991, and 8% in 2009).[420] The restraint is essentially a lap belt only, for even if the seat is equipped with a 3-point belt, the shoulder harness will not fit across the torso of a child that small, and it will offer little protection. NHTSA urges that children under 4'9'', and certainly children less than 5 years old not be restrained with belts alone, but with a FMVSS No. 213 seat appropriate to their weight and height. Nevertheless, belts have some benefits for children under 5. NHTSA's 1986 evaluation, based on a double-pair comparison analysis of 1975-to-1984 FARS data, estimates that lap belts reduce fatality risk of toddlers 1 to 4 years old by 33 percent. That is substantially lower than the 54 percent "as used" effectiveness of the actual mix of correctly used and misused safety seats, let alone the effectiveness of correctly used safety seats. It is about the same as the effectiveness of lap belts for adults (27% in the front seat and 32% in the rear seat – see the FMVSS No. 208 chapter).[421]

Fatality reduction – LTVs: NHTSA's 1996 study also showed statistically significant fatality reductions for child safety seats in LTVs. For infants less than 1 year old, safety seats reduced overall fatality risk by 58 percent. For toddlers 1 to 4 years old, the reduction was 59 percent. The study showed a 48-percent fatality reduction by lap belts for toddlers 1 to 4 years old. This is the same as the estimated effectiveness of lap belts for adults in the front seat.[422]

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[418] Evans (1986a); Partyka, S. C. (1984b). *Restraint use and fatality risk for infants and toddlers*. Washington, DC: National Highway Traffic Safety Administration, National Center for Statistics and Analysis; Kahane (1986, February), pp. 140-163; Partyka, S. C. (1988b). *Lives saved by child restraints from 1982 through 1987*. (Report No. 807 371). Washington, DC: National Highway Traffic Safety Administration; Hertz, E. (1996, December). *Revised estimates of child restraint effectiveness*. Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/96855.PDF. (This is a summary report that does not show the detailed analyses, but they are set up the same way as in Partyka's 1988 report).

[419] (1983). *51 young lives*. (HSL Report No. No. DOT HS 034 896). Nashville, TN: Tennessee Highway Patrol; Kahane (1986, February), pp. 96-99.

[420] Phillips (1980, May), p. 33; Datta & Guzek (1992, March), p. 29; Pickrell & Ye (2010a, September) shows 4 percent use for 1-to-3 year olds (p. 20) and 20 percent for 4-year-olds (p. 6).

[421] Kahane (1986, February), pp. 161-164; this data is entirely before 1986 – i.e., before State buckle-up laws began to bias belt-use reporting in FARS.

[422] Hertz (1996, December).

Fatality reduction – recent findings: In 2013, NHTSA released estimates of fatality reduction by child safety seats (combining rear-facing, forward-facing, and booster seats), based on FARS data from 1995 to 2009. The analysis method is a double-pair comparison, similar to the analysis by Hertz. Fatality reduction is estimated for all types of crashes; also, separately for frontal impacts without rollover and for side impacts without rollover. The analysis combines crash data for cars and LTVs, producing a single estimate.[423]

Crash Type	Child's Age	Fatality Reduction (%)
All crashes	less than 1 year	71
	1 to 3 years	57
	4 to 7 years	58
Frontal impacts (w/o rollover)	less than 4 years	53
	4 to 7 years	43
Side impacts (w/o rollover)	less than 4 years	42
	4 to 7 years	51

The analysis shows statistically significant fatality reductions for children in each age group – in all crashes, in frontal impacts, and in side impacts. The overall fatality reduction for infants less than a year old (71%) and toddlers 1 to 3 years old (57%) are quite similar to the Hertz results (71% in cars and 54% in LTVs for infants, 54% in cars and 59% in LTVs for toddlers 1 to 4 years old). The new results also suggest that safety seats are about equally effective for 1-to-3 year olds (57%) and 4-to-7 year olds (58%).

Injury reduction – passenger cars: NHTSA's 1986 evaluation furnished three sets of estimates of injury reduction by safety seats in passenger cars. In a file that combined all available detailed investigations of crashes selected by probability sampling – the 1974-to-1975 RSEP, the 1977-to-1979 NCSS, the 1979 pilot test of NASS at the NCSS sites, and the 1979-to-1983 NASS – the rate of fatal or hospitalizing injuries per 100 children less than 6 years old involved in towaway crashes was 56 percent lower for children in safety seats than for unrestrained children. The reduction was statistically significant. However, it is an overestimate of the overall "as used" effectiveness, because these investigators classified children in grossly misused seats as "unrestrained." If they had been classified as safety seat users, injury reduction would have been an estimated 46 percent in 1984.[424]

An analysis of 1981-to-1983 Pennsylvania crashes computed injury rates per 100 children, adjusting for the child's age and seating position. Compared to unrestrained children, safety seats reduced fatal-and-serious (K + A) injury risk by 43 percent, moderate-to-fatal (K + A + B) injury risk by 45 percent, and overall (K + A + B + C) injury risk by 31 percent. Here, too, many chil-

[423] Sullivan, L. K., Louden, A. E., & Echemendia, C. G. (2013, December). *Child restraint side impact test procedure development*. (Docket No. NHTSA-2014-0012-0002, pp. 1-4). Washington, DC: National Highway Traffic Safety Administration.
[424] Kahane (1986, February), pp. xxxiv and 201-214.

dren in grossly misused seats may have been classified as "unrestrained." The 1986 report concludes that K + A + B injury reduction would have been closer to 37 percent if they had all been classified as safety seat users.[425]

As part of the 1986 evaluation, NHTSA conducted 36 frontal or oblique-frontal sled tests, each with 3 or 4 3-year-old dummies, at speeds ranging from 11 to 35 mph. Dummies were unrestrained, or in safety seats of four different types – correctly used, grossly misused, or in various modes of partial misuse. NHTSA calibrated the probability of hospitalizing head or torso injury as a function of speed for the unrestrained dummy – and various seat types/use modes. A mathematical model computed overall effectiveness from the calibrated relationships. Correctly used, the various types of safety seats reduced the risk of hospitalizing injuries in frontal crashes by an average of 61 percent, relative to the unrestrained dummy. The average effectiveness of the partially misused seats was 38 percent. Not surprisingly, the dummies in grossly misused seats had the same injury risk as unrestrained dummies. When correct use, partial misuse and gross misuse were weighted by their frequency of occurrence in the observational survey, the average "as used" effectiveness of safety seats in frontal crashes was 40 percent.[426]

Injury reduction – LTVs: NHTSA has not statistically analyzed the injury reduction by safety seats for children who are occupants of LTVs. However, given that the analysis by Hertz showed quite similar fatality-reducing effectiveness for safety seats in cars and LTVs, it seems possible that their injury-reducing effect in LTVs might also be similar to their effect in cars.

Upper tethers and anchorages (not yet fully evaluated)

LATCH (lower anchors and tethers for children – not yet fully evaluated)

On March 5, 1999, NHTSA published a final rule amending FMVSS No. 213 to require safety seats to have lower anchorage attachments and a means (such as a top tether on a forward-facing seat) to meet more stringent excursion limits. The final rule also established FMVSS No. 225 to require motor vehicles to have anchorages for attaching the child safety seat lower anchorage connector and tether hook. On forward-facing child safety seats (with a few exceptions), testing with upper tethers with reduced excursion requirements became effective on September 1, 1999, and testing with installation using lower attachments became effective on September 1, 2002. In motor vehicles, the phase-in of upper tether anchorages extended from September 1, 1999, to September 1, 2000, and the lower anchorages from September 1, 2000, to September 1, 2002. A vehicle with three or more designated forward-facing rear seating positions is required to have tether anchorages in at least three of those positions and lower anchorages in at least two of those positions. The objectives of the regulation are to secure seats more tightly in the vehicle, make their installation easier and more uniform, and reduce the probability of misuse.[427]

Forward-facing safety seats with upper tethers have been available dating back to 1970. Upper tethers reduce the tilting or rotation of the seat during a crash, because they provide a second attachment of the seat to the vehicle (in addition to the lap belt or lower anchor attachments). Sled

[425] *Ibid*., pp. xxxiv and 169-184; rates were adjusted for age and seating position by multidimensional contingency table analysis.
[426] *Ibid*., pp. 235-305, especially p. 301.
[427] *Federal Register* 64 (March 5, 1999): 10786; 49 CFR, Parts 571.213 S5.9 and 571.225 S4.

testing shows unequivocally that tethered seats, when correctly used, have less head excursion than other types. However, observational surveys showed that most seats did not have tethers, and among those that did, only 15 percent of tethers were attached in 1984, in part because many vehicles did not have tether anchorages. FMVSS No. 225 requires vehicles to have tether anchorages; forward-facing child safety seats have been equipped with upper tethers ever since the more stringent excursion limits of FMVSS No. 213 went into effect.[428]

The method of securing a rear-facing or forward-facing safety seat by the vehicle's seat belts can vary considerably from seat to seat and from vehicle to vehicle, creating opportunities for misuse. The fit of the belts is often loose, especially if the seat should be secured with an additional locking clip to prevent spooling of the belt, but the locking clip is not used. The lower anchors of the LATCH system – the lower anchor in the vehicle and attachment on the rear-facing or forward-facing safety seat – establishes an alternative, more uniform attachment system that does not rely on the seat belt or on a locking clip. Lower anchor installation is an alternative but it does not supplant the earlier method of securing safety seats with the vehicle's seat belts; either method, carried out per instructions, is satisfactory.

In 2005, NHTSA conducted a survey of 1,121 children from birth to age 4 in child safety seats riding in the rear seats of vehicles to observe how seats were installed and used and to ask the drivers about their knowledge and opinions of LATCH.[429] Key findings were:

- 55 percent use of upper tethers (for forward-facing safety seats at seating positions equipped with upper anchors) – much higher than the 15 percent in 1984;
- 60 percent use of lower anchors (for rear-facing and forward-facing safety seats at seating positions equipped with the anchors – i.e., 40 percent were still attached with the belts, even though anchors were available);
- In 13 percent of the observations, the child safety seat was placed in a seating position in the vehicle not equipped with lower anchors and where the seat belt was the only way to secure the child safety seat to the vehicle;
- 81 percent of the drivers who used the upper tether to attach the safety seat said the tethers were easy to use; 74 percent of drivers who used lower anchors said they were easy to use;
- 75 percent of drivers who had used lower anchors on some occasions and seat belts on other occasions to attach safety seats preferred the anchors; and
- 61 percent of upper-tether nonusers and 55 percent of lower-anchor nonusers cited their lack of knowledge – not knowing what they were, that they were available in the vehicle,

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428 Bayer, A. R., Jr., & Peterson, B. S. (1978). *Child restraint systems testing*. (Report No. DOT HS 803 408). Washington, DC: National Highway Traffic Safety Administration; Kelleher, B. J., & Walsh, M. J. (1978). Sled Test Comparisons of Child Restraint Performance. *Twenty-Second Stapp Car Crash Conference*. (Paper No. 780903). Warrendale, PA: Society of Automotive Engineers; Kelleher, B. J., Walsh, M. J., Dance, D. M., & Gardner, W. T. (1983). An experimental study of the effects of child restraint improper installation and crash protection for larger size children. *SAE Child Injury and Restraint Conference Proceedings*. (Paper No. 831602, Publication No. P-135, pp. 31-51). Warrendale, PA: Society of Automotive Engineers, 1983; Radovich (1983); Kahane (1986, February), pp. xliv, 30-47 and 106-134.

429 Decina, L. E., Lococo, K. H., & Doyle, C. T. (2006, December). *Child restraint use survey – LATCH use and misuse*. (Report No. DOT HS 810 679). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810679.PDF.

the importance of using them, or how to properly use them - as the reason for not using them.

NHTSA is analyzing the results of a follow-up survey to find out if consumers have become more familiar with LATCH as these systems have become more widespread in the vehicle fleet. The agency also intends to analyze crash data to see if upper tethers have made forward-facing safety seats more effective.

Booster seats (not yet fully evaluated)

Booster seats are recommended after a child exceeds the weight or height limit for the forward-facing seat he or she has been using and until he or she reaches the manufacturer-specified weight limit for that booster seat or a height of 4’9’’. Booster seats essentially raise the child up high enough that the vehicle’s manual 3-point belt fits over one shoulder and diagonally across the thorax, as it would for an adult. The lap portion of the 3-point belt should fit snugly around the hips. When the 3-point belt is thus correctly positioned, it should provide greater benefits for these children than a seat belt alone without the booster seat. Some booster seats also have their own shields or 5-point harnesses for use by children at the lower end of the weight range. Some booster seats have their own seat backs, while others use the vehicle’s seat back.[430]

Booster seats have been available to the public since 1981, but early use rates were low.[431] During the mid-1990s, NHTSA and the safety community increased emphasis on protecting children who had outgrown forward-facing seats but were not yet tall enough for optimum results with a 3-point belt. In January 1996, FMVSS No. 213 began to use a dummy simulating a 6-year-old child to test seats with higher weight limits, such as booster seats; starting 2005, the dummy had to be the Hybrid III type.[432] The TREAD Act of 2000 and Anton’s Law of 2002 have provisions to enhance occupant protection for children in this age group. On February 27, 2012, NHTSA issued a final rule amending FMVSS No. 213 with specifications for a 10-year-old dummy to test seats designed for children weighing over 65 pounds.[433] Over the years, most of the States amended their child passenger protection laws to increase the age when a child may graduate from a safety seat to seat belts alone. As of 2011, 7 State laws require the use of a safety seat for children up to and including 8 years old and 20 State laws require the use of a safety seat for children up to and including 7-year-olds.[434]

NHTSA plans to evaluate the fatality-reducing effectiveness of booster seats, based on FARS data, by the same method it used for rear-facing and forward-facing safety seats. There is not yet sufficient data for the analysis because FARS only began coding booster seats as a separate category of restraint use in 2008; furthermore, FARS relies on State crash data for information and many States have not yet begun or only recently began to classify booster seats as a separate category.

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[430] NHTSA. (2005, September). *A parent’s guide to buying and using booster seats*. (Report No. DOT HS 809 503). Washington, DC: National Highway Traffic Safety Administration. Available at buckleup.mt.gov/docs/nhtsa-guide-buying-boosters.pdf.
[431] Kahane (1986, February), pp. 64-68.
[432] *Federal Register* 60 (July 6, 1995): 35126; *Federal Register* 69 (July 16, 2004): 42595.
[433] *Federal Register* 77 (February 27, 2012): 11651.
[434] *Traffic safety facts 2011*, pp. 186-193.

However, in 2010, NHTSA released preliminary statistical analyses of nonfatal injury rates, based on data through 2007 from three States that pioneered reporting of booster seats as a separate category: Kansas, Nebraska and Washington. Among 4-to-8 year olds there is evidence of reduced risk of injury when restrained by booster seats rather than just by 3-point belts. The estimated magnitude of this effect is a 14-percent reduction in risk of any type of injury for the booster seats relative to the 3-point belts. Conversely, among 3- and 4-year-olds there is some evidence of increased risk of injury with booster seats rather than with the more age-appropriate forward-facing seats, although there is not enough data to draw statistical conclusions.[435] Until NHTSA is able to analyze FARS data on booster seats, the agency will assume that their fatality reduction for 5-to-8 year olds is about the same as the effectiveness of forward-facing seats for 1-to-4 year olds. NHTSA's most recent analysis of FARS, although the data did not yet permit analyzing booster seats as a separate category from rear-facing or forward-facing seats, does show that the fatality reduction for safety seats (whatever type they may have been) is about the same for 1-to-3 year old and 4-to-7 year old children (57% and 58%, respectively).[436]

Safety benefits of riding in the rear seat

Why the rear seat can be safer: The closer the occupant sits to the point of impact, the greater the risk of fatal injury. That is because fatal crashes often result in severe damage, but rarely to the entire vehicle. They can demolish the portion of the passenger compartment closest to the impact, while the furthest portion remains nearly intact. A frontal impact is twice as dangerous for front seat occupants as rear seat occupants, whereas a rear impact is twice as dangerous for the rear seat occupants.[437] But this is not a trade-off. High-speed frontal impacts are far more common than high-speed rear impacts, resulting in greater overall fatality risk to front seat occupants:

- Collisions with fixed objects are usually frontal impacts, unless the vehicle has yawed out of control, and even then they are rarely rear impacts.
- When two vehicles collide, usually at least one of them and sometimes both have frontal damage, but rear-to-rear collisions are rare.
- Head-on collisions often involve a dangerous closing speed because the two vehicles are moving in opposite directions; rear impacts are often of low severity because both vehicles are moving in the same direction.

For example, during 2011, there were 10,770 occupants of cars and LTVs fatally injured in frontal impacts and only 1,113 in rear impacts.[438] A second advantage for the unrestrained rear seat occupant in a frontal crash is that he or she will contact the back of the front seat, a more benign surface than the steering assembly, instrument panel, or windshield header contacted by the unrestrained front seat occupant. This advantage may be lost to some extent if both occupants are correctly restrained. Nevertheless, a rear seat occupant, restrained or unrestrained, ought to

[435] Sivinski, R. (2010, July). *Booster seat effectiveness estimates based on CDS and State data*. (Report No. DOT HS 811 338). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811338.pdf.
[436] Sullivan, Louden, & Echemendia (2013, December), pp. 1-4.
[437] Evans (1991), pp. 47-51.
[438] *Traffic safety facts 2011*, p. 109.

have lower fatality risk than a front seat occupant **with the same safety equipment**. On the other hand, for many years, the front seat has been the first place to get new safety equipment (3-point belts, pretensioners, and load limiters), and sometimes the only place (frontal air bags, as of June 2014).

Fatality reduction: Evans analyzed fatality risk of passenger car occupants 16 or older by seating position, based on FARS data from 1975 to 1985, when almost no cars were equipped with air bags and 94 percent of the fatally injured occupants were unrestrained. He demonstrated that unrestrained drivers and adult RF passengers of passenger cars had almost exactly the same fatality risk in a crash. In other words, in crashes where both seats were occupied by people of the same age and gender, the ratio of driver to RF passenger fatalities was 1:1. But outboard rear seat occupants had 26 percent lower fatality risk than drivers and RF passengers of the same age and gender. Center rear seat occupants had 37 percent lower fatality risk than drivers and RF passengers: the center rear seat has an additional safety advantage, because it is far away from the sides as well as the front of the car.[439]

Children, too, can be substantially safer in the rear seat. In NHTSA's 1986 evaluation, double-pair comparison analyses of 1975-to-1984 FARS data showed that an unrestrained child less than 5 years old had 27 percent lower fatality risk in the rear seat than in the front seat. For a child in a safety seat, the fatality risk was 20 percent lower in the rear seat than in the front seat: not as large an effect as for the unrestrained child, but still substantial.[440]

These benefits persisted in later vehicles without air bags. Three NHTSA publications in 1996 and 1997 cite an analysis of 1988-to-1994 FARS data showing that both restrained children and unrestrained children experienced a 26 [or 27] percent reduction in fatality risk in the rear seat relative to the front seat.[441]

The following analysis of MY 1981-to-1995 passenger cars without air bags in 1991-to-1999 FARS data supplies more detailed results. Children of all ages and adolescents, restrained as well as unrestrained, obtained a substantial benefit for riding in an outboard rear seat rather than the RF seat, and an even larger fatality reduction if they traveled in the center rear seat. Specifically, children up to 12 years old, both restrained and unrestrained, experienced statistically significant fatality reductions close to 30 percent for moving from the RF seat to an outboard rear seat, and close to 45 percent for moving from the RF seat to the center rear seat:

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[439] Evans (1991), pp. 47-51; Kahane (2000, December), p. 6.

[440] Kahane (1986, February), pp. xxxiv and 164-167; in the double-pair comparison, the fatality ratio of children to their drivers is compared for children in the front seat and children in the rear seat.

[441] Hertz (1996, December); *Federal Register* 62 (November 21, 1997): 62406, Footnote 23; *Air bags & on-off switches*; the supporting analysis is not available, and it is unknown if it included children < 5 years old or < 13 years old, or if it was limited to passenger cars or included LTVs.

CARS WITHOUT AIR BAGS	Fatality Reduction Relative to Right Front Seat (%)			
	Outboard Rear Seat		Center Rear Seat	
Age Group	Restrained	Unrestrained	Restrained	Unrestrained
0 – 4	36	26	46	29
5 – 12	29	36	47	59
0 – 12	**33**	**31**	**46**	**47**
13 – 15	11	30	49	44

Barrier-certified frontal air bags have made it much more important for children to ride in the rear seat, less so for adolescents and adults. The benefits of frontal air bags for RF passengers 13 and older narrowed the difference between the front and rear seats for those groups. But children are much safer in the rear seat, without air bags, than in the front seat of a car with barrier-certified air bags. For example, barrier-certified air bags with 1990s technology were estimated to increase the fatality risk of an infant RF passenger in a rear-facing safety seat by a factor of approximately 5½ (see the FMVSS No. 208 chapter). Thus, the fatality reduction for moving that infant to the rear seat is not merely 36 to 46 percent, as shown in the above table, but close to 90 percent. Similarly, barrier-certified air bags may have increased the fatality risk of a toddler in a forward-facing safety seat by approximately 70 percent; that toddler will be 62 percent safer in an outboard rear seat and 68 percent safer in the center rear seat than in the RF seat.[442] Redesigned frontal air bags starting in 1998 greatly reduced these extra risks and advanced air bags even more, but children, especially the younger ones, continue to be substantially safer in the rear seat. Double-pair comparison analyses of MY 1991-to-2004 cars and LTVs equipped with frontal air bags in 1991-to-2003 FARS data showed lower fatality risk in the rear seat than in the front seat for child passengers up to age 12 in frontal impacts; moreover the risk was lower in each age group: less than 6, 6 to 8, and 9 to 12 years old.[443]

More children are riding in the rear seat: Since the mid-1990s, NHTSA, the manufacturers and the safety community have campaigned to inform the public about the hazard of air bags to children and the need for children to ride in the rear seat of vehicles with air bags. A national "Air Bag and Seat Belt Safety Campaign," for example, was launched in 1986. These campaigns

[442] For example, if the fatality risk of an infant in the RF seat of a car without air bags is 1, the risk with air bags is 5.5; the risk in the center rear seat is 1 - .46 = .54; the reduction is 1 - .54/5.5 = 90 percent.
[443] Kuppa, S., Saunders, J., & Fessahaie, O. (2005, June). Rear seat occupant protection in frontal crashes. *Proceedings of the Nineteenth International Technical Conference on the Enhanced Safety of Vehicles*. (Paper No. 05-0212). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/pdf/esv/esv19/05-0212-O.pdf.

make it clear that the rear seat is the safest place for a child in all vehicles, including those without air bags.[444]

The public has responded. Substantially fewer children less than 8 years old rode in the front seat in 2001 than in 1995. NHTSA analyzed State crash data from Florida, Maryland and Utah for 1995 to 2001. The distribution of seating positions of the 363,579 child passengers in these mostly low-severity crashes is probably about the same as in the general, non-crash-involved traffic stream. In 2001, only 8 percent of 0-to-3 year-old infants and toddlers still rode in the front seat, down from 26 percent in 1995 and the proportion of 4-to-7 year-old children in the front seat decreased to 19 percent from 33 percent. However, the proportion of 8-to-12 year-old children in the front seat only declined to 35 percent from 39 percent.[445]

When a child is the only passenger in the vehicle, the driver may be reluctant to have the child ride alone in the rear seat. But even here, there were dramatic changes between 1995 and 2001 for children 7 or younger (but not for 8-to-12 year olds). Fewer children are riding in the front seat, not only in vehicles with passenger air bags, but even in vehicles without air bags:

Vehicles With Only One Passenger, a Child 12 or Younger

		Percent in Front Seat		
		Age < 4	Age 4-7	Age 8-12
All vehicles				
	1995	52	78	88
	2001	17	43	79
Vehicles with dual air bags	1995	49	75	88
	2001	14	36	76
Vehicles without air bags	1995	52	78	88
	2001	22	54	84

Furthermore, NHTSA is pleased to report that the percentage of children riding in the rear seat did not decrease after the introduction of advanced frontal air bags in 2003 to 2007. Conceivably, some parents might mistakenly believe that the deployment-suppression features of advanced air

[444] (2006, October). *National Safety Council honors Air Bag & Seat Belt Safety Campaign for lifesaving achievements*. Itasca, IL: National Safety Council. Available at www.nsc.org/Pages/NationalSafetyCouncilHonorsAirBagandSeatBeltSafetyCampaign.aspx; *Air bags & on-off switches*.

[445] Kindelberger, J., & Starnes, M. (2003, November). *Moving children from the front seat to the back seat: The influence of child safety campaigns*. (Report No. DOT HS 809 698). Available at www-nrd.nhtsa.dot.gov/Pubs/809-698.pdf.

bags have eliminated all concerns about the safety of the front seat – whereas, as explained above, the rear seat can be a safer place for child passengers for numerous reasons besides air bags. A statistical analysis of CY 2004-to-2010 crash data from Florida, Georgia, Michigan, New York State, Washington State, and Wisconsin shows that the percentage of children sitting in the rear seat is nearly identical for vehicles with advanced air bags and earlier vehicles with redesigned, but not certified-advanced air bags.[446]

[446] Greenwell (2013, July), pp. 22-23.

FMVSS No. 214, “Side impact protection”

This standard is associated with three vehicle modifications whose safety benefits have been evaluated by NHTSA:

- **Side door beams**
- **TTI(d) improvement in passenger cars by structure and padding**
- **Curtain and side air bags**

Before 1969, the side doors of passenger cars were nearly empty shells of sheet metal, and offered little protection to occupants in side impacts. Side door beams, running longitudinally inside the door, were a first step to provide some crush resistance and structural strength, but they were not enough to resist a high-speed impact by another vehicle. NHTSA, the manufacturers and the safety community researched additional structural improvements to resist crush and they designed padding to cushion the occupant. They developed a dynamic crash test, a dummy, and an injury criterion called TTI(d) – thoracic trauma index (dummy) – to measure how well a vehicle protects its occupants. Side air bags provide additional cushioning for the occupant’s thorax and pelvis; they further improve TTI(d) performance. Curtain air bags and side air bags with head protection cushion the occupant’s head in side impacts.

The second paragraph of FMVSS No. 214 says, “The purpose of this standard is to reduce the risk of serious and fatal injury … in side impact crashes by specifying strength requirements for side doors [and] limiting the forces, deflections, and accelerations measured on anthropomorphic dummies in test crashes.”[447] First, FMVSS No. 214 set strength requirements for doors, effective January 1, 1973, in passenger cars and extended to pickup trucks, vans, buses and SUVs up to 10,000 pounds GVWR, effective September 1, 1993. Next, it added a dynamic crash test requirement, phased in for passenger cars from September 1, 1993, to September 1, 1996, and effective for LTVs up to 6,000 pounds GVWR on September 1, 1998. Most recently, it added a crash test of a 20 mph side impact with a pole, with phase-in scheduled from September 1, 2010, to September 1, 2014.

Side door beams

History: During the 1960s, the manufacturers conducted research and tests to improve side impact protection. Hedeen and Campbell at GM developed side door beams, and the company also developed a static test for measuring a door’s crush resistance. The beams were installed in MY 1969 full-size GM cars. The test procedure became SAE Recommended Practice J367 in March 1970, but it did not specify pass-fail criteria. NHTSA announced its intention to regulate side door strength with an ANPRM in October 1968, followed by several NPRMs. The final rule issued in October 1970, with an effective date of January 1, 1973, built upon the SAE practice and added pass-fail criteria. A rigid steel cylinder is gradually forced into the middle of the door. The top of the cylinder is nearly level with the bottom of the window and the bottom of the cylinder is 5 inches above lowest point of the door. The cylinder must encounter an average crush resistance of at least 2,250 pounds during the first 6 inches of crush, an average of 3,500 pounds over the first 12 inches, and a peak of at least 7,000 pounds or twice the vehicle’s curb weight

[447] 49 CFR, Part 571.214.

(whichever is less) somewhere in the first 18 inches. Most domestic cars were equipped with the beams at some point during MY 1969 to 1973 and, of course, all cars had them after January 1, 1973 (mid-MY 1973).[448]

LTVs, with their higher sills and more rigid construction, are more robust than cars when they are hit in the side by another vehicle, but they share cars' vulnerability in side impacts with fixed objects. As part of its effort to bring safety requirements for LTVs up to the same level as cars, NHTSA extended the static strength test of FMVSS No. 214 to LTVs, effective September 1, 1993. Most LTVs received side door beams in MY 1994, but a few make-models in MY 1991, 1992 or 1993.[449]

What they are and how they work: The side door beam "is a metal bar of channel design, typically 8 inches wide and with channels 2 inches deep. It is located inside [each side] door, close to the outside surface, about 10 inches above the sill. It runs the length of the door, being attached to the door frame vertical members at the hinge and latch ends of the door. … In some vehicles, the beam is accompanied by a beam cover, stiffener … mounting flanges … [and/or] a local reinforcement of the B-pillar at the floor level."[450] "Channel design" resembles fluting or corduroy, running from the front to the rear of the beam, and it is a feature that adds strength to metal structures. In MY 1979 to 1981, the weight of the beams ranged from 5 to 7 pounds per door in 4-door cars, and 10 to 21 pounds per door in 2-door cars.[451]

In a direct side impact by another vehicle, the front of the striking vehicle will push the door structure of the struck vehicle inwards until it hits the occupant's torso at close to that vehicle's original impact speed. Injury risk is high under these circumstances. Therefore, any additional structure in the struck vehicle that engages the striking vehicle is welcome. By putting some crush on the front of the striking vehicle and/or transmitting force to the remainder of the struck vehicle and accelerating it sideways, the structure can reduce the amount of intrusion toward the occupant, slow down the rate of that intrusion, and possibly reduce the risk of serious injury.

Whereas any added strength is welcome, it is obvious that a 5-to-21 pound beam, stretching from one end of the door to the other without much support in the middle, has limited power to resist a severe and perpendicular impact into the middle of the door by a 2,000-to-5,000 pound vehicle. The 10-inch gap between the beam and the sill is an additional weak point. The beams might be somewhat effective in lower-speed impacts. NHTSA's 1982 evaluation found that side door

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[448] Kahane, C. J. (1982, November). *An evaluation of side structure improvements in response to Federal Motor Vehicle Safety Standard 214*. (Report No. DOT HS 806 314, pp. 100-108). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/806314.PDF; Hedeen, C. E., & Campbell, D. D. (1969). *Side impact structures*. (Paper No. 690003). New York: Society of Automotive Engineers; *Federal Register* 33 (October 5, 1968): 14971, 33 (December 11, 1968): 18386, 35 (January 21, 1970): 813, 35 (April 23, 1970): 6513, 35 (October 30, 1970): 16801; SAE. (1971). *1971 SAE Handbook*. New York: Society of Automotive Engineers, pp. 962-963.

[449] Walz, M. C. (2004, February). *Evaluation of FMVSS 214 side impact protection for light trucks: Crush resistance requirements for side doors*. (Report No. DOT HS 809 719). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809719.PDF; *Federal Register* 56 (June 14, 1991): 27427.

[450] Kahane (1982, November), p. 106.

[451] *Ibid*., p. 380.

beams reduced the depth of maximum crush from an average of 10 inches to 8 inches in compartment-centered towaway impacts by another vehicle.[452]

A hypothesis is that the beam might be especially effective when the impact has a strongly frontal component of force, especially in typical side impacts with fixed objects where a vehicle is traveling forward and skidding off the road at the same time. The side of the vehicle contacts the pole or tree, but the direction of force is oblique frontal. Rather than merely absorbing energy, the beam acts like an internal "guard rail" to deflect the vehicle and allow it to slide past the pole or tree, with a longer, shallower crush pattern and, ultimately, a lower delta V. Furthermore, the simultaneous contact of the fixed object with the high beam and the low sill, rather than just the sill, keeps the vehicle upright and reduces the risk of damage to the "greenhouse" area of the occupant compartment (above the window sills). Indeed, NHTSA's 1982 evaluation showed that side door beams significantly changed damage patterns in side impacts with fixed objects. The ratio of the maximum depth of crush to the width of crush decreased from .24 to .15. There was less damage to the occupant compartment and more to the fenders. There was less greenhouse damage. Integrity of the side doors was better preserved.[453]

Expected benefits: Given the effects of side door beams on damage patterns and severity, it would not be a surprise if beams were found to reduce fatalities in single-vehicle crashes, but not in multivehicle crashes. They might reduce nonfatal injuries in the less severe multivehicle crashes. Since the beams affect the overall damage pattern to the vehicle in single-vehicle crashes and help reduce the severity of the crash, the reduction in delta V might benefit the far-side as well as the near-side occupants. Because there is a beam in every side door on a vehicle, drivers, front seat passengers and rear seat passengers can benefit.

Fatality reduction – passenger cars: NHTSA's analysis, published in 1982, was based on 1975-to-1981 FARS data.[454] This data is best suited for comparing overall fatality risk of occupants of outboard seats (i.e., next to a door: drivers; right front, left rear, and right rear passengers) in side impacts, before and after the installation of side door beams, relative to a control group of fatalities in frontal impacts. In one analysis, the data encompassed cars of the first 2 MY with beams (e.g., 1969 and 1970 Chevrolet Impala, 1973 and 1974 Chevrolet Nova) versus cars of the same or equivalent make-models in the last two MY before beams (e.g., 1967 and 1968 Chevrolet Impala, 1971 and 1972 Chevrolet Nova). Frontal crashes are an acceptable control group because there were few innovations that affected fatality risk in frontal impacts during those model years; specifically, every car in the analysis was equipped with energy-absorbing steering assemblies. The 1975-to-1981 FARS statistics for fatalities in single-vehicle crashes were[455]:

[452] *Ibid*., p. 301.
[453] *Ibid*., pp. 33-43 and 281-329.
[454] *Ibid*., pp. 22-25 and 143-182.
[455] *Ibid*., p. 157.

SINGLE-VEHICLE CRASHES	Side-Impact Fatalities	Frontal Fatalities	Risk Ratio
Last 2 MY before beams	2,505	4,325	.579
First 2 MY with beams	2,137	4,303	.497

This is a statistically significant 14-percent fatality reduction in single-vehicle side impacts with side door beams: 1 – [(2,137/2,505) / (4,303/4,325)] = .143.[456]

Analyses by other techniques confirmed the 14-percent fatality reduction.[457] Effectiveness was nearly identical in near-side impacts (14%) and far-side impacts (15%). When "single-vehicle side impacts" were limited to collisions with a single fixed object (and impacts by trains, rollovers with principally side damage and complex off-road excursions were excluded), effectiveness rose to 23 percent.[458]

Using 1980 as the "baseline" year, the evaluation estimated that side door beams would eventually save 480 lives per year in single-vehicle crashes of passenger cars, when all cars on the road were equipped with them. When NHTSA subsequently added the dynamic crash test and, later, the pole test to FMVSS No. 214, resulting in possible further modification of side structure as well as addition of padding or air bags, the agency still retained the static test requirement, in part, to assure that, whatever the benefits of the new requirements, the already existing benefits of side door beams in single-vehicle crashes would also be preserved.[459]

By contrast, none of the analyses showed a statistically significant effect for side door beams on fatalities in multivehicle crashes. Point estimates were close to zero.

Fatality reduction – LTVs: Similar analyses were performed with 1989-to-2001 FARS data to estimate the effect of side door beams in LTVs, where they were introduced in MY 1994 or shortly before that. In single-vehicle side impacts, side door beams reduced fatality risk by a statistically significant 19 percent. The reduction was larger in near-side impacts (25%) than in far-side impacts (11%). Using 1999 to 2002 as the "baseline" years, the evaluation estimated that side door beams would eventually save 151 lives per year in single-vehicle side impacts of LTVs, when all LTVs on the road have the beams.[460]

This evaluation, too, did not show a statistically significant effect for side door beams on fatalities in multivehicle crashes. Point estimates by all analysis methods were close to zero.

Injury reduction – passenger cars: NHTSA's 1982 evaluation used data NCSS, the predecessor of NASS. The injury rate – the number of fatal or hospitalizing injuries per 100 occupants involved in side-impact towaway crashes – was computed for cars with side door beams and

[456] 90 percent confidence bounds: 7 to 21 percent.
[457] Other techniques included: limiting the data to the first year with beams and the last year without them; regression of the ratio of side to frontal fatalities by beam status, vehicle age and other factors.
[458] *Ibid*., pp. 157 and 354.
[459] *Ibid*., pp. 385-388; 90 percent confidence bounds: 300-660.
[460] Walz (2004, February); 95 percent confidence bounds for effectiveness: 4 to 32 percent; for lives saved per year: 22-285.

compared to the rate in cars without the beams. These injury rates were controlled for belt use, rural/urban, speed limit, frame or unibody construction, or other factors by multidimensional contingency table analysis, a predecessor of the logistic regression method widely used today. Also, in some analyses, the data was limited to cars produced 2 (or 5) MY just before and after the make-model was equipped with the beams.[461]

In single-vehicle side impact crashes, the analyses showed a statistically significant 25-percent reduction of fatal or hospitalizing injuries for side door beams.[462]

At the nonfatal level, beams were also effective in some multivehicle crashes. When a vehicle was struck in the side by another vehicle and the damage was centered in the occupant compartment area, side door beams reduced near-side occupants' rate of hospitalizing injuries by a statistically significant 25 percent. But for far-side occupants in all multivehicle crashes, and for near-side occupants when the damage was not centered on the compartment, the effect of side door beams was close to zero.[463]

Using 1980 as the "baseline" year, the evaluation estimated that side door beams would prevent 4,550 nonfatal hospitalizations per year in single-vehicle crashes and 4,920 in multivehicle crashes when all cars on the road are equipped with the beams. That adds up to 9,470 nonfatal hospitalizations prevented per year.[464]

Injury reduction – LTVs: NHTSA has not analyzed the effect of side door beams on nonfatal injuries in LTVs. Databases such as NCSS or NASS-CDS with detailed information on nonfatal injuries have considerably fewer side-impact cases for LTVs than for passenger cars.

TTI(d) improvement in passenger cars by structure and padding

History of the FMVSS No. 214 upgrade: By the late 1970s, if not earlier, researchers suspected that side door beams alone were insufficient to significantly attenuate intrusion in a severe side impact by another vehicle and reduce fatality risk to the near-side occupant of the struck car. At a public Side Impact Conference on January 31, 1980, NHTSA outlined its plans to upgrade FMVSS No. 214 with a dynamic test.[465]

Unlike the early FMVSS that largely incorporated other organizations' test procedures and existing safety technologies, the FMVSS No. 214 upgrade necessitated many years of research, anal-

[461] Kahane (1982, November), pp. 183-266; Kahane, Smith, & Tharp (1977).
[462] Kahane (1982, November), pp. 12 and 25-33; 90 percent confidence bounds: 11 to 35 percent.
[463] *Ibid*., pp. 10, 12, 25-33 and 186; 90 percent confidence bounds: 6 to 38 percent; damage to the side of a car is "centered on the compartment" if the centerpoint of the damage (CRASH program parameter D) is in a range from 15 inches behind to 45 inches ahead of the longitudinal centerpoint of the car.
[464] *Ibid*., pp. 15, and 388-397; 90 percent confidence bounds: 4,300 to 14,700 hospitalizations prevented.
[465] NHTSA. (1980). *Side impact conference*. (Report No. DOT HS 805 614). Washington, DC: National Highway Traffic Safety Administration.

ysis and testing by NHTSA and the safety community to develop comprehensive and self-sufficient science:[466]

- A review of crash data, indicating that the archetypal side impact fatality in the 1980's involved a fast-moving car striking a slow-moving car in the door, at a right angle: a typical intersection collision.
- A review of injury data, indicating that a large proportion of the nearside occupants' life-threatening injuries occurred when the sides of their torsos contacted the interior side surface (most frequently the door) of the car. (Head injuries are also a frequent cause of fatalities in side impacts, but were not the principal focus of this rulemaking; they are addressed by FMVSS No. 201 and by curtain air bags.)
- The thoracic trauma index (TTI) was found to be an excellent predictor of thoracic injury severity in experimental side impacts to cadavers.[467] TTI = ½ (GR + GLS), where GR is the greater of the peak accelerations of either the upper or the lower rib, expressed in g's and GLS is the lower spine (T12 vertebra) peak acceleration. Pelvic g's are an additional injury criterion, but TTI is the key predictor of life-threatening injuries.
- Development of a side impact dummy (SID) on which TTI (as well as pelvic g's) can be reliably measured in a side impact test configuration. The injury score measured on the dummy is called TTI(d).
- A moving deformable barrier (MDB) was developed to represent a generic 3,000-pound passenger vehicle. The test procedure simulates a MDB moving 30 mph hitting, at a right angle, the door area of a subject vehicle, traveling 15 mph. (It is accomplished by having the MDB travel at 33.54 mph at an angle of 63° with respect to the longitudinal centerline of a stationary test vehicle. The wheels of the MDB are "crabbed" 27° toward the rear of the test vehicle to obtain a right-angle contact.[468])
- Testing various production MY 1980-to-1988 passenger cars to learn the baseline distribution of TTI(d). Some baseline testing continued after the final rule was issued in 1990, up to MY 1993, just before the phase-in period for the MDB test requirement.
- Two technologies were demonstrated that, singly or in combination could significantly reduce TTI(d) from its baseline levels in production vehicles:
    - **Structure** modifications such as substantially strengthening pillars, sills, roof rails, seats or cross-members of a car, and stronger overlap between doors and pillars, sills, etc., to slow down and reduce the extent of door intrusion into the passenger compartment.

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[466] Kahane, C. J. (2007, January). *An evaluation of side impact protection – FMVSS 214 TTI(d) improvements and side air bags*. (Report No. DOT HS 810 748, pp. 11-12). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810748.PDF.

[467] (1990). *Final regulatory impact analysis - New requirements for passenger cars to meet a dynamic side impact test FMVSS 214*. (NHTSA Report No. DOT HS 807 641). Washington, DC: National Highway Traffic Safety Administration.

[468] The goal is to simulate a typical 90° intersection collision in which the full front of a fast-moving vehicle (the MDB) hits the side of a slower-moving vehicle. A crash test with two moving vehicles would be quite complicated; instead, the same effect is achieved by having the side-impacted test vehicle stationary and the MDB towed into the test vehicle. The MDB must be towed at an oblique angle to the test vehicle to obtain the correct resultant direction of force. In order to have the flat front of the MDB hit the side of the test vehicle, the MDB cannot be pointed in the direction it travels but has to be tilted toward one side and advance diagonally. This is called "crabbing" because some species of crabs walk that way.

- Energy-absorbing foam **padding** in the door cavity positioned to interact with an occupant's thoracic region can cushion the impact forces the thorax.

- Regulatory analysis[469] to estimate the lives saved by decreasing TTI(d) to various levels, and the extent of vehicle modifications needed to secure those levels.

On October 30, 1990, NHTSA issued the final rule amending FMVSS No. 214 to phase in a dynamic test of side impact protection during MY 1994 to 1997. FMVSS No. 214 recognizes the greater difficulty of protecting occupants in 2-door cars: it allows TTI(d) up to 90 in 2-door cars, but limits 4-door cars to 85. FMVSS No. 214 also includes test limits on pelvic g's and has door retention requirements to reduce occupant ejection. At least 10 percent of passenger cars produced between September 1, 1993, and August 31, 1994, had to meet the standard; at least 25 percent of cars produced between September 1, 1994, and August 31, 1995; at least 40 percent of cars between September 1, 1995, and August 31, 1996; and all cars after September 1, 1996. During that phase-in period, manufacturers declared ("certified") what make-models complied with FMVSS No. 214. NHTSA advised the public on what models were certified.[470]

The dynamic test requirement of FMVSS No. 214 has also applied to LTVs up to 6,000 pounds GVWR since September 1, 1998; TTI(d) may not exceed 85 (same as 4-door cars).[471] NHTSA has little evidence that LTVs required or received substantial modifications in structure or padding to meet FMVSS No. 214. The relatively high, rigid floors of these vehicles, plus the side door beams already in them (see above) were usually adequate for compliance with the dynamic test. Statistical analyses of crash data did not show any significant fatality reductions after the dynamic test requirement went into effect for LTVs. Thus, the remainder of this section focuses on passenger cars.[472]

Voluntary improvements before MY 1994: The development of FMVSS No. 214 from 1980 to 1993 was an iterative process with feedback between NHTSA and the manufacturers, and extensive public participation. Manufacturers could test TTI(d) in their existing vehicles and compare it to levels proposed for FMVSS No. 214 or achieved by competitors in tests by public organizations.

TTI(d) in 2-door cars averaged 110 for those MY 1981-to-1990 cars that were tested and the results made public. It ranged as high as 131. Manufacturers had voluntarily improved to an average 97 by MY 1993, the year before the phase-in for FMVSS No. 214 – much closer to, but still somewhat above the 90 allowed by the future standard. The best score among the tested pre-standard 2-door cars was 82. There was relatively less improvement in 4-door cars: from 80 in MY 1981 to 1990 down to 74 in MY 1993; furthermore, even the earlier average is better than the 85 eventually permitted by the future standard. Two-door cars are intrinsically more vulnerable than 4-door cars in side impacts, because the door of a 2-door car is usually much longer than the front door of a 4-door car. Impacting vehicles are less likely to strike pillars, more likely to hit the long, weakly supported door area between pillars. In any case, manufacturers took steps to

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469 *Ibid*.
470 *Federal Register* 55 (October 30, 1990): 45752; *NHTSA hails safety features in model year 1994 passenger cars and light trucks and vans*, Press Release No. NHTSA 38-93, U. S. Department of Transportation, Office of the Assistant Secretary for Public Affairs, Washington, 1993.
471 *Federal Register* 60 (July 28, 1995): 38749.
472 Kahane (2007, January), pp. 33-34 and 63-65.

redesign some of the worst performers, especially among 2-door cars, before FMVSS No. 214 took effect. For example, one manufacturer ran a cross member across the A-pillars through the dash, reinforced the B-pillar at the sill level and added some floor stiffeners.[473]

Improvements from MY 1994 to 1997: In MY 1997, the average TTI(d) of 2-door cars was 72 and of 4-door cars, 64. These averages are well below (better than) the requirements of FMVSS No. 214 (90 and 85, respectively) and the average levels in MY 1993 (97 and 74). After 1997, TTI(d) stayed about the same in cars without side air bags.[474]

Structural modifications and padding were the principal technologies used to meet FMVSS No. 214 before side air bags. The manufacturers provided NHTSA with detailed lists and diagrams showing what changes were made to achieve compliance during the phase-in period. The information suggests that make-models accounting for approximately 56 percent of new cars received substantial structural modifications, usually accompanied with padding; 27 percent of the fleet received padding only, or padding with minor structural modifications; whereas 17 percent of cars remained essentially unchanged from previous years, implying that even the pre-1994 models of these cars could have met FMVSS No. 214.[475]

NHTSA also reviewed TTI(d) test results for pre-standard vehicles to post-standard compliance tests of the same make-models. Specifically, the agency identified 15 relatively high-sales make-models (eight 2-door cars and seven 4-door cars) that substantially improved TTI(d) from an earlier to a later MY. TTI(d) improved by an average of 23 units. The statistical analysis of the effect of TTI(d) improvement after MY 1993 is based on these 15 make-models.[476]

Fatality reduction – passenger cars: NHTSA's 1999 and 2007 evaluations both try to estimate the percentage fatality reduction given a 1-unit improvement in TTI(d). The 1999 evaluation is based on crash data for pre-standard vehicles of MY 1980 to 1992, whereas the 2007 evaluation concentrates on 15 make-models that substantially improved TTI(d) after 1993. The earlier result is used to estimate the effect of TTI(d) improvement when TTI(d) is in a range of 90 or more, while the latter serves to estimate the effect when TTI(d) is in the range below 90.[477]

The 1999 evaluation used a cross-sectional approach, rather than a "before-after" analysis, to estimate the benefit of TTI(d) improvements. It compared the side-impact fatality risk of cars with good TTI(d) scores for their body type (namely, < 102 for 2-door cars and < 78 for 4-door cars) to cars with poor scores for their body type (namely, > 115 for 2-door and > 95 for 4-door). At that time NHTSA had TTI(d) scores for 43 pre-standard (MY 1980 to 1992) make-model-MY combinations, 17 of which were 2-door cars and 26 were 4-door. The evaluation gathered 1980-to-1998 FARS cases of outboard front seat occupant fatalities in each of these 43 make-model-MY combinations, including cars from earlier/later model years and corporate "twins" of essen-

[473] Kahane, C. J. (1999, October). *Evaluation of FMVSS 214 - Side impact protection: Dynamic performance requirement; Phase 1: Correlation of TTI(d) with fatality risk in actual side impact collisions of model year 1981-1993 passenger cars*. (Report No. DOT HS 809 004, pp. vii, 6 and 19-23). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809004.PDF.
[474] Kahane (2007, January), pp. 17-29.
[475] Kahane (1999, October), pp. vii and 139-143.
[476] Kahane (2007, January), pp. 35-46, especially Table 2-1a on p. 40.
[477] *Ibid*., pp. 65-68.

tially identical design. "Side-impact fatality risk" is the ratio of occupant fatalities in side impact crashes (where the principal impact is at a 2 o'clock-to-4 o'clock or 8 o'clock-to-10 o'clock location) to fatalities in purely frontal crashes (where the principal impact is at a 12 o'clock location and the most harmful event is not a rollover).[478]

Purely frontal crashes are an acceptable control group because cars of the 1980s did not substantially change their technologies for occupant protection in frontal crashes (cars with air bags or automatic belts were excluded from the analysis). The data file comprised 10,983 cases of occupant fatalities in side impacts and 12,019 in frontals. Separate analyses were performed for the 2-door cars and the 4-door cars. Analysis techniques included:

- Correlation of TTI(d) with side-impact fatality risk across the various make-model-MY groups.[479]
- Comparing the fatality risk of the cars with the best TTI(d) scores to the cars with the poorest scores.[480]
- Logistic regression of the probability that a fatality is in a side impact (and not in a frontal), as a function of TTI(d), curb weight, driver age, and other variables.[481]

In the 2-door cars, all three analysis methods showed significantly lower fatality risk in the cars with lower TTI(d) scores. For example, cars with TTI(d) > 115 had more fatalities in side impacts than in pure frontals, whereas cars with TTI(d) < 102 had substantially fewer:[482]

2-DOOR CARS	Side Impact Fatalities	Purely Frontal Fatalities	Risk Ratio
Models with TTI(d) > 115 (avg. = 123)	812	760	1.068
Models with TTI(d) < 102 (avg. = 94)	528	654	.807

[478] Kahane (1999, October), pp. 11-18 and 24-31; FARS does not specify the direction of force, only the impact location; it also does not specify whether the impact included, or was limited to the occupant compartment area.
[479] *Ibid*., pp. 31-45.
[480] *Ibid*., pp. 47-71.
[481] *Ibid*., pp. 73-103.
[482] *Ibid*., p. 51.

This is a statistically significant 24-percent reduction of side impact fatalities with lower TTI(d): 1 – [(528/654) / (812/760)] = .244. More precisely, a logistic regression estimated that fatality risk was reduced by a statistically significant **0.927 percent per unit reduction of TTI(d)**. Importantly, this reduction comprises all types of side impacts: multivehicle and single-vehicle crashes, near-side and far-side impacts.[483] Corresponding analyses of 4-door cars, however, did not show statistically significant relationships between TTI(d) and side-impact fatality risk in the pre-standard vehicles. Unlike the 2-door cars, a large portion of the crash data on 4-door cars involved vehicles with TTI(d) scores clustered in a relatively narrow range from 78 to 94, making it statistically more difficult to find correlations between TTI(d) and risk.[484] As stated above, the "lives-saved" model of this report will use the 0.927-percent estimate for 2-door cars only and for the pre-standard model years when TTI(d) averaged over 90 for those cars; it will use this estimate for computing the effects of the voluntary TTI(d) reductions before MY 1994.

The 2007 evaluation is a "before-after" analysis of crash data for 15 high-sales make-models that substantially reduced TTI(d) after 1993. It is based on FARS and GES data from 1993 to 2005. Analysis techniques included:

- Comparison of overall fatality rates per 1,000 crash-involved occupants, before and after the TTI(d) improvement.[485]
- Aggregate logistic regression, across the various make-models, of each model's before-to-after fatality reduction by the magnitude of its TTI(d) improvement.[486]
- Contingency-table analysis of side-impact fatalities relative to a control group of fatally injured pedestrians and bicyclists struck by cars of the same 15 make-models (based on FARS data only).[487]

Unlike the 1999 evaluation, TTI(d) improvements in this lower range of TTI(d) have statistically significant benefits only in near-side impacts by another vehicle: not in far-side impacts or single-vehicle crashes. On the other hand, unlike the 1999 evaluation, there are significant benefits in 4-door cars, similar to those in 2-door cars. For example, the comparison of overall fatality rates per 1,000 occupants shows a 21-percent reduction in these 15 make-models after the TTI(d) improvement (which averaged 23 units in these models):[488]

Multivehicle Crashes 2- and 4-Door Cars	Near-side Fatalities	Near-side Occupants	Fatality Rate	Fatality Reduction
Before TTI(d) improvement	1,452	458,872	3.16	
After TTI(d) improvement	1,096	440,109	2.49	21 %

483 *Ibid*., pp. 91-100.
484 *Ibid*., pp. 37-45, 63-71 and 85-87.
485 Kahane (2007, January), pp. 47-51.
486 *Ibid*., pp. 53-54.
487 *Ibid*., pp. 59-63.
488 *Ibid*., p. 49.

More precisely, the average of the effects estimated by the three analysis techniques is that fatality risk is reduced by **0.863 percent per unit reduction of TTI(d)**.[489] As stated above, this reduction is limited to near-side impacts in multivehicle crashes, but it does include 4-door as well as 2-door cars. The "lives-saved" model of this report will use the 0.863-percent estimate for the model years when TTI(d) averaged less than 90, which includes all model years of 4-door cars. Overall, the 2007 evaluation estimated that, relative to MY 1980-to-1985 baseline vehicles, voluntary and post-standard TTI(d) reductions by structure and padding had reduced fatality risk in near-side impacts by other vehicles by a cumulative 17 percent in 4-door cars (confidence bounds, 7 to 27%) and by a cumulative 33 percent in 2-door cars (confidence bounds, 18 to 47%).[490]

Injury reduction – passenger cars: NHTSA has not statistically analyzed the effect of TTI(d) improvements on nonfatal injuries. Statistical analyses, as shown above, would be restricted to make-models whose TTI(d) history is known; NASS-CDS, the database with detailed information on nonfatal injuries does not have enough serious-injury cases for those specific make-models to conduct an analysis corresponding to the preceding analyses of fatality reduction based on FARS data.

Curtain and side air bags

During the 1990s, manufacturers and suppliers developed curtain and side air bags to protect an occupant's head, torso and pelvis in side impacts – specifically near-side impacts to the side of the vehicle adjacent to where the occupant is seated – even more effectively than the structure and padding originally employed to meet FMVSS Nos. 201 and 214. Some curtain air bags may also be designed to deploy in rollover crashes and/or to reduce an occupant's risk of complete or partial ejection from the vehicle in crashes, but these are discussed in the chapter on FMVSS No. 226, "Ejection mitigation." Side air bags were first offered in MY 1996 in the United States on 0.3 percent of vehicles sold that year. In MY 2011, 97 percent of new cars and LTVs were equipped with some type of curtain and/or side air bags.

Types of air bags: There are four major categories of air bags designed to deploy in side impacts.[491]

Torso air bags provide an energy-absorbing cushion between the occupant's torso and the vehicle's side structure during lateral impacts. They usually are built into the seat and deploy from there, but sometimes are built into the door. Some, but not all torso bags extend downward to also protect the pelvis. Volvo introduced torso bags in the United States, making them standard

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[489] *Ibid*., pp. 65-67; confidence bounds, 0.33 to 1.46 percent fatality reduction.
[490] *Ibid*., pp. 28 and 67-68. The cumulative 17 percent reduction in 4-door cars and 33 percent in 2-door cars are derived as follows: average TTI(d) decreased in 4-door cars from 85 in MY 1981-to-1985 baseline cars to 63 in post-standard cars without side air bags, an improvement of 22 units entirely in the under-90 range of TTI(d), where the fatality reduction per unit is an estimated 0.863 percent. $1 - (1 - .00863)^{22}$ = 17% cumulative reduction. Average TTI(d) decreased in 2-door cars from 114 in MY 1981-to-1985 baseline cars to 69 in post-standard cars without side air bags, an improvement of 24 units in the above-90 range where the reduction per unit is 0.927 percent plus 21 units in the under-90 range of TTI(d) where the fatality reduction per unit is an estimated 0.863 percent. $1 - [(1 - .00927)^{24} \times (1 - .00863)^{21}]$ = 33% cumulative reduction.
[491] Kahane (2014, January), pp. 1-8.

equipment on all their MY 1996 cars. Audi, BMW, and Cadillac began to furnish torso bags as standard equipment on some 1997 models and offer them as options on others. The first LTVs with standard torso bags were the 1998 Chevrolet Venture, Oldsmobile Silhouette, Pontiac Trans Sport vans and Mercedes SUVs.

Curtain air bags are built into the roof-rail area above the side window and deploy downward to cover the window area. They provide a cushion between the occupant's head and some of the rigid surfaces of the vehicle interior, such as the roof rail, the window sill, the A-pillar, and the B-pillar. They might also prevent partial or complete ejection of the occupant through the side-window area and prevent direct occupant contact with the striking vehicle or object. Some early designs of curtain bags had a limited longitudinal span, leaving a substantial portion of the window uncovered or they were inflatable tubular structures with a limited vertical span. Many recent curtains cover a wide longitudinal and vertical span, including most of the side-window area and the harder structures around it. BMW introduced inflatable tubes for head protection, in combination with torso bags in their 1998 500-series and 700-series cars. In 1999, Mercedes E-series and Volvo S-80 were equipped with curtains plus torso bags. Head curtains alone, without torso bags, did not appear until MY 2001, as options in some Chrysler, Dodge, and Saturn cars. Recently, suppliers have developed a head-impact air bag for use in convertibles; it covers an area similar to a curtain, but deploys up from the door rather than down from the roof rail.

Combination bags are torso bags that deploy outward from the seat and then quickly upward to also provide head protection. Unlike curtains, they cover a somewhat limited area immediately to the occupant's side. Intuitively, they might not have as much effect as curtain air bags in preventing ejection or in an oblique lateral impact, i.e., if the occupant's trajectory is toward the front of the window area, which is not covered by the air bag. Combination bags were standard in 1999 on Lincoln Town Car and Continental and Infiniti Q45, G20, and QX4; also optional on some other Ford Motors cars and LTVs. By 2010, combination bags were limited primarily to convertibles, where there is no roof rail for installing a curtain air bag.

Curtain plus torso bags provide the most extensive side-impact protection. The curtains are separate from the torso bags, although they usually share components such as sensors and the control module. As stated above, BMW 500- and 700-series had curtain plus torso bags in 1998, Mercedes E-series and Volvo S-80 in 1999. By MY 2006, curtain plus torso bags, the configuration that covers the largest area and intuitively appears to provide the most protection were the clear preference for separate curtain and torso bags. In MY 2011, 85 percent of new cars and LTVs were equipped with curtain plus torso bags for drivers and RF passengers.

Relevant FMVSS and consumer information programs: No safety standard explicitly requires vehicles to have curtain or side air bags, but several FMVSS, NCAP, and the Insurance Institute for Highway Safety's side-impact tests and ratings have prompted or encouraged their installation.[492] As discussed above, NHTSA phased a dynamic side-impact test into FMVSS No. 214 from MY 1994 to 1997. In late 1996, NHTSA expanded NCAP to include side impacts at speeds 5 mph faster than the test in FMVSS No. 214; in 2003, IIHS expanded its rating system to in-

[492] Teoh, E. R., & Lund, A. K. (2011, June). IIHS side crash test ratings and occupant death risk in real-world crashes. *22nd Enhanced Safety of Vehicles Conference*. (Paper No. 11-0165). Washington, DC: National Highway Traffic Safety Administration. Available at www-esv.nhtsa.dot.gov/Proceedings/22/files/22ESV-000165.pdf.

clude side impacts with an MDB simulating the front end of a typical pickup truck or SUV and with dummies simulating 5th-percentile females. Since torso air bags tend to substantially improve TTI(d) scores, the publication of NCAP star ratings for side impacts based to a large extent on TTI(d) may have been an incentive to expedite the introduction of torso bags in vehicles. The IIHS test, which employs a taller MDB and a shorter dummy than NCAP to elicit head impacts, may have been an incentive to introduce inflatable head protection as well as torso bags. The agency has listed, since 1996, the makes and models of vehicles that offer curtain and/or side air bags in its annual *Buying a Safer Car* brochures[493] and at www.safercar.gov. In 2007, the agency further upgraded FMVSS No. 214 by adding a crash test of a 20 mph side impact with a pole, at a 75° angle (i.e., 15° forward of a purely lateral impact). The phase-in is scheduled for MY 2011 to 2015. NHTSA anticipated that head-protection air bags – i.e., curtain bags if possible; combination bags or door-mounted head-impact bags in convertibles without a roof rail – would generally be installed to meet the new requirement, because they appeared to be the principal technology available for cushioning an occupant in oblique impacts.[494]

The upgrade of FMVSS No. 201, "Occupant protection in interior impact," from MY 1999 to 2003 reduced the risk of head injury from contact with the A-, B- and other pillars, the front and rear roof header, the roof side rails, and the upper roof. Many of these injuries were happening in side impacts. Initially, most manufacturers added energy-absorbing materials in the target areas to meet the standard, but curtain bags were a strategy for further reduction of head injuries. In fact, NHTSA modified some of the test procedures of FMVSS No. 201 in 1998 to facilitate introduction of inflatable head protection.[495]

Finally, in 2011, NHTSA issued FMVSS No. 226, "Ejection mitigation," with a phase-in scheduled for MY 2014 to 2017.[496] The goal is to prevent the ejection of unrestrained occupants and the partial ejection of belted occupants in rollovers and other crashes. NHTSA anticipated that containment of the occupant would be achieved in many vehicles by curtain air bags designed to deploy in rollovers, stay inflated for several seconds – a curtain that stays inflated for six seconds was found to be sufficient to prevent ejection during rollover – and be large enough to cover the window area and strong enough to contain the occupant. In other words, the new standard not only assumes many vehicles will have curtains or similar technology but is also likely influencing parameters such as the size of the curtains, when they deploy, and how long they stay inflated.

Expected benefits: Curtain and side air bags would be expected to reduce fatalities and serious injuries in near-side impacts – i.e., for the driver in a left-side impact and for the RF passenger in

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[493] Available for 2000 to 2005 at icsw.nhtsa.gov/safe_car_new/ (click on SaferCar2000, SaferCar2001, BASC2002, BASC2003, BASC2004, or BASC2005) and for 2006 to 2010 at www.safercar.gov/Vehicle+Shoppers/Resources/Buying+a+Safer+Car+brochures.

[494] *Federal Register* 72 (September 11, 2007): 51908; Kahane (2007, January), pp. 11-29.

[495] *Federal Register* 63 (August 4, 1998): 41451; soon after curtain bags first became available on some cars, NHTSA amended FMVSS No. 201 to facilitate their introduction on other vehicles. Recognizing that the 15 mph headform test might be a problem in target areas where the undeployed air bag is stored (and, furthermore, an inappropriate test if the bag usually deploys at that speed), NHTSA offered an alternative compliance procedure. Manufacturers have the option to reduce the speed of the headform test to 12 mph on target areas where the bag is stored, provided they can also meet an 18 mph lateral (90-degree) crash test for the full vehicle into a pole – with HIC < 1000. The pole test simulates a head impact with the deployed bag.

[496] *Federal Register* 76 (January 19, 2011): 3212.

a right-side impact. Torso bags should reduce injuries to the thorax; also to the pelvis if the bag extends downwards. Curtains can be expected to reduce head injuries. Combination bags would help for both types of injuries. Separate curtain and torso bags might be even more effective, because they extend over a larger area. Curtain and side air bags ought to be effective in both cars and LTVs.

It is not intuitively clear if curtains or side air bags would have a substantial effect in far-side impacts. The rationale for a possible effect is that they might cushion an occupant who gets across the seat and contacts interior surfaces on the far side (which may become more likely if that person is not belted and/or not blocked by other occupants – e.g., an unbelted driver when the RF seat is unoccupied). In fact, NASS-CDS data showed ample numbers of occupants with severe (AIS 4 to 6) injuries after their heads contacted surfaces on the far side of the vehicle; the air bags deploy on both sides and most current designs would remain inflated until after the occupant reached the other side of the vehicle. Nevertheless, it is unclear if these possible effects would likely be large enough to be statistically significant in analyses of crash data.[497]

Fatality reduction – passenger cars and LTVs: The principal analysis technique in NHTSA's 2014 evaluation is based on FARS data from 1993 to 2011. It is a disaggregate logistic regression of the odds ratio of driver and RF passenger fatalities in near-side impacts of MY 1994-to-2011 cars and LTVs to control group cases of pedestrians and bicyclists struck and fatally injured by these cars and LTVs. The dependent variable equals 1 when a fatality case is a driver or RF passenger of one of these cars or LTVs in a near-side impact and it equals 2 when a fatality case is a pedestrian or bicyclist (in any type of crash involving these cars and LTVs). The independent variables include one variable for each of the four major types of curtain and side air bags; indicators as to whether the vehicle meets the head-impact upgrade of FMVSS No. 201 and/or is equipped with ESC; the driver's age and gender; the vehicle's body type, mass, and footprint; and roadway/environmental variables such as rural/urban, day/night, speed limit, CY, and the State where the crash occurred. Only cars and LTVs that were equipped with frontal air bags and certified to the dynamic-test upgrade of FMVSS No. 214 are included. The technique makes it possible to estimate the effect of curtain and side air bags above and beyond the effect of structure and padding installed to meet FMVSS Nos. 201 and 214 and independently of any crash-mitigating effect of ESC. The regression comprises 73,228 data points, including 36,933 fatalities in near-side impacts and 36,295 control-group fatality cases (pedestrians and bicyclists). The 36,933 near-side fatality cases include 1,944 with torso bags only, 443 with curtains only, 1,316 with combination bags, and 1,871 with curtain plus torso bags: enough data for statistically meaningful results for each type of air bag.[498]

All four types of air bags significantly reduced fatality risk in near-side impacts. The estimated reductions and their 95-percent confidence bounds are:

[497] Kahane (2007, January), pp. 105-109.
[498] Kahane (2014, January), pp. 11-21.

Fatality Reduction Near-Side Impacts	Point Estimate (%)	Confidence Bounds (%) Lower	Upper
Curtain + torso	31.3	25.0	37.1
Combination	24.8	17.7	31.2
Curtain only	16.4	3.0	28.0
Torso only	7.8	.4	14.7

Curtain plus torso bags – the type installed in 85 percent of MY 2011 cars and LTVs – appear to be the most effective type. In general, curtain plus torso bags or combination bags – which protect both the head and the thorax – appear to be more effective than curtains alone or torso bags alone. NHTSA checked the regression results for curtain plus torso bags with two alternative analyses for a subgroup of make-models that switched directly from no side air bags to curtain plus torso bags, limited to a range of at most 3 MY before and 3 MY after the transition, and for which the ESC status did not change during that range of MY. These alternatives are a contingency-table analysis of near-side fatalities relative to control-group fatalities (pedestrians and bicyclists) and a computation, using FARS and GES data, of near-side fatality rates per 1,000 occupants involved in near-side impacts. They confirm the results of the logistic regression.[499] For example, the FARS-GES analysis shows a 31.8-percent fatality reduction for curtain plus torso bags (nearly the same as the 31.3% in the regression):

	Near-Side Fatalities (FARS)	Near-Side Occupants (Weighted GES)	Fatality Rate	Fatality Reduction
Without side air bags	1,221	378,973	3.22	
With curtain plus torso bags	493	224,431	2.20	31.8 %

Corresponding analyses of far-side impacts do not support firm conclusions about the benefits of curtains or side air bags in far-side impacts. The regression analysis does show a statistically significant 12.3-percent reduction for curtains or combination bags (confidence bounds, 5.2 to 18.9%). This is a considerably smaller effect than in near-side impacts and, moreover, it is not confirmed by the contingency-table and FARS-GES analyses, both of which show little or no effect for curtain plus torso bags in far-side impacts. The "lives-saved" model in this report will not attribute fatality reductions to any type of curtain or side air bags in far-side impacts, but the agency may study the subject once again when more data become available.[500]

Injury reduction: NHTSA may statistically analyze the effect of curtain and side air bags on serious nonfatal injuries when more crash data becomes available.

[499] *Ibid*., pp. 26-29.
[500] *Ibid*., pp. 31-35.

FMVSS No. 216, "Roof crush resistance"

This standard is associated with a vehicle modification whose safety benefits have been evaluated by NHTSA and with an upgrade that is currently (June 2014) phasing in:

- **Redesign of true hardtops as pillared hardtops or sedans**
- **2013-2016 roof crush resistance upgrade (not yet evaluated)**

FMVSS No. 216 is a performance standard limiting the amount of crush allowed when a load is gradually applied to the roof of a vehicle. The purpose of FMVSS No. 216 "is to reduce deaths and injuries due to the crushing of the roof into the occupant compartment in rollover crashes."[501] FMVSS No. 216 took effect for passenger cars on September 1, 1973. It was extended to most pickup trucks, vans and SUVs up to 6,000 pounds GVWR, effective September 1, 1993.[502] The upgraded standard, specifying heavier loads, is called FMVSS No. 216a; it began to phase in on September 1, 2012, full compliance for all new vehicles up to 10,000 pounds GVWR by MY 2016.[503]

Redesign of true hardtops with B-pillars/original version of FMVSS No. 216

Most passenger cars built since September 1, 1973, have easily complied with the original version of FMVSS No. 216. It is also believed most cars built before that date could have met the standard. It was primarily full-sized true hardtops of the late 1960s and early 1970s that had typically borderline or worse performance. This body style was phased out – redesigned as a pillared hardtop or sedan – a few years before or after FMVSS No. 216 took effect in 1973. Although some true hardtops were built after 1973 and did meet FMVSS No. 216, they were pretty much gone by the late 1970s. NHTSA evaluated the safety benefits of the redesign, regardless of FMVSS No. 216's role in motivating it.

As for LTVs, NHTSA believes they met FMVSS No. 216 well before 1993, and that there were no substantial changes in roof design around that time. For that reason, NHTSA does not plan to evaluate the 1993 version of FMVSS No. 216 for LTVs.

Regulatory history: In October 1967, almost six years before the eventual effective date of FMVSS No. 216, NHTSA issued an ANPRM broaching possible limits on the intrusion of a vehicle's roof, front, side and rear structures into the passenger compartment during crashes. The roof intrusion portion of the ANPRM was a starting point for FMVSS No. 216. The industry developed a procedure for measuring static roof crush resistance, SAE Recommended Practice J374, dated December 1968, without defining specific pass-fail levels. Soon after, the new generation of hardtops with more vulnerable roof structures spurred NHTSA to issue FMVSS No. 216, with a NPRM in January 1971, a final rule in December 1971 and an effective date of September 1, 1973. The FMVSS largely incorporates the J374 procedure and sets a 5-inch limit on

[501] 49 CFR, Part 571.216.
[502] *Federal Register* 36 (December 8, 1971): 23299, 56 (April 17, 1991): 15510.
[503] *Federal Register* 74 (May 12, 2009): 22347.

crush given a load of 1½ times the unloaded vehicle weight, but no more than 5,000 pounds if the vehicle is a passenger car, applied to one of the sides of the roof, at the forward edge.[504]

A rather simple quasi-static test (where the load is gradually applied) was preferred to a staged rollover crash because there was no repeatable, standardized rollover test that would have worked for all make-models. However, the application of the load in the static test to the front and side of the roof resembles many rollover crashes. A vehicle is required to support 1½ times its weight, rather than just its own weight, because rollovers involve an additional dynamic load when the vehicle flips onto its roof. However, passenger cars weighing over 3,333 pounds need only support a 5,000 pound load, less than 1½ times their weight and are essentially held to a less strict FMVSS No. 216 requirement, since they are generally less rollover-prone than LTVs and lighter passenger cars.

How it works One obvious danger in rollover crashes is that when a vehicle flips or bounces onto its roof, that impact could push the roof into the compartment far enough to contact and harm an occupant. However, not all fatalities in rollover crashes involved occupant contact with the roof and could have been avoided if the roof had not been crushed. For the unrestrained occupant, injuries from being ejected or tossed against interior surfaces are common, especially if the rollover is just one event in a sequence of impacts. In fact, some of the early research suggested that roof crush strength had little practical correlation with injury risk. Nevertheless, at least intuitively, a weak enough roof in a severe enough rollover is likely to collapse and harm occupants. In more recent years, when higher belt use has reduced the risk of ejection in rollovers, roof crush surely has become more important.[505]

The principal structures that resist roof crush are the roof itself, its side, front and back rails, and the two, three or four pillars on each side that hold it up. The A-pillars are on both sides of the windshield. In a sedan, the B-pillars are prominently visible between the front and back side-windows; in a true hardtop, the B-pillar extends only from the floor to where the windows begin, and does not support the roof; in a "pillared hardtop," the B-pillar extends fully to the roof, somewhat hidden in the metal between the front side-window and the "opera" window. The C-pillars are behind the rear side-windows. Station wagons also have D-pillars on both sides of the tailgate.

Four design factors increase roof crush resistance. One, obviously, is thicker or stronger materials in the roof, rails or pillars. A second is to have as many pillars as possible, specifically a full B-pillar. A third is to build a smaller car, reducing the unsupported surface area of the roof and the distance between pillars. A fourth is to arch the roof and angle the pillars inward, an intrinsically better weight-bearing design. The last three factors are the exact opposite of the popular

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[504] Kahane (1989, November), pp. 4-8; *Federal Register* 32 (October 13, 1967): 14278, 36 (January 6, 1971): 166, 36 (December 8, 1971): 23299; SAE. (1973). *1973 SAE Handbook*. New York: Society of Automotive Engineers, p. 1172.

[505] Kahane (1989, November), pp. 32-36; Hight, P. V., Siegel, A. W., & Nahum, A. M. (1972). Injury mechanisms in rollover collisions. *Proceedings of Sixteenth Stapp Car Crash Conference*. New York: Society of Automotive Engineers; Huelke, D. F., Marsh, J. C. IV & Sherman, H. W. (1972). Analysis of rollover accident factors and injury causation. *Proceedings of the Sixteenth Conference of the American Association for Automotive Medicine*. Morton Grove, IL: American Association for Automotive Medicine; Huelke, D. F., & Compton, C. (1983, October). Injury frequency and severity in rollover car crashes as related to occupant ejection, contacts and roof damage. *Accident Analysis and Prevention*, *15*.

"look" in the late 1960s and early 1970s, featuring the largest cars ever, true hardtops with continuous glass along the side, and a "lower, longer, wider" profile with a wide, flat roof. It is not surprising that large hardtops of the 1968-75 era were, on the average, the worst performers on roof crush tests. The manufacturers phased out true hardtops, not all at once but year-by-year as they restyled their various model lines, either by redesigning them as pillared hardtops (e.g., Chevrolet Monte Carlo in 1973, Ford Mustang in 1974) or by completely dropping the hardtop option from their catalogs (e.g., Dodge Aspen in 1976, GM full-sized cars in 1977). By the later 1970s, downsizing was in and the "lower, longer, wider" look was passé.

Expected benefits: Improved roof crush resistance might be expected to reduce fatality risk in rollover crashes for occupants who were not ejected from the vehicle. It would benefit occupants at any seating position.

Evaluation findings: NHTSA's study, published in 1989, includes roof crush testing by the FMVSS No. 216 procedure on cars built before and after the standard took effect; statistical analyses of average roof-crush depth in actual crashes; and statistical analyses of fatality risk for non-ejected occupants in rollover crashes. The analyses compare true hardtops to cars with full B-pillars, taking into account vehicle size and before/after FMVSS No. 216.

Roof-crush tests: Compliance test results for 108 cars of MY 1974 to 1985 were supplemented by running the FMVSS No. 216 test procedure on 14 pre-standard cars of MY 1964 to 1972, selected from make-models that were compliance-tested in 1974 or 1975. Most cars passed easily: 80 percent of them had less than half the crush allowed by FMVSS No. 216. Larger and heavier cars had significantly greater roof crush than smaller and lighter cars. Full-sized and intermediate hardtops had significantly more crush than sedans of those sizes. The worst performers were full-sized hardtops of the 1968-to-1975 era: 10 were tested, only 2 had less than half the crush allowed by FMVSS No. 216, and they accounted for 4 of the 6 worst scores among all the cars.[506]

Roof-crush depth in rollover crashes: 1982-to-1986 NASS, 1977-to-1979 NCSS, and 1968-to-1978 MDAI data was combined with appropriate case weighting.[507] They generated a file of roof-damage rollover crashes with information on roof crush (as measured by the extent zone in the Collision Deformation Classification[508]) and the make-model and body style of each case vehicle. After adjusting for car size, the average extent of roof crush in cars with full B-pillars (sedans, coupes, pillared hardtops, hatchbacks, station wagons) changed very little between MY 1964 and 1982. Up until 1967, true hardtops had about the same roof crush as cars with full B-pillars. However, in seven of the eight model years between 1968 and 1975, the hardtops had more average crush than pillared cars of the same size – a statistically significant difference. After 1975, there are only a few true hardtops in the data.[509]

Fatality reduction: NHTSA evaluated the risk of a non-ejection fatality in a rollover crash, based on logistic regression using 1975-to-1986 FARS data. The ratio of non-ejection rollover fatalities to non-ejection frontal-fixed-object fatalities in model-year 1966-to-1981 cars was calibrated by

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[506] Kahane (1989, November), pp. 39-69.
[507] Kahane, Smith, & Tharp (1977).
[508] (1985). Recommended practice No. J224 MAR 80. *1985 SAE Handbook*, Vol. 4. Warrendale, PA: Society of Automotive Engineers.
[509] Kahane (1989, November), pp. 71-86.

B-pillar status (true hardtop, full B-pillar), FMVSS No. 216 status (pre-1971, 1971-74 transition, post-1974), track width and curb weight. This ratio was a statistically significant 15 percent higher in true hardtops than in pillared cars of the same size, before 1976. In other words, phasing out the true hardtops has saved lives. The analysis showed little or no effect for FMVSS No. 216 in cars with full B-pillars – i.e., the safety benefit derived from phasing out true hardtops, not from any changes within the pillared cars. After controlling for car size, the average non-ejection rollover fatality risk in cars of the late 1970s, nearly all equipped with full B-pillars, was 7.4 percent lower than in cars of the early 1970s, a near 50-50 mix of hardtops and sedans.[510] Using 1982 as the "baseline" year, the evaluation estimated the phasing out of true hardtops saved approximately 110 lives per year.[511]

2013-2016 roof crush resistance upgrade (not yet evaluated)

In 2009, NHTSA upgraded FMVSS No. 216 to establish or increase strength requirements for the passenger compartment roof in some vehicles; the upgraded standard is called FMVSS No. 216a.[512] Before the upgrade, the standard applied only to vehicles up to 6,000 pounds GVWR and the test involved loading the roof with 1½ times the vehicle's unloaded vehicle weight (and no more than 5,000 pounds if the vehicle is a passenger car). The upgrade extends the standard to vehicles up to 10,000 pounds GVWR; test weight is 3 times the unloaded vehicle weight for vehicles under 6,000 pounds GVWR; it is 1½ times the unloaded vehicle weight for vehicles from 6,000 to 10,000 pounds GVWR. The phase-in schedule for the upgrade began with at least 25 percent of new MY 2013 vehicles, 50 percent for MY 2014, 75 percent for MY 2015, and full compliance for all new vehicles by MY 2016.

NHTSA plans to evaluate the upgrade by roof crush testing and statistical analyses of crash data. The upgraded roof crush test of FMVSS No. 216 will be performed on selected pre-standard vehicles and their crush measurements compared to compliance-test results for post-standard vehicles of the same makes and models. Statistical analyses of FARS and GES data will compare fatality risk in rollover crashes before and after the upgrade. Analyses of FARS-MCOD and GES data will compare head- and neck-injury risk in rollovers before and after the upgrade.

[510] *Ibid*., pp. 159-167.
[511] *Ibid*., pp. 214-217.
[512] *Federal Register* 74 (May 12, 2009): 22347.

FMVSS No. 223, "Rear impact guards for heavy trailers"

FMVSS No. 224, "Rear impact protection for heavy trailers"

These two standards regulate one safety technology for heavy trailers with GVWR over 10,000 pounds that has been partially evaluated by NHTSA and that is primarily designed to protect the occupants of cars and LTVs that collide with the rear of the trailers:

- **Underride guards for heavy trailers**

The bodies of heavy trailers usually ride fairly high above the ground. The front ends of LTVs and especially passenger cars are relatively low. When the front of a car or LTV hits the rear of a trailer, there is a risk that the car's hood will underride the trailer, with little structural engagement. The trailer can intrude into the passenger compartment of the car or LTV, with great danger to the occupants. The underride guard is attached to the rear of the trailer and extends below the body of the trailer. It is designed to engage the hood of the car or LTV and prevent underride. Ideally, the underride guard should extend low enough to engage even small cars, be wide enough to catch impacts near the corners of the trailer, and be strong enough to not fold or break out of the way upon impact.

History: NHTSA issued FMVSS Nos. 223 and 224 in January 1996. FMVSS No. 223 specifies the height, width, length, and strength requirements for rear impact guards for trailers and semi-trailers; FMVSS No. 224 establishes requirements for the installation of rear-impact guards on trailers and semi-trailers with GVWR of 10,000 pounds or more manufactured on or after January 24, 1998. FMVSS Nos. 223 and 224 do not apply to pole trailers, pulpwood trailers, low-chassis vehicles, special purpose vehicles, "wheels back" vehicles, or temporary living quarters – generally because these vehicles ride closer to the ground than van-type trailers or because the "wheels back" feature prevents underride from occurring, since striking vehicles contact those wheels and do not underride the back of the vehicle.[513]

However, the Truck Trailer Manufacturers Association (TTMA) had already issued a voluntary Recommended Practice RP 92-94 in April 1994 that included all the essential elements of the subsequent NHTSA standards except for the energy absorption requirement. Subsequently, Transport Canada issued CMVSS No. 223, "Rear impact guards," effective in 2005, which not only encompasses FMVSS Nos. 223 and 224 but also sets somewhat higher strength requirements than those FMVSS.[514] Before 1998, trailers and semi-trailers were Federally regulated by Federal Motor Carrier Safety Regulations (FMCSR) that incorporated specifications for rear-impact guards developed by the Interstate Commerce Commission in 1952.[515] The ICC guards were substantially narrower and smaller than those required by the current NHTSA standard and the TTMA recommended practice. The ICC guards were not required to meet strength tests.

In other words, there are five generations of underride guards: (1) The original state of no guards at all, which had ended by 1952; (2) The narrow ICC/FMCSR guard from 1952 to approximately 1994; (3) A transition circa 1994 to the TTMA guard which has the dimensions of current guards but not necessarily their strength; (4) Certification to the strength requirements of FMVSS Nos.

[513] 49 CFR, Parts 571.223 and 571.224; *Federal Register* 61 (January 24, 1996): 2004.
[514] laws-lois.justice.gc.ca/PDF/C.R.C.,_c._1038.pdf.
[515] www.fmcsa.dot.gov/rules-regulations/administration/fmcsr/fmcsrruletext.aspx?reg=393.86.

223 and 224 in 1998, although some earlier guards might have met those requirements; and (5) Certification to even greater strength requirements of CMVSS No. 223 in 2005; although not mandatory in the United States, current trailers are designed to the Canadian requirements to allow operation throughout North America.

Expected benefits: Passenger compartment intrusion increases fatality and injury risk in frontal impacts. Successful underride guards would reduce the likelihood of intrusion when cars or LTVs impact the rear of heavy trailers, without otherwise changing the distribution of delta v in those crashes. That should result in fewer deaths and serious injuries. The underride guards would have little or no effect in crashes where the car or LTV contacts the sides of the trailer or the truck that is pulling the trailer.

Fatality and serious-injury reduction: NHTSA's evaluation, published in 2010, compares occupant fatalities in cars and LTVs when these vehicles impact the rear of heavy trailers to fatalities in a control group of crashes where the cars impact some other part of the trailer or impact the tractor.[516] Two almost insuperable impediments to evaluation precluded statistically meaningful results: (1) FARS and most other databases available to NHTSA do not record the MY or VIN of trailers, leaving no clue as to the design of their underride guards; (2) The gradual evolution of standards for underride guards does not allow a simple before-after or all-versus-nothing comparison. As of 2010, Florida was the only State crash file available to NHTSA that recorded the trailers' MY and VIN. The analysis is based on Florida data from CY 1989 to 2006; of course, the number of fatality cases in a single State is limited. The two categories of trailers considered are MY 1998 and later, which would include guards certified to FMVSS and/or CMVSS Nos. 223 and 224; and MY 1980 to 1993, before the TTMA voluntary standard, which would probably be mostly the narrow ICC/FMCSR guards. The technique is a multidimensional contingency-table analysis of car/LTV occupants' odds of survival in rear impacts versus other impacts, in crashes with MY 1998+ versus MY 1980-to-1993 trailers – using a SAS procedure called CATMOD to estimate if the newer guards have reduced risk in rear impacts relative to the other crashes and also to control for the CY of the crash (because crash distributions in Florida have changed over time). The analysis estimates a 27-percent reduction in rear-impact fatalities with the newer trailers, but the estimate falls short of statistical significance, due to the limited data (chi-square = 0.88, where 3.84 is needed for significance at the two-sided .05 level). A corresponding analysis of the risk of fatalities and serious injuries (categories K and A in the Florida data) shows 6.5 percent lower risk with the newer guards, likewise not statistically significant.

Although the observed estimates are positive, the limited data and lack of statistical significance do not permit a conclusion that the newer guards have reduced fatalities or serious injuries. The model to compute lives saved in Part 2 of this report will not attribute any fatality reduction for car or LTV occupants to improved underride guards for heavy trailers. In a 2009 NHTSA analysis of 122 NASS-CDS fatality cases in frontal impacts, despite seat belt use and air bags, of cars and LTVs of MY 2000 or later, 12 of the 122 fatalities involve rear underride of a heavy trailer

[516] Allen, K. (2010, October). *The effectiveness of underride guards for heavy trailers*. (Report No. DOT HS 811 375, pp. 16-22). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811375.pdf.

(although this data does not describe the type of underride guard on the trailer, which may have been built before FMVSS Nos. 223 and 224, or how the guard performed in the crash).[517]

[517] Bean et al. (2009, September), pp. 33-39.

FMVSS No. 226, "Ejection mitigation"

This standard is associated with one safety technology that has been evaluated by NHTSA:

- **Rollover curtains**

FMVSS No. 226 is a performance standard in which a headform is propelled toward various targets in side glazing areas. The goal is to prevent ejection of unrestrained occupants and to prevent the partial ejection of belted occupants in rollovers and other crashes. The standard began to phase in during MY 2014. NHTSA anticipates that curtain air bags that deploy in rollovers will be the principal technology used to meet the standard. Rollover curtains began to appear in production vehicles in MY 2002 and were in 45 percent of new vehicles by MY 2011; however, early versions of rollover curtains were most likely not compliant with the future performance requirements of FMVSS No. 226. It is also conceivable that another technology, laminated glass-plastic glazing, could be employed for side windows, but so far it has not appeared in production vehicles. The standard only allows laminated glazing as a supplement to rollover curtains in movable side windows. However, fixed side windows could have laminated glass as the sole countermeasure.

Regulatory history: NHTSA issued FMVSS No. 226 on January 19, 2011. A headform propelled toward various targets in glazing areas may not extend more than 100 mm beyond a vertical reference plane defined by the original point of contact of the headform and the interior surface of the unbroken vehicle glazing. The test is performed with any tempered glass removed and any laminated glass broken so as to reproduce realistic real world conditions. The standard applies to cars and LTVs with GVWR up to 10,000 pounds, except convertibles and some other vehicles. The phase-in period includes 25 percent of new vehicles produced from September 1, 2013, through August 31, 2014; 50 percent from September 1, 2014, through August 31, 2015; 75 percent from September 1, 2015, through August 31, 2016; and all new vehicles starting September 1, 2016.[518] But manufacturers began installing rollover curtains well in advance of the phase-in. As stated above, 45 percent of new vehicles had rollover curtains in MY 2011, including 79 percent of new LTVs (where rollovers have been more of a safety issue) and 9 percent of passenger cars (which are less rollover-prone).

How rollover curtains work: The standard defines a "deployable ejection mitigation device" – e.g., a curtain air bag that is designed to deploy in rollovers, stay inflated for 6 seconds,[519] and be large enough to cover the side-window area and strong enough to contain the occupant, as evidenced by successful testing with the headform impacts. Curtains would be needed on all side windows, including both front and rear seats, back to at least the third row.[520] A curtain air bag designed for side impacts can be upgraded to a rollover curtain by adding a rollover sensor in the vehicle and modifying the electronic control module that sends the signal to deploy. Curtains that deploy in rollovers first became available on 2002 Ford Explorers and Mercury Mountaineers (although agency testing indicates that these early curtains would not have met all the require-

[518] 49 CFR, Part 571.226; *Federal Register* 76 (January 19, 2011): 3212.
[519] Investigations of rollover crashes show that vehicles may transverse long distances and roll over several times; unbelted occupants are often ejected at the end of the rollover sequences, whose duration ranges up to six seconds.
[520] In vehicles with more than three rows of seats, the standard applies to the first three rows of seats and to 600 mm beyond the third row of seats; see 49 CFR Part 571.226 S5.2.1.2(a).

ments of future FMVSS No. 226). As more side-impact curtains have been upgraded to rollover curtains over the past 12 years, curtains have generally been designed to cover a larger area and stay inflated longer.

Expected benefits: Rollover curtains should reduce occupant ejections in first-event rollover crashes. Keeping occupants within the vehicle – preventing ejection of unbelted occupants and averting partial ejection of belted occupants – will save lives and prevent serious injuries, because ejection increases fatality risk in a crash by a factor of nearly four, all else being equal.[521] But the benefit of rollover curtains need not be limited to preventing ejections. A well-designed curtain that deploys in rollovers could mitigate injury severity in head impacts with structures such as pillars, roof side rails, and side window sills – just as curtains that deploy in side impacts mitigate head injuries in near-side impacts. The principal analysis will address overall fatality risk in first-event rollovers.

Benefits are not necessarily limited to first-event rollovers. There could also be an effect in subsequent-event rollovers after frontal impacts, to the extent that injuries are due to ejection or occur during the rollover sequence after the initial impact. Rollover curtains could even have an incremental benefit over non-rollover curtains in side impacts. The issue here is not the rollover sensor, because the side impact has already deployed the curtains. The issue is whether the other features that tend to be characteristic of rollover curtains, such as covering a larger area and/or staying inflated for a longer time might save some occupants, especially those who are ejected or injured in a subsequent rollover. These types of curtains might also mitigate injuries in oblique or small-overlap frontal impacts if they deploy in those types of impacts.

Fatality reduction: NHTSA's 2014 evaluation is based on FARS data from 1999 to 2011. The principal analysis is a disaggregate logistic regression of the odds ratio of driver and RF passenger fatalities in first-event rollovers of MY 2000-to-2011 CUVs and truck-based SUVs to control group cases of pedestrians and bicyclists struck and fatally injured by these CUVs and SUVs. Cars, pickup trucks, and vans are excluded from the analyses because few of them had rollover curtains until near the end of that timeframe. It is important to note that this preliminary evaluation includes all types of curtains that deploy in rollovers; it is not limited to those that certified, or could have certified to FMVSS No. 226.

The dependent variable equals 1 when a fatality case is a driver or RF passenger of one of these vehicles in a first-event rollover and it equals 2 when a fatality case is a pedestrian or bicyclist (in any type of crash involving these CUVs and SUVs). The key independent variable is the presence or absence of rollover curtains (the presence or absence of other types of air bags is unimportant, because they would not ordinarily deploy in a first-event rollover). The other independent variables are indicators as to whether the vehicle meets the head-impact upgrade of FMVSS No. 201 and/or is equipped with ESC; the driver's age and gender; the vehicle's body type, mass, and footprint; and roadway/environmental variables such as rural/urban, day/night, speed limit, CY, and the State where the crash occurred.[522] The technique makes it possible to estimate the effect of rollover curtains above and beyond the effect of structure and padding in-

[521] Sikora (1986).
[522] However, the driver's belt use is not an independent variable: belt use might not be accurately reported for the usually surviving and often uninjured drivers of the vehicles that hit pedestrians or bicyclists; see Kahane (2000, December), pp. 10-19 and Kahane (2014, January, pp. 31-32).

stalled to meet FMVSS Nos. 201 and independently of any crash-mitigating effect of ESC. The regression comprises 9,550 data points, including 4,801 fatalities in first-event rollovers and 4,749 control-group fatality cases (pedestrians and bicyclists). The 4,801 rollover cases include 130 with rollover curtains: not a large number, but enough data for statistically meaningful initial results. The analysis attributes a strong and statistically significant 41.3-percent overall fatality reduction to rollover curtains in first-event rollover crashes (confidence bounds, 22.4 to 55.5%).[523]

Although the data in these analyses is limited to CUVs and SUVs, the "lives saved" model in this report will assume a similar effectiveness for cars and other LTVs.

NHTSA checked the regression results with a contingency-table analysis for a subgroup of make-models that shifted to rollover curtains without simultaneously adding ESC, limited to a range of at most 3 MY before and 3 MY after the transition. This analysis found a statistically significant 46.3-percent fatality reduction for rollover curtains, similar to the regression result.[524]

CUVs and SUVs	First-Event Rollover Fatalities	Ped/Bike Fatalities	Risk Ratio
Without rollover curtains	331	457	.724
With rollover curtains	82	211	.389

The effectiveness of rollover curtains in preventing fatal ejections in first-event rollovers is especially relevant to FMVSS No. 226. Without rollover curtains, approximately 63 percent of the driver and RF passenger fatalities in first-event rollovers were ejected from the vehicle. The preceding regression analysis, when the occupant fatality cases are limited to ejected occupants, estimates a 45.5-percent reduction of fatal ejections with rollover curtains (confidence bounds, 23.2 to 61.3%). It is quite similar to the 41.3 percent overall fatality reduction in first-event rollovers.[525]

Analyses of subsequent-event rollovers showed little effect for rollover curtains. Analyses of near-side and far-side impacts generated mixed results, with two analyses showing rollover curtains significantly more effective than non-rollover curtains, but three analyses not showing a significant difference.[526] Data is limited for now; these analyses should be repeated in three or four years when more there is more data to work with, making it possible to limit the analysis to curtains meeting all requirements of FMVSS No. 226. For the time being, the "lives saved" model in this report will attribute a fatality reduction to rollover curtains in first-event rollovers, but it will not attribute an incremental fatality reduction to them in other types of crashes.

Injury reduction: NHTSA has not statistically analyzed the effect of rollover curtains on nonfatal injuries.

[523] Kahane (2014, January), pp. 36-40.
[524] *Ibid*., pp. 40-42.
[525] *Ibid*., pp. 42-43.
[526] *Ibid*., pp. 43-49.

FMVSS No. 301, “Fuel system integrity”

FMVSS No. 301 is a performance standard that limits the amount of fuel allowed to spill from a vehicle after a crash test impact from any one of several directions, or during a static rollover test. The standard was substantially upgraded in MY 1976 to 1978 and then again in MY 2005 to 2009; both upgrades were accompanied by substantive vehicle modifications and both were evaluated by NHTSA:

- **1976-1978 upgrade: rollover, rear-impact and lateral-impact tests**
- **2005-2009 upgrade: rear-impact and lateral-impact tests**

The first paragraph of FMVSS No. 301 says, “The purpose of this standard is to reduce deaths and injuries occurring from fires that result from fuel spillage during and after motor vehicle crashes.”[527] Approximately 29,000 cars and LTVs per year catch fire after being involved in a crash.[528] The 1995 FARS indicates that 1,433 occupants of these 29,000 cars and LTVs were fatally injured (although not necessarily from burns, but possibly due to interior impacts, ejection, or other reasons; by CY 2011, fatalities had dropped to 1,087). NHTSA also estimated that approximately 309 of these 1,433 deaths were caused primarily by burns due to post-collision vehicle fires, not from other injury sources. Rear impacts were the most frequent crash type among the burn fatalities, accounting for approximately 143 of those fatalities (46%).[529]

1976-1978 upgrade: rollover, rear-impact and lateral-impact tests

Regulatory history: FMVSS No. 301 is one of NHTSA’s initial safety standards, with an effective date of January 1, 1968, for passenger cars. Originally, cars only had to pass a frontal impact test into a rigid barrier at 30 mph. Fuel spillage after the impact is not allowed to exceed 1 ounce while the car is still in motion and 5 ounces during the first 5 minutes after the car comes to a stop. During the next 25 minutes, fuel spillage may not exceed 1 ounce during any 1-minute interval.[530]

Cost analyses by the agency did not show any substantive changes from model year 1967 to 1968 needed to meet the original FMVSS No. 301.[531] Statistical analyses of post-crash fire rates did not show a significant difference between pre-1968 and MY 1968+ cars.[532] NHTSA believes

[527] 49 CFR, Part 571.301.
[528] Parsons, G. G. (1990, November). *Motor vehicle fires in traffic crashes and the effects of the fuel system integrity standard*. (Report No. DOT HS 807 675, pp. xvii and 3-25 – 3-28). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/807675.PDF.
[529] *Federal Register* 65 (November 13, 2000): 67693.
[530] Parsons (1990, November); *Federal Register* 32 (February 3, 1967): 2414.
[531] McLean, R. F., Eckel, C., & Cowan, D. (1978, October). *Cost evaluation for four Federal Motor Vehicle Standards, Volume I*. (Report No. DOT HS 803 871, pp. 63-77). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS803871.pdf.
[532] Reinfurt, D. W. (1981, June). *A statistical evaluation of the effectiveness of FMVSS 301: Fuel system integrity*. (Report No. DOT HS 805 969). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS805969.pdf; Flora, J. D., Beitler, P., Bromberg, J., Goldstein, N., & O’Day, J. (1979). *An evaluation of FMVSS 301 – Fuel system integrity*. (Report No. UM-HSRI-79-42). Ann Arbor, MI: University of Michigan Transportation Research Institute.

that cars sold in the United States generally would have been capable of meeting the FMVSS No. 301 frontal impact test for some years before the regulation was proposed or issued.[533]

During the 1970s, FMVSS No. 301 was significantly upgraded over a three-year phase-in period. Effective September 1, 1975 (i.e., in MY 1976), passenger cars had to meet a static rollover test. Immediately after the frontal test, the damaged vehicle is slowly rotated 90°, 180° (upside-down) and 270°, holding at each of these positions for 5 minutes. Fuel spillage may not exceed 1 ounce during any 1-minute interval in this process.

Effective September 1, 1976, cars had to meet 30 mph frontal, oblique-frontal and rear-impact tests, plus a 20 mph lateral test, each followed by a static rollover test, with the same limits on fuel spillage as in the original frontal test. The rear and lateral impacts involve a 4,000-pound moving barrier striking a stationary vehicle. Rear and lateral impacts are, in a sense, more stringent tests than the frontal impact, because they come closer to the location of the fuel tank in most vehicles. LTVs with GVWR less than or equal to 6,000 pounds had to meet 30 mph frontal and rear-impact tests followed by static rollover. LTVs with GVWR 6,000-10,000 pounds (including small LTV-based school buses) had to meet the frontal test without static rollover.

Effective September 1, 1977, all LTVs up to 10,000 pounds GVWR (including small school buses) had to meet the same requirements as passenger cars: frontal, oblique-frontal, rear and lateral tests with subsequent rollover. Also, on April 1, 1977, the requirements were extended to large school buses with GVWR over 10,000 pounds, but excluding the subsequent rollover tests.[534]

Vehicle modifications in the mid-1970s: The type and extent of modifications near the time of the MY 1976-to-1978 upgrade varied greatly by make-model. Strategies used by the manufacturers include:

- Strengthening the fuel tank or other components of the fuel delivery system.
- Strengthening the structures that hold the fuel tank in place.
- Shielding the fuel tank and delivery system from other parts of the vehicle.
- Relocating parts of the fuel system further away from other parts of the vehicle or areas likely to be damaged during impacts.
- Relocating other parts of the vehicle further away from the fuel system, or reshaping them to make them less likely to damage the fuel system.[535]

Expected benefits: Improved fuel system integrity ought to reduce the number of post-crash fires that are primarily sustained by fuel spillage. The measures used to improve fuel system integrity might not be effective in certain crashes that are far more severe than the levels tested in FMVSS No. 301. Not all fatalities in vehicles with post-crash fires are due to the fire; occupants primarily injured by interior components, or due to ejection, could have had the same injury severity even without the fire.

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[533] Parsons, G. G. (1983, January). *Evaluation of Federal Motor Vehicle Standard 301-75, fuel system integrity: passenger cars*. (Report No. DOT HS 806 335, p. 3). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/HS806335.pdf.

[534] Parsons (1990, November), p. 1-3; *Federal Register* 39 (March 21, 1974): 10588, 39 (November 21, 1974): 40857, 40 (August 6, 1975): 33036, 40 (October 10, 1975): 47790.

[535] Parsons (1990, November), pp. 4-11 – 4-22.

Post-crash fire reduction – passenger cars: NHTSA's evaluation, published in 1990, is based on 1982-to-1987 State crash data from Maryland, Michigan, and Ohio. Crash-involved cars are grouped by MY and CY. The proportion of crashes accompanied by post-crash fires is analyzed by a linear regression, with FMVSS No. 301 (MY 1976+ = post-standard) and vehicle age as the dependent variables. (Fire rates increased strongly as cars aged, but the rates were uncorrelated with curb weight.) The analysis indicated that post-standard cars had 14 percent fewer fires than pre-standard cars, after controlling for vehicle age.[536] The reduction is statistically significant. Using 1982 to 1987 as the "baseline" years, the evaluation estimated that there would be 3,900 fewer fires annually when the entire car fleet meets FMVSS No. 301.[537]

Post-crash fire reduction – LTVs: A similar analysis was performed on the proportion of LTV crash involvements with fires (except that here MY 1977+ = post-standard). However, this analysis did not show a statistically significant reduction of post-crash fires with FMVSS No. 301.[538]

Fatality reduction – passenger cars: A similar analysis was also performed on 1975-to-1988 FARS data: a regression on the proportion of fatal crash involvements followed by fires. After controlling for vehicle age, the observed effect of FMVSS No. 301 was close to zero and not statistically significant. NHTSA was unable to conclude that FMVSS No. 301 has had any effect on fatal fires. Another analysis, based on direct comparison of the fire rates N model years before versus after FMVSS No. 301, also showed little or no effect for FMVSS No. 301 after controlling for vehicle age.[539] "No reduction in fire-related fatalities was found; the force levels encountered in fatal fire crashes may generally exceed the levels set by the Standard."[540] That suggests the 14-percent overall reduction of fires, discussed above, happened primarily in the less severe, nonfatal crashes.

The probability of fire increases with vehicle age. During 1975 to 1988 people began to hold onto their vehicles longer and scrap them later. As the median age of vehicles increased, the number of fatal crash involvements followed by fires grew from 1,300 in 1975 to 1,800 in 1988.[541]

Fatality reduction – LTVs: Similar analyses were performed on the proportion of fatal LTV crash involvements with fires (except that here MY 1977+ = post-standard). They did not show a statistically significant effect for FMVSS No. 301.[542]

2005-2009 upgrade: rear-impact and lateral-impact tests

Regulatory history: After 1978, many cases of fire continued to be reported, especially in fatal crashes. As stated above, NHTSA estimated in 2000 that approximately 309 deaths per year were caused by burn injuries due to post-collision vehicle fires; rear impacts accounted for approximately 143 of these fatalities (46%). On April 12, 1995, NHTSA issued an ANPRM to consider upgrading FMVSS No. 301, possibly including changes in the system performance tests, new

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536 95 percent confidence bounds: 7 to 21 percent
537 Parsons (1990, November), pp. xix, 2-1 – 2-33, and 4-2.
538 *Ibid*., pp. xx and 2-63 – 2-82.
539 *Ibid*., pp. xx and 2-53 – 2-62.
540 *Ibid*., p. xxiv.
541 *Ibid*., p. xviii.
542 *Ibid*., pp. xx and 2-91 – 2-98.

tests of individual components, and criteria to address environmental and vehicle-aging effects on the integrity of the fuel system.[543] On November 6, 2000, after reviewing the research and the public comments to the ANPRM, NHTSA issued, an NPRM limiting the upgrade to more stringent rear- and lateral-impact test procedures for vehicles up to 10,000 pounds GVWR.[544]

NHTSA issued a final rule on December 1, 2003.[545] It replaced the September 1, 1976, rear-impact test (30 mph by a 4,000-pound rigid barrier and 100 percent overlap) with a 50 mph impact by a 3,000-pound MDB. The new test is not across the entire rear of the test vehicle but overlaps just 70 percent of it, starting from the side with the fuel filler. Thus, the lower mass and deformable face of the MDB make the new test somewhat less severe, but the much higher speed and less-than-full overlap make it much more severe. The test is more severe for lighter vehicles, because of the finite mass of the MDB (conservation of momentum). The lateral impact of September 1, 1976, (20 mph by a 4,000-pound rigid barrier) is superseded by adding a fuel-retention requirement to the already existing compliance test for FMVSS No. 214: a 33.5 mph lateral impact by a 3,000-pound deformable barrier. The rear-impact test phased in 40 percent of cars and LTVs produced from September 1, 2006, to August 31, 2007 (i.e., MY 2007); 70 percent of cars and LTVs produced from September 1, 2007, to August 31, 2008; and all cars and LTVs produced on or after September 1, 2008. The lateral test phased in two years earlier, from MY 2005 to 2007.

Expected benefits: NHTSA stated in 2003 that the new rear-impact test would be a major upgrade, as evidenced by test results for 13 selected cars and LTVs of MY 1996 to 1999. Six of the 13, including 6 of the 11 with curb weight less than 3,500 pounds failed the proposed new test. In 2012, NHTSA tested an additional 16 vehicles of MY 1996 to 2000; 10 of these also failed the new test. In all, 16 of the 29 MY 1996-to-2000 vehicles, including 15 of the 25 with curb weight less than 3,500 pounds failed the rear-impact test that phased in during MY 2007 to 2009. NHTSA does not have detailed information on how vehicles were modified between MY 2000 and MY 2009 to meet the rear-impact upgrade. However, based on the failure modes observed in the tests of pre-standard vehicles, NHTSA believes that the principal modifications have been to the design and packaging (surrounding protective structures) of the fuel filler neck and the fuel tank. NHTSA concluded that bringing all new vehicles into compliance with the new rear-impact test would prevent fire-related fatalities and injuries. By contrast, the agency stated that the new lateral-impact requirement would have considerably less effect on safety, as evidenced by only one failure in over 100 tests of pre-standard vehicles to the new requirement. A primary goal of the new lateral-impact requirement was to eliminate regulatory burden by incorporating FMVSS No. 301 into the existing compliance test for FMVSS No. 214, rather than requiring a separate crash test.[546]

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[543] *Federal Register* 60 (April 12, 1995): 18566.
[544] *Federal Register* 65 (November 13, 2000): 67693.
[545] *Federal Register* 68 (December 1, 2003): 67068.
[546] (2003, November). *Final regulatory impact analysis, FMVSS No. 301 upgrade*. (Docket No. NHTSA-2003-16523-002, Chapter III). Washington, DC: National Highway Traffic Safety Administration; Pai, J. (2014, June). *Evaluation of FMVSS No. 301, "fuel system integrity," as upgraded in 2005 to 2009*. (Report No. DOT HS 812 038). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/812038.pdf.

Fatality reduction – cars and LTVs: The principal analysis in NHTSA's evaluation, published in 2014, is based on FARS data from CY 2008 to 2011 for cars and LTVs of MY 2004 to 2011. The technique is a contingency-table analysis of fatalities in rear impacts to vehicles before and after certification to the new rear-impact requirement of FMVSS No. 301, comparing the fatalities in crashes with post-crash fires to the fatalities in rear impacts without fires.[547]

Fatalities in Rear Impacts	With Post-Crash Fire	Without Fire	Odds Ratio
Before FMVSS No. 301 certification	40	1,680	.0238
After FMVSS No. 301 certification	12	1,160	.0103

This is a statistically significant 56.6-percent reduction in the odds of fire in fatal rear impacts. A review of the 59 individual fatality cases in rear impacts with post-crash fires in NASS-CDS from 1991 to 2011, suggests that a high proportion, 62.2 percent of these fatalities are attributable to burn injuries (and only 37.8 percent are attributable to impact trauma). Thus, the evaluation estimates that the vehicle modifications in response to the upgraded rear-impact requirements of FMVSS No. 301 prevent 35.2 percent (.566 x .622) of the fatalities in rear-impact crashes with post-crash fires. This effectiveness estimate will be used in the "lives saved" model. The evaluation estimates that when all vehicles on the road will meet the new rear-impact requirements, the standard may save 23 lives per year.

A corresponding analysis of side-impact crashes does not show a reduction of fatal post-crash fires after the new lateral-test requirement went into effect, consistent with NHTSA's conclusions at the time of the final rule.

NHTSA's evaluation also asked whether the rear-impact upgrade might have ancillary benefits in other types of crashes, such as first-event rollovers. The improvements to the filler neck and fuel tank, as described above, might be useful regardless of the direction of impact and/or if the vehicle is inverted; specifically, the rear-impact test includes turning the vehicle upside-down and onto its left and right sides. The data did not show a reduction of frontal or lateral impacts with fatal post-crash fires after vehicles certified to the new rear-impact requirement, but it did show a statistically significant 36.2-percent reduction in the odds of fire in fatal first-event rollovers. The NASS-CDS data shows 25.2 percent of these fatalities are attributable to burns. That suggests a possible 9.1 percent (.362 x .252) of the fatalities in first-event rollovers with post-crash fires. The agency is uncertain, however, to what extent, if any, this reduction is attributable to the upgrade of FMVSS No. 301. No fatality reduction in rollovers will be attributed to FMVSS No. 301 in the "lives saved" model of this report.

[547] Pai (2014, June).

NCAP: New Car Assessment Program

NHTSA's New Car Assessment Program is not a regulation or a standard, but a program of testing the crashworthiness and crash avoidance capabilities of new cars and LTVs and publishing the results for the public. NCAP began in 1978 with frontal crash testing of MY 1979 passenger cars. LTVs were first tested in MY 1983. In 1995, the Insurance Institute for Highway Safety began its own program of crash testing and public information, based on an offset-frontal impact. NCAP expanded to side impact testing in MY 1997 and IIHS started testing vehicles in side impacts, using a somewhat different procedure, in 2003. NCAP began to provide information on the rollover resistance of vehicles in MY 2001. Five major categories of NCAP and IIHS information have been available since 2003 or earlier. So far, NHTSA has only fully evaluated, based on retrospective statistical analyses of crash data, the first of these rating systems and the vehicle modifications in response to them:

- **Frontal NCAP-related improvements in cars without air bags,**
- **Frontal NCAP in vehicles with air bags (not evaluated),**
- **Offset-frontal IIHS tests (partially evaluated),**
- **Side NCAP and IIHS side impact testing (not evaluated), and**
- **Rollover-resistance NCAP (partially evaluated).**

In NCAP's frontal-impact test the full front of the vehicle crashes into a rigid barrier at 35 mph, the same as the current test speed for FMVSS No. 208. However, the NCAP test was originally 5 mph faster than the test speed in FMVSS Nos. 204, 208, 212, 219, and 301, the NHTSA regulations that set basic performance requirements in frontal impacts, which were tested at 30 mph until September 1, 2007. NCAP's side-impact test, at 38.5 mph is 5 mph faster than the 33.5 mph dynamic test in FMVSS No. 214. One purpose of NCAP or IIHS testing, of course, is to enable consumers to compare the performance of different vehicles they might want to buy. Manufacturers know what the NCAP tests are and they have the option to design their vehicles for optimum performance in the tests. Even though NCAP has no "pass-fail" criteria, manufacturers have improved performance over the years by introducing, modifying or fine-tuning safety equipment. For example, voluntary introductions of technologies such as pretensioners and load-limiters for seat belts (not required by any FMVSS as of June 2014) have improved performance on NCAP tests. When consumers and manufacturers respond to the information, the end result is a fleet of vehicles with better test performance.

In addition to those five rating systems, IIHS and NHTSA have offered other ratings or information, especially during the past few years. These, too, have not yet been retrospectively evaluated by statistical analyses of crash data. IIHS began testing and rating head restraints in 1995,[548] roof strength in 2009,[549] vehicle performance in small-overlap frontal impacts in 2012,[550] and front crash prevention systems (such as forward collision warning) in 2013.[551] For MY 2012, NCAP added an overall vehicle score; an oblique pole test at 20 mph with a 5th-percentile female driver dummy; information on the availability of ESC, forward collision warning systems,

[548] www.iihs.org/iihs/ratings/ratings-info/rear-head-restraints-test.
[549] www.iihs.org/iihs/news/desktopnews/roof-strength-is-focus-of-new-rating-system-4-of-12-small-suvs-evaluated-earn-top-marks.
[550] www.iihs.org/iihs/ratings/ratings-info/frontal-crash-tests.
[551] www.iihs.org/iihs/ratings/ratings-info/front-crash-prevention-tests.

and lane departure warning systems; and injury criteria for chest deflection, femur load, and neck tension and compression. On the existing frontal and side impact tests, NCAP shifted from a 50th percentile male dummy to a 5th-percentile female dummy in the RF seating position (frontal) and rear seating position (side impact).[552]

Frontal NCAP-related improvements in cars without air bags

NCAP history and procedure: Title II of the Motor Vehicle Information and Cost Savings Act of 1973 authorized NHTSA to develop consumer information on the crashworthiness of passenger vehicles. The agency developed a 35 mph frontal impact test into a rigid barrier with belted dummies at the driver's and RF seats. The test setup was essentially identical to the one used in NHTSA's basic frontal crashworthiness standards at that time, except 5 mph faster. (Subsequently, phasing in from September 1, 2007, to September 1, 2010, the speed of the test in FMVSS No. 208 with the belted 50th percentile male dummy was raised from 30 mph to 35 mph, equal to the NCAP test speed.) The same injury criteria as in FMVSS No. 208 – originally the head injury criterion, chest g's and femur load – were measured on the dummies.[553]

In MY 1979, the first year of testing, fewer than 25 percent of the cars were able to meet the FMVSS No. 208 criteria (HIC < 1,000, chest g's < 60 and femur load < 2,500 pounds on each leg) in the 35 mph test. (Of course, the only requirement of FMVSS No. 208 at that time was for vehicles with automatic occupant protection to meet those criteria at 30 mph.) By MY 1986 to 1991, over 60 percent of passenger cars met the FMVSS No. 208 criteria at 35 mph. Manufacturers had begun "designing to 35 mph" a large proportion of their vehicles. Specifically, during the first four years of NCAP, 1979 to 1982, HIC averaged 1,052 and chest g's 54.9. By MY 1983, modifications that improved NCAP performance had worked their way through the production cycle. In MY 1983 to 1986, average HIC had dropped to 915 and chest g's even more so, to 46.8. In MY 1987 to 1991 HIC continued to improve to 827, while chest g's remained about the same, at 46.5.[554]

Vehicle modifications and their purpose: NHTSA's films and other data from NCAP tests are public information. Manufacturers, if they chose, had the opportunity to study results of the initial NCAP tests of their MY 1979-to-1981 cars. They could identify the contacts that were driving up HIC or chest g's on the dummies and they could test out a variety of remedies by running their own 35 mph impacts. Subsequent modifications were not limited to a single, specific technology, but included adjusting the belt system, the steering assembly, the instrument panel, and the seat structure, taking into account how belted dummies interacted with those systems in 35 mph tests. For example, manufacturers:

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[552] *Federal Register* 73 (July 11, 2008): 40016, 76 (July 29, 2011): 45453; chest deflection superseded chest peak g's; furthermore HIC_{15} (the highest value of HIC during any 15 millisecond duration) superseded HIC_{36} (measured over a 36 millisecond duration).

[553] *The Motor Vehicle Information and Cost Savings Act of 1973*, Public Law 92-513, as amended, 15 *United States Code* 1912-2012.

[554] Kahane, C. J. (1994, January). *Correlation of NCAP performance with fatality risk in actual head-on collisions*. (Report No. DOT HS 808 061, pp. 1-2). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/808061.PDF; before MY 2012, HIC was measured over a 36 millisecond duration (HIC_{36}).

- Reduced spool-out of the seat belts in crashes. Excessive spool-out allowed head impacts with frontal components. Strategies to reduce spool-out included adding a web-locking mechanism, relocating the D-ring, modifying the retractor or shortening the belts;
- Found ways to reduce upward movement of the steering assembly in crashes and keep it away from the driver's head;
- Reduced dashboard intrusion into the occupant compartment;
- Stiffened the front seat cushion; and
- Realigned the seats relative to the steering assembly and instrument panel to provide additional ride-down space for occupants.[555]

Expected benefits: Strategies to optimize the performance of belted dummies in 35 mph frontal barrier impacts might likely have the largest benefits for belted occupants in frontal crashes, generally, and especially in frontal crashes that have a velocity change (delta V) in the vicinity of 35 mph (i.e., severe, but not extreme) and resemble an impact with a flat barrier (hitting a wide object or another vehicle, with plenty of overlap).

Fatality reduction – passenger cars: In 1994, NHTSA published a study of the *Correlation of NCAP Performance with Fatality Risk in Actual Head-On Collisions*. It was based on 1979-to-1992 FARS data, specifically head-on collisions of two passenger cars of MY 1979 to 1991, each with a belted driver, resulting in a fatality to one or to both of the drivers. Head-on collisions are ideally suited for studying frontal crashworthiness differences between two cars. Both cars are subjected to essentially the same frontal collision. It does not matter if one of them had a "safe" driver and the other, an "unsafe" driver; at the moment they collide head-on, how safely anybody was driving before the crash is nearly irrelevant to what happens in the crash. Which driver dies and which driver survives depends primarily on the intrinsic relative crashworthiness of the two cars, their relative weights, and the age and gender of the two drivers (which influence their vulnerability to injury).[556]

If car 1 and car 2 have the same weight and are equally crashworthy and both drivers are the same age and gender the likelihood of a driver fatality in a head-on collision would be expected to be equal in car 1 and car 2. When vehicle weight and/or driver age/gender are not the same, the expected fatality risk for each driver is calibrated from the FARS data by a logistic regression. The expected fatality risk for driver 1 is

$$\frac{\exp[.616 - 5.427(\log W_1 - \log W_2) + .0531(A_1 - A_2) + .34(F_1 - F_2)]}{1 + \exp[.616 - 5.427(\log W_1 - \log W_2) + .0531(A_1 - A_2) + .34(F_1 - F_2)]}$$

where W_1 is the curb weight of car 1, A_1 is the age of driver 1, F_1 is 1 if driver 1 is female, 0 if male, and the various numbers are the regression coefficients (betas). The expected fatality risk for driver 2 is

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[555] Hackney, J., & Quarles, V. (1982). The New Car Assessment Program – Status and Effect. *Ninth International Technical Conference on Experimental Safety Vehicles*. (Report No. DOT HS 806 341, pp. 809-82). Washington, DC: National Highway Traffic Safety Administration; Hackney, J., & Ellison, C. (1986). A review of the effects of belts systems, steering assemblies, and structural design on the safety performance of vehicles in the New Car Assessment Program. *Tenth International Technical Conference on Experimental Safety Vehicles*. (Report No. DOT HS 806 916, pp. 380-413). Washington, DC: National Highway Traffic Safety Administration.

[556] Kahane (2013, May), pp. x-xi.

$$\frac{\exp[.616 + 5.427(\log W_1 - \log W_2) - .0531(A_1 - A_2) - .34(F_1 - F_2)]}{1 + \exp[.616 + 5.427(\log W_1 - \log W_2) - .0531(A_1 - A_2) - .34(F_1 - F_2)]}$$

For example, given 100 fatal head-on collisions between 3,000-pound cars driven by belted, 20-year-old males and 2,500-pound cars driven by belted, 50-year-old females, the formulas predict 9 deaths among the young males in the heavier cars and 97 deaths among the older females in the lighter cars (for a total of 106 fatalities in the 100 collisions, since some of them resulted in fatalities to both drivers).[557]

Cars with average crashworthiness will experience an actual number of fatalities close to what is predicted by the formulas. If a group of cars consistently experiences fewer driver fatalities than expected in their head-on collisions, then this group of cars is more crashworthy than the average car of similar mass. More generally, given a set of head-on collisions between one group of cars A and another group of cars B, it is possible to compare the crashworthiness of the two groups. For example, if the actual fatalities in the crashes and the sums of the expected probabilities of fatality (based on the formulas) are as follows:

Head-On Collisions between Groups A and B

	Car Group A	Car Group B
Actual fatalities	60	100
Expected fatalities	68	92

Then the fatality reduction for Group A relative to Group B is

$$1 - [\ (60/68)\ /\ (100/92)\ ] = 18.8 \text{ percent}$$

Specifically, NHTSA's evaluation compares actual and expected fatalities when Group A consists of cars with good scores on one or more NCAP parameters and Group B consists of cars with poor scores. For example, in 125 head-on collisions between cars with chest g's ≤ 56 on the NCAP test (a group averaging 44.6 chest g's on the test) and cars with chest g's > 56 (averaging 63.4 chest g's), with both drivers belted, the actual number of driver fatalities relative to the expected was 18.7 percent lower in the cars with the good scores than in the cars with the poor scores. The evaluation also considered many other sets of head-on collisions between groups of make-models with good and poor NCAP scores, where "good" and "poor" were defined on the basis of a single injury criterion – HIC, chest g's or femur load – or on various combinations of those criteria. Consistently, the actual fatality risk (relative to expected – i.e., after controlling for vehicle weight, driver age and gender) was significantly lower in the make-models with the better NCAP scores.[558]

As stated above, the average NCAP performance of new cars improved substantially between MY 1979 and MY 1991, with the largest improvement coming around 1983 to 1986. Therefore,

[557] Kahane (1994, January), p. 9.
[558] *Ibid*., pp. 79-118.

we would expect a corresponding reduction over time of fatality risk in head-on collisions. Indeed, NHTSA's evaluation showed that MY 1983-to-1986 cars had a statistically significant 20-percent reduction of fatality risk, relative to MY 1979-to-1982 cars, for belted drivers in car-to-car head-on collisions.[559]

NHTSA's evaluation is based entirely on analyses of belted drivers in head-on crashes between two cars. The data was limited almost entirely to cars without air bags. It is unknown if the 20-percent fatality reduction in these crashes would extend to other types of crashes. There might be a similar effect for belted drivers in frontal impacts with the side or rear of another passenger car (i.e., car-to-car, but not head-on) and – more tenuously – in frontal impacts with LTVs, heavy trucks or fixed objects, all of which are usually more rigid than cars. The results are least likely to extend to unbelted drivers, or any kind of non-frontal impacts. Also, these results for drivers of cars without air bags need not apply to passengers, or to drivers of cars with air bags. However, the "lives saved" model in this report will only attribute a potential benefit to NCAP when the belted driver of a passenger car without air bags frontally impacts another passenger car.

Frontal NCAP in vehicles with air bags (not evaluated)

The preceding scenario of NCAP in cars without air bags uniquely combines three features that, together, provide confidence that the benefits shown by the analysis can be attributed to NCAP and are not double-counting the effects of other safety improvements:

- The improvements took place in the 1980s, well after the introduction of 3-point belts (MY 1974) and before the introduction of frontal air bags – i.e., during an extended period without any substantial new regulations or other programs to improve frontal crashworthiness;
- It is known how manufacturers modified the vehicles during the early 1980s (see above list) and it is reasonably clear that improved NCAP performance was a reason for the modifications; and
- The analysis based on head-on collisions is especially suited for identifying differences in crashworthiness, without confounding factors such as where and how well vehicles of different make-models are driven.

Because the remaining test programs do not present all three of these features, NHTSA declines to attribute specific benefits to them in the "lives saved" model of this report, even if analyses show the better-performing vehicles are safer, because it might result in double-counting the effects of other technologies and regulations.

The proportion of new vehicles equipped with air bags increased greatly from 1990 onwards. The relationship between NCAP scores and fatality risk in actual head-on collisions in vehicles with air bags may be different from the result found in NHTSA's 1994 evaluation of MY 1979-to-1991 cars, mostly without air bags, described above. Other developments in frontal NCAP not considered in the 1994 evaluation include the extensive test results and crash data now available on LTVs, and the five-star rating system initiated in 1994 to make NCAP results more useful to

[559] *Ibid*., pp. xvi and 129-142.

the public.[560] Crash data involving head-on collisions of cars and LTVs equipped with driver or dual air bags could potentially be analyzed, using the five-star rating system to distinguish between "good" and "poor" NCAP performance. NHTSA, however, has already evaluated several technologies that arrived after 1990 and that protect occupants in frontal impacts: redesigned frontal air bags, advanced air bags, pretensioners and load limiters, and the head-impact upgrade of FMVSS No. 201. Some of these technologies directly contributed to better NCAP results.[561] Thus, the benefits found in a potential evaluation of NCAP might double-count the effects attributed to those technologies in the other evaluations.

Offset-frontal IIHS tests (partially evaluated)

In 1995, IIHS began testing and issuing information on vehicles' performance in offset-frontal impacts (subsequently renamed "moderate-overlap" impacts). The tests are run at 40 mph (5 mph higher than frontal NCAP), but into a barrier with a deformable, energy-absorbing face. The impact is "offset" in that the contact area between the test vehicle and the barrier extends only 40 percent across the front of the test vehicle, from the left corner to just short of the centerline. The test simulates a typical head-on crash in which a vehicle strays only partially into the lane of an oncoming vehicle. Each vehicle receives a rating of "good," "acceptable," "marginal," or "poor" for its overall performance and on four specifics: structural integrity, head protection, chest protection, and occupant kinematics.[562] In MY 2000, only 24 percent of new vehicles achieved a "good" overall rating, with 35 percent "acceptable," 20 percent "marginal," and 21 percent "poor." By MY 2007, 86 percent of new vehicles rated good, with 13 percent acceptable, under 1 percent marginal, and no poor ratings at all. Because the offset concentrates force on the left side of the test vehicle rather than spreading it across the entire front, the test provides valuable information on the vehicle's structural integrity. Vehicles "with poor or marginal performance on the IIHS offset test, especially structural performance … tend to allow more instrument-panel, toe-pan or floor-pan intrusion and deformation than the latest designs [with good or acceptable performance]."[563]

Farmer's statistical analysis of relative fatality risk in actual crashes between passenger cars with good and poor frontal-offset ratings, controlling for covariates such as the mass of the vehicles and the age of the drivers and based on the fairly limited data available in 2005, shows a 34-percent lower fatality risk for the driver of the good-rated vehicle across all crashes; the reduction is 74 percent in head-on crashes.[564] More generally, NHTSA's 2012 evaluation of relationships between mass, footprint, and fatality risk includes IIHS test performance as a covariate. That process generates estimates of the association between test performance and fatal-crash risk

[560] Hackney, J. R., & Kahane, C. J. (1995). *The New Car Assessment Program: Five Star Rating System and vehicle safety performance characteristics*. (Paper No. 950888). Warrendale, PA: Society of Automotive Engineers; NHTSA. (1993). *New Car Assessment Program: Response to the NCAP FY 1992 congressional requirements – report to the Congress*. Washington, DC: National Highway Traffic Safety Administration.
[561] Walz (2003).
[562] Farmer, C. M. (2005). Relationships of frontal offset crash test results to real-world driver fatality ratings. *Traffic Injury Prevention*, *6,* pp. 31-37; IIHS. (2012, December). *Moderate overlap frontal crashworthiness evaluation crash test protocol (Version XIV).* Arlington, VA: Insurance Institute for Highway Safety. Available at www.iihs.org/iihs/ratings/technical-information/technical-protocols.
[563] Bean et al. (2009, September), pp. 6-8 and 15.
[564] Farmer, (2005).

per billion VMT, while controlling for the driver's age and gender; the car's mass, and footprint; and roadway/environmental variables such as rural/urban, day/night, speed limit, CY, and the State where the crash occurred. In collisions of passenger cars with fixed objects or with other vehicles (excluding motorcycles), cars with marginal or poor overall performance have a statistically significant 10-percent higher fatal-crash rate than cars with good or acceptable overall performance. Cars with poor structural performance had a statistically significant 14-percent higher fatal-crash rate than cars with good or acceptable structural performance (and an 8%-increase for marginal relative to good or acceptable performance).[565]

Given the evidence that structural integrity of the passenger compartment in frontal impacts has improved in vehicles over the past 20 years (1994 to 2014), it might be possible to estimate a specific fatality reduction in frontal impacts for improved structures. NHTSA, however, does not currently have enough information to quantify the effect; it is also possible that some of the preceding effectiveness estimates for occupant-protection technologies introduced during that period, such as pretensioners, load limiters, and advanced air bags, may to some extent include the effects of improved vehicle structures.

Side NCAP and IIHS side impact testing (not evaluated)

After September 1, 1996, when all cars were required to meet a dynamic side impact test as part of FMVSS No. 214, NHTSA expanded NCAP to provide consumer information on vehicle performance in side impacts. In the NCAP tests, the MDB strikes the side of the target vehicle at 38.5 mph, 5 mph faster than in the FMVSS No. 214 test. The agency uses a five-star rating system for outboard front seat occupants and outboard rear seat occupants. Before MY 2012, the rating was based on the TTI(d) scores for the dummies in the tests. (Effective MY 2012, the agency modified the injury criteria used to computed the star rating and also added a pole test.[566]) As discussed in the chapter on FMVSS No. 214, the principal tool for reducing TTI(d) after MY 1997 was to install side air bags.[567]

In 2003, IIHS expanded its rating system to include side impacts in which a 3,300-pound MDB simulating the front end of a typical pickup truck or SUV impacts the side of the test vehicle at 31 mph and at a 90° angle. The dummies in the test vehicles simulate 5th-percentile females (near-side, front and rear seats). Each vehicle receives a rating of "good," "acceptable," "marginal," or "poor" for its overall performance, its structural integrity, and its protection of dummies' head, neck, thorax, pelvis, and legs. The IIHS test, which employs a taller MDB and a shorter dummy than NCAP to elicit head impacts, may have been an incentive to introduce inflatable head protection as well as torso bags.[568] To the extent that Side NCAP and the IIHS side impact ratings may have encouraged and expedited the installation of curtain and/or side air bags, they have made valuable contributions to safety – but the "lives saved" model of this report already

[565] Kahane, C. J. (2012, August). *Relationships between fatality risk, mass, and footprint in model year 2000-2007 passenger cars and LTVs – Final report*. (Report No. DOT HS 811 665, pp. 77-79). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811665.PDF.
[566] *Federal Register* 73 (July 11, 2008): 40016, 76 (July 29, 2011): 45453.
[567] See also Kahane (2007, January), pp. 17-29, especially Figures 1-11 and 1-12.
[568] Teoh & Lund (2011, June).

measures the effects of curtain and side air bags and in that regard it would not need additional computations for these rating programs.

Rollover-resistance NCAP (partially evaluated)

In MY 2001, NHTSA expanded NCAP with ratings of one to five stars for rollover resistance, based on the static stability factor (SSF), which equals one half of the track width divided by the height of the center of gravity above the road: the higher the SSF, the less "top-heavy" the vehicle. This measurement identified the location of the center of gravity of the vehicle and correlated this to the risk of a tripped rollover crash. Linear and logistic regressions, based on crash data for MY 1994-to-1998 vehicles, show a remarkably strong relationship between SSF and rollover rate per 100 single vehicle crashes.[569] Starting with MY 2004 vehicles, NHTSA has issued rollover resistance star ratings that combine information from the SSF (based on measurements of stationary vehicles) with information on whether any wheels lift off the ground during dynamic tests called "fishhook maneuvers," which consist of an abrupt left turn followed by abrupt right turn (or vice-versa) and are conducted at 35 to 45 mph.[570] NHTSA evaluated the trend of the SSF from MY 1985 to 2003 for passenger cars and LTVs.[571]

	Average SSF	
	MY 1985	MY 2003
Passenger cars	1.36	1.41
Pickup trucks	1.18	1.18
SUVs (including CUVs)	1.08	1.17
Minivans	1.11	1.24
Full-size vans	1.09	1.12

Static stability improved the most for SUVs and minivans, less for cars and full-sized vans. Average SSF did not change for pickup trucks. SUVs and minivans had, on the average, poor static stability in 1985 but had improved to about the same level as pickup trucks by 2003 – but all four types of LTVs had average SSF lower than passenger cars. NHTSA has not yet evaluated the trend after 2003 or quantified the effect of these trends on fatal rollover crashes.

[569] *Federal Register* 66 (January 12, 2001): 3388.
[570] *Federal Register* 68 (October 14, 2003): 59250.
[571] Walz, M. C. (2005, June). *Trends in the static stability factor of passenger cars, light trucks, and vans*. (Report No. DOT HS 809 868, p. 8). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809868.PDF.

SUMMARY TABLES FOR PART 1

Tables 1-2, 1-3 and 1-4 summarize the effectiveness estimates for safety technologies obtained in past evaluation reports, as discussed in the preceding chapters of Part 1. Table 1-2 summarizes the estimated percentage reductions in fatalities; Table 1-3, nonfatal injuries; and Table 1-4, crashes (always specifying to what group of crashes/injuries/fatalities these percentages apply – but for more detail, refer back to the preceding chapters). The effectiveness estimates in Table 1-2 are also used in this report's model to assess lives saved by vehicle safety technologies from 1960 to 2012. When NHTSA has evaluated a safety technology more than once (e.g., CHMSL), the latest estimates are the ones shown in Tables 1-2, 1-3 and 1-4.

Tables 1-3 and 1-4 also summarize the estimated annual benefits of nonfatal injury reduction and crash avoidance, as stated in NHTSA's evaluation reports. However, those estimates of benefits, in general, are not directly comparable and do not add up to the overall crash avoidance and injury reduction by all the FMVSS in, say, 2002. NHTSA does not have enough "building blocks" to develop models for overall crash avoidance and injury reduction comparable to the analysis of fatal crashes in Part 2 of this report.

Table 1-2: Estimates of Fatality Reduction
in NHTSA Evaluations of Safety Technologies

FMVSS No.	SAFETY TECHNOLOGY	Vehicle Type	Fatality-Reducing Effectiveness Estimate(s)
105: Hydraulic brake systems; 135: Light vehicle brake systems			
	Dual master cylinders		
		Cars and LTVs	0.7% reduction of all fatal crash involvements
	Front disc brakes		
		Cars and LTVs	0.17% reduction of all fatal crash involvements
	Rear-wheel ABS		
		LTVs	No significant overall effect
	4-wheel ABS		
		Cars	No significant overall effect
			13% reduction of collisions with non-occupants
			9% increase in run-off-road crashes
		LTVs	No significant overall effect
			14% reduction of collisions with non-occupants
108: Lamps, reflective devices			
	Side marker lamps		
		Cars and LTVs	No significant effect
	Center high mounted stop lamps		
		Cars and LTVs	No significant effect
	Retroreflective tape		
		Heavy trailers	29% reduction of cars and LTVs hitting the side or rear of a heavy trailer in the dark
	Daytime running lights		
		Cars and LTVs	No significant effect
	Amber rear turn signals		
		Cars and LTVs	No significant effect

Table 1-2 (continued): Estimates of Fatality Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No.
SAFETY TECHNOLOGY
Vehicle Type — Fatality-Reducing Effectiveness Estimate(s)

FMVSS No. / Safety Technology / Vehicle Type	Fatality-Reducing Effectiveness Estimate(s)
126: Electronic stability control	
Cars	60% reduction of first-event rollovers
	31% reduction of fixed-object impacts
	16% reduction of culpable involvements in multi-vehicle crashes
LTVs	74% reduction of first-event rollovers
	45% reduction of fixed-object impacts
	16% reduction of culpable involvements in multi-vehicle crashes
201: Occupant protection in interior impact	
Voluntary middle and lower instrument panel improvements	
Cars and LTVs	15.9% in frontal crashes, for unrestrained RF passengers
1999-2003 head injury protection upgrade	
Cars and LTVs	4.28% reduction in overall fatality risk for all occupants in all crashes (excluding occupants riding outside the passenger compartment)
202: Head restraints	
Head restraints for front seat	
Cars and LTVs	No significant effect
203: Impact protection from the steering control; 204: Steering control rearward displacement	
Energy-absorbing steering assemblies	
Cars and LTVs	12.1% in frontal crashes, for drivers
205: Glazing materials	
HPR windshields	
Cars and LTVs	No significant effect
Glass-plastic windshields	
Cars	No significant effect

Table 1-2 (continued): Estimates of Fatality Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Fatality-Reducing Effectiveness Estimate(s)
206: Door locks and retention components	
Improved locks for side doors	
Cars	15.38% reduction of ejection fatalities in rollovers (excluding occupants riding outside the passenger compartment)
LTVs	9.8 % reduction of ejection fatalities in rollovers (excluding occupants riding outside the passenger compartment)
207: Seating systems	
Seat back locks	
2-door cars	No significant effect
208: Occupant crash protection; 209: Seat belt assemblies; 210: Seat belt assembly anchorages	
Lap belts for front seat (age 5+)	
Cars	27% overall fatality reduction
LTVs	48% overall fatality reduction
Lap belts for rear seat (age 5+)	
Cars	32% overall fatality reduction
LTVs	63% overall fatality reduction
3-point belts for front seat (age 5+)	
Cars	45% overall fatality reduction
LTVs	60% overall fatality reduction
3-point belts for rear seat (age 5+)	
Cars	44% overall fatality reduction
LTVs	73% overall fatality reduction
Seat belts for child passengers age 1-4 (lap or 3-point; front or rear seat)	
Cars	33% overall fatality reduction
LTVs	48% overall fatality reduction

Table 1-2 (continued): Estimates of Fatality Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Fatality-Reducing Effectiveness Estimate(s)
208: Occupant crash protection (continued)	
Automatic 2-point belts (age 5+)	
Cars	32% overall fatality reduction
Belt pretensioners and load limiters	
Cars, CUVs, and minivans	12.8% fatality reduction for a belted driver or RF passenger relative to a belted driver or RF passenger in a vehicle without pretensioners or load limiters
Truck-based LTVs	No significant effect
Frontal air bags, barrier-certified	
Cars and LTVs	10.8% overall fatality reduction for belted drivers
	14% overall fatality reduction for unbelted drivers
	11.9% overall fatality red. for belted RF age 13+
	15.4% overall fatality red. for unbelted RF age 13+
	22% fatality increase for child passengers < 13 (varies considerably depending on age/restraint use)
Frontal air bags, sled-certified	
Cars and LTVs	same as barrier-certified for drivers and RF age 13+
	No significant overall effect for child passengers < 13 (but fatality increases for some subgroups)
Frontal air bags, advanced	
Cars and LTVs	same as barrier-certified for drivers and RF age 13+
	No significant increase for any subgroup of child passengers < 13
Manual on-off switches for air bags	
Pickup trucks	86% of switches were turned off for infants in a rear-facing child seat in the RF seat of the truck
	74% of switches turned off for children age 1-6
	83% of switches turned on for adults (age 13+)

Table 1-2 (continued): Estimates of Fatality Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Fatality-Reducing Effectiveness Estimate(s)
212: Windshield mounting	
Adhesive windshield bonding	
Cars and LTVs	15% fatality reduction for people ejected through the windshield portal
213: Child restraint systems; 225: Child restraint anchorage systems	
Child safety seats	
Cars	71% overall fatality reduction for infants (age < 1)
	54% overall fatality reduction for children 1 to 8 years old
LTVs	58% overall fatality reduction for infants (age < 1)
	59% overall fatality reduction for children 1 to 8 years old
Riding in the rear seat, children < 13 years old	
Cars w/o air bags	33% reduction for restrained in the outboard rear seat relative to restrained in the RF seat
	31% reduction for unrestrained in the outboard rear seat relative to unrestrained in the RF seat
	46% reduction for restrained in the center rear seat relative to restrained in the RF seat
	47% reduction for unrestrained in the center rear seat relative to unrestrained in the RF seat
214: Side impact protection	
Side door beams	
Cars	14% fatality reduction for occupants of outboard seats in single-vehicle side impacts
LTVs	19% fatality reduction for occupants of outboard seats in single-vehicle side impacts

Table 1-2 (continued): Estimates of Fatality Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Fatality-Reducing Effectiveness Estimate(s)
214: Side impact protection (continued)	
TTI(d) improvement by structure and padding	
2-door cars	0.927% fatality reduction per unit reduction of TTI(d), when TTI(d) is in a range above 90, for outboard front seat occupants in all side impacts
	0.863% fatality reduction per unit reduction of TTI(d), when TTI(d) is in a range below 90, for outboard front seat occupants, but only in near-side impacts by another vehicle
	33% cumulative fatality reduction from MY 1985 to MY 1997 for outboard front seat occupants in near-side impacts by another vehicle
4-door cars	0.863% fatality reduction per unit reduction of TTI(d), when TTI(d) is in a range below 90, for outboard front seat occupants, but only in near-side impacts by another vehicle
	17% cumulative fatality reduction from MY 1985 to MY 1997 for outboard front seat occupants in near-side impacts by another vehicle
Curtain plus torso bags	
Cars and LTVs	31.3% fatality reduction for drivers and RF passengers in near-side impacts
Combination head/torso bags	
Cars and LTVs	24.8% fatality reduction for drivers and RF passengers in near-side impacts
Curtain bags only	
Cars and LTVs	16.4% fatality reduction for drivers and RF passengers in near-side impacts
Torso bags only	
Cars and LTVs	7.8% fatality reduction for drivers and RF passengers in near-side impacts

Table 1-2 (continued): Estimates of Fatality Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Fatality-Reducing Effectiveness Estimate(s)
216: Roof crush resistance	
Eliminate true hardtops	
Cars	7.4% reduction of non-ejection fatalities in rollover crashes (excluding occupants riding outside the passenger compartment)
226: Ejection mitigation	
Rollover curtains	
Cars and LTVs	41.3% overall fatality reduction in first-event rollover crashes
	45.5% reduction of ejection fatalities in first-event rollover crashes
301: Fuel system integrity	
1975-1977 upgrade: rollover, rear- and lateral-impact tests	
Cars and LTVs	No significant effect
2005-2009 upgrade: rear- and lateral-impact tests	
Cars and LTVs	35.2% fatality reduction in rear impacts with post-crash fires
	No significant effect in other crashes with post-crash fires
NCAP: New Car Assessment Program	
Frontal NCAP-related improvements	
Cars w/o air bags	20% fatality reduction for MY 1986 and later cars, relative to MY 1979 cars, for belted drivers in frontal collisions with other passenger cars

Table 1-3: Estimates of Injury Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Injury-Reducing Effectiveness Estimate(s) / Injuries Prevented per Year When All Vehicles on the Road Have the Technology
105: Hydraulic brake systems; 135: Light vehicle brake systems	
Dual master cylinders	
Cars and LTVs	0.7% reduction of all injury crash involvements
	24,000 injuries of any severity prevented per year (computation used 1979-80 as the baseline year)
Front disc brakes	
Cars and LTVs	0.17% reduction of all injury crash involvements
	5,700 injuries of any severity prevented per year (computation used 1979-80 as the baseline year)
Rear-wheel ABS	
LTVs	No significant effect
4-wheel ABS	
Cars	6% overall reduction of nonfatal-injury crash involvements
	17% reduction of culpable involvements in multi-vehicle crashes where someone is injured
LTVs	8% overall reduction of nonfatal-injury crash involvements
	20% reduction of culpable involvements in multi-vehicle crashes where someone is injured
108: Lamps, reflective devices	
Side marker lamps	
Cars and LTVs	21% reduction of injury-producing nighttime angle collisions when both vehicles in a crash have the lamps
	93,000 injuries of any severity prevented per year (computation used 1979-80 as the baseline year)
Center high mounted stop lamps	
Cars and LTVs	4.3% reduction of injuries to people involved in front-to-rear collisions
	58,000-70,000 injuries of any severity prevented per year (computation used 1994 as the baseline year)

Table 1-3 (continued): Estimates of Injury Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Injury-Reducing Effectiveness Estimate(s) / Injuries Prevented per Year When All Vehicles on the Road Have the Technology
108: Lamps, reflective devices (continued)	
Retroreflective tape	
Heavy trailers	29% reduction of cars and LTVs hitting the side or rear of a heavy trailer in the dark
	3,100-5,000 injuries of any severity prevented per year (computation used 2001 as the baseline year)
Daytime running lights	
Cars and LTVs	No significant effect
Amber rear turn signals	
Cars and LTVs	5.3% reduction of injuries to people involved in front-to-rear impacts where the lead vehicle is turning or preparing to turn
121: Air brake systems	
ABS for heavy truck-tractors	10% reduction of culpable involvements in multi-vehicle crashes where someone is injured
126: Electronic stability control	
Cars	72% reduction of first-event rollovers
	45% reduction of fixed-object impacts
	13% reduction of culpable involvements in multi-vehicle crashes
LTVs	64% reduction of first-event rollovers
	67% reduction of fixed-object impacts
	13% reduction of culpable involvements in multi-vehicle crashes
201: Occupant protection in interior impact	
Voluntary middle and lower instrument panel improvements	
Cars	29% reduction of AIS $\geq$ 2 injuries from instrument panel contact in frontal crashes, for RF passengers
	8,000 AIS $\geq$ 2 injuries prevented per year (computation used 1982 as the baseline year)

Table 1-3 (continued): Estimates of Injury Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. SAFETY TECHNOLOGY Vehicle Type	Injury-Reducing Effectiveness Estimate(s) Injuries Prevented per Year When All Vehicles on the Road Have the Technology
201: Occupant protection in interior impact (continued)	
1999-2003 head injury protection upgrade	
Cars and LTVs	32% reduction of AIS ≥ 4 head injuries from upper-interior injury sources for all occupants in all crashes (excluding occupants riding outside the passenger compartment)
202: Head restraints	
Head restraints for front seat	
Cars	16.9% injury reduction in rear-impact crashes with fixed or integral head restraints
	10.4% injury reduction in rear-impact crashes with adjustable head restraints
	85,000 injuries of any severity prevented per year with a fleet of fixed or integral head restraints (computation used 1979 as the baseline year)
	52,000 injuries of any severity prevented per year with a fleet of adjustable head restraints (computation used 1979 as the baseline year)
LTVs	6.1% injury reduction in rear-impact crashes with any type of head restraint
	14,900 injuries of any severity prevented per year (computation used 1999 as the baseline year)
203: Impact protection from the steering control; 204: Steering control rearward displacement	
Energy-absorbing steering assemblies	
Cars	38.4% reduction of fatal or hospitalizing injuries due to contact with the steering assembly in frontal crashes
	23,000 nonfatal hospitalizations prevented per year (computation used 1978 as the baseline year)

Table 1-3 (continued): Estimates of Injury Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. SAFETY TECHNOLOGY Vehicle Type	Injury-Reducing Effectiveness Estimate(s) Injuries Prevented per Year When All Vehicles on the Road Have the Technology
205: Glazing materials	
HPR windshields	
Cars	74% reduction of AIS ≥ 2 lacerations due to windshield contact
	56% reduction of AIS 2-to-4 facial fractures due to windshield contact
	72% reduction of AIS 2-to-4 injuries of the eyes, nose and mouth due to windshield contact
	25% reduction of AIS 1 lacerations due to windshield contact
	39,000 AIS ≥ 2 lacerations prevented per year (computation used 1982 as the baseline year)
	8,000 AIS 2-to-4 facial fractures
	The preceding 47,000 AIS 2-to-4 injuries include 19,000 injuries to the eyes, nose or mouth
Glass-plastic windshields	
Cars	No significant effect
207: Seating systems	
Seat back locks	
2-door cars	No significant effect
208: Occupant crash protection; 209: Seat belt assemblies; 210: Seat belt assembly anchorages	
Lap belts for front seat	
Cars	33% overall AIS ≥ 3 injury reduction
	22% overall AIS ≥ 2 injury reduction
	8% overall AIS ≥ 1 injury reduction
Lap belts for rear seat	
Cars	37% overall fatal-and-serious (K + A) injury reduction
	33% overall moderate-to-fatal (K + A + B) injury reduction
	11% overall (K + A + B + C) injury reduction

Table 1-3 (continued): Estimates of Injury Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No.	
SAFETY TECHNOLOGY	Injury-Reducing Effectiveness Estimate(s)
Vehicle Type	Injuries Prevented per Year When All Vehicles on the Road Have the Technology
3-point belts for front seat	
Cars	45% overall AIS ≥ 3 injury reduction
	46% overall AIS ≥ 2 injury reduction
	13% overall AIS ≥ 1 injury reduction
Frontal air bags	
Cars and LTVs	12% overall AIS ≥ 3 injury reduction for belted occupants age 13+
	4% overall AIS ≥ 2 injury reduction for belted occupants age 13+
	21% overall AIS ≥ 3 injury reduction for unbelted occupants age 13+
	21% overall AIS ≥ 2 injury reduction for unbelted occupants age 13+
212: Windshield mounting	
Adhesive windshield bonding	
Cars and LTVs	15% AIS 3-to-5 injury reduction for people ejected through the windshield portal
	171 AIS 3-to-5 injuries prevented per year (computation used 1982 as the baseline year)
213: Child restraint systems; 225: Child restraint anchorage systems	
Child safety seats	
Cars and LTVs	46% overall reduction of fatal or hospitalizing injuries for children less than 6 years old
	31% reduction of overall (K + A + B + C) injuries

Table 1-3 (continued): Estimates of Injury Reduction in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Injury-Reducing Effectiveness Estimate(s) / Injuries Prevented per Year When All Vehicles on the Road Have the Technology
214: Side impact protection	
Side door beams	
Cars	25% reduction of fatal or hospitalizing injuries for occupants of outboard seats in single-vehicle side impacts
	25% reduction of fatal or hospitalizing injuries for near-side occupants in side impacts by another vehicle, centered in the occupant compartment area
	9,470 nonfatal hospitalizations prevented per year (computation used 1980 as the baseline year)
301: Fuel system integrity	
1975-77 upgrade: rollover, rear- and lateral-impact tests	
Cars	14% reduction in all post-crash fires
	3,900 fires prevented per year (unknown number of injuries; computation used 1982-87 as the baseline years)
LTVs	No significant effect

Table 1-4: Estimates of Crash Avoidance in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Crash-Reducing Effectiveness Estimate(s) / Crashes Avoided per Year When All Vehicles on the Road Have the Technology
103: Windshield defrosting and defogging	
Rear-window defoggers	
Cars	No significant effect
105: Hydraulic brake systems; 135: Light vehicle brake systems	
Dual master cylinders	
Cars and LTVs	0.7% reduction of all crash involvements
	40,000 police-reported crashes avoided per year (computation used 1979-80 as the baseline year)
Front disc brakes	
Cars and LTVs	0.17% reduction of all injury crash involvements
	9,800 police-reported crashes avoided per year (computation used 1979-80 as the baseline year)
Rear-wheel ABS	
LTVs	No significant effect
4-wheel ABS	
Cars	6% overall reduction of crash involvements
	17% reduction of culpable involvements in multi-vehicle crashes
LTVs	8% overall reduction of crash involvements
	20% reduction of culpable involvements in multi-vehicle crashes
108: Lamps, reflective devices	
Side marker lamps	
Cars and LTVs	16.8% reduction of nighttime angle collisions when both vehicles in a crash have the lamps
	106,000 police-reported crashes avoided per year (computation used 1979-80 as the baseline year)

Table 1-4 (continued): Estimates of Crash Avoidance in NHTSA Evaluations of Safety Technologies

FMVSS No. / SAFETY TECHNOLOGY / Vehicle Type	Crash-Reducing Effectiveness Estimate(s) / Crashes Avoided Per Year When All Vehicles on the Road Have the Technology
108: Lamps, reflective devices (continued)	
Center high mounted stop lamps	
Cars and LTVs	4.3% reduction of rear impacts
	92,000-137,000 police-reported crashes plus 102,000 unreported crashes avoided per year (computation used 1994 as the baseline year)
Retroreflective tape	
Heavy trailers	29% reduction of cars and LTVs hitting the side or rear of a heavy trailer in the dark
	7,800 police-reported crashes avoided per year (computation used 2001 as the baseline year)
Daytime running lights	
Cars and LTVs	No significant effect
Amber rear turn signals	
Cars and LTVs	5.3% reduction of injuries to people involved in front-to-rear impacts where the lead vehicle is turning or preparing to turn
121: Air brake systems	
ABS for heavy truck-tractors	10% reduction of culpable involvements in multi-vehicle crashes
126: Electronic stability control	
Cars	72% reduction of first-event rollovers
	45% reduction of fixed-object impacts
	13% reduction of culpable involvements in multi-vehicle crashes
LTVs	64% reduction of first-event rollovers
	67% reduction of fixed-object impacts
	13% reduction of culpable involvements in multi-vehicle crashes

PART 2

Lives Saved by Vehicle Safety Technologies and Associated Federal Motor Vehicle Safety Standards, 1960 to 2012

Summary of the Estimation Method

From 1960 to 2012, over 2.3 million people died in motor vehicle crashes in the United States. Starting in 1975, FARS has furnished detailed information on over 1.6 millionof these fatality cases. Using FARS data, we have built a model from which we can estimate how many additional people would have died had it not been for the vehicle safety technologies affecting passenger cars and LTVs. We can also estimate how many lives have been saved by each technology, year-by-year, from 1960 through 2012. The analysis updates a report issued by NHTSA in 2004 that estimated vehicle safety technologies had saved 328,551 lives from CY 1960 through 2002.[572] The estimates are updated through 2012 by incorporating FARS data from 2003 through 2012 into the analysis and by including the effects of safety technologies that NHTSA has evaluated since the previous report.

Each 100 actual fatality cases in FARS represent a potentially even greater number of fatalities that could have happened if the vehicles had not been equipped with any safety technologies. The actual fatality cases are the starting point for a model to estimate the lives saved by vehicle safety technologies. The model is similar to the technique that NHTSA has been using since 1993 to estimate the number of lives saved each year by seat belts, frontal air bags and child safety seats.[573] That technique is essentially expanded to the other safety standards.

For example, FARS might have records of 100 driver fatalities, wearing seat belts, in MY 2001 cars equipped with frontal air bags, in frontal multivehicle crashes with primary impact point 12 o'clock (i.e., directly frontal). The NHTSA evaluations reviewed in Part 1 of this report estimate that frontal air bags reduce fatality risk for belted drivers by 25.3 percent in 12 o'clock frontal crashes. Thus, if the cars had not been equipped with air bags, there would have been not 100 but

$$100/(1 - .253) = 134 \text{ potential fatalities.}$$

In other words, the existence of these 100 actual fatality cases with frontal air bags in FARS implies that the MY 2001 vehicles were involved in 134 crashes potentially fatal to their drivers. However, 34 of those potentially fatal crashes did not become FARS fatality cases because the air bag saved the driver's life.

[572] Kahane (2004, October).
[573] *Traffic safety facts 2012 data – Occupant protection*; Kahane (1996, August), pp. 19-20; Glassbrenner, D., & Starnes, M. (2009, December). *Lives saved calculations for seat belts and frontal air bags.* (Report No. DOT HS 811 206). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811206.pdf.

Three-point belts reduce drivers' fatality risk by an estimated 42 percent in multivehicle frontal impacts. If seat belts as well as air bags had been removed from those cars, the number of potential fatalities would have increased from 134 to

$$134/(1 – .42) = 231 \text{ potential fatalities.}$$

That implies the use of seat belts saved 231 – 134 = 97 lives. But the benefits of the safety technologies do not stop here. Even after stripping the air bags and 3-point belts, these MY 2001 cars would still have had energy-absorbing steering assemblies to protect their drivers. Those assemblies reduce drivers' fatality risk in frontal collisions by an estimated 12.1 percent. If the energy-absorbing steering assemblies in these cars had been replaced by pre-1968 rigid columns, there would have been not 231 but

$$231/(1 – .121) = 263 \text{ potential fatalities.}$$

The energy-absorbing columns saved an implicit 263 – 231 = 32 lives. The 100 actual fatality cases in FARS imply the existence of 263 potentially fatal crash cases. They imply that the three safety technologies (frontal air bags, seat belts, energy-absorbing columns) saved a combined total of 163 lives: 34 by frontal air bags, 97 by seat belts and 32 by energy-absorbing columns.

The process works the same in reverse: consider a population of MY 1966 cars, not equipped with energy-absorbing columns, 3-point belts or frontal air bags, involved in 12 o'clock frontal multivehicle crashes, resulting in fatalities to 263 drivers. If these cars had been equipped with energy-absorbing columns (introduced in 1967 to 1968) but not yet 3-point belts (introduced primarily in 1974) or frontal air bags (introduced in 1985 to 1997), the columns would have reduced the fatalities by 12.1 percent, from 263 to 231. If, in addition, the cars had been equipped with 3-point belts and the drivers had buckled up, the belts would have reduced those fatalities by 42 percent, from 231 to 134. Finally, the addition of frontal air bags would have reduced the remaining fatalities by 25.3 percent, from 134 to 100.

In other words, the model begins with numbers of actual FARS fatality cases and inflates those numbers step-by-step, using the effectiveness estimates from the NHTSA evaluations documented in Part 1 of this report, until all FMVSS and safety technologies **relevant to this type of crash** have been "removed" from the vehicle – until the vehicle has been downgraded to a level of safety performance characteristic of the 1950s rather than its actual model year. The effects of safety technologies are "removed" in the reverse chronological order that they were historically introduced into vehicles. Starting, say, with an MY 2012 vehicle, we first "remove" the relevant safety device most recently introduced, say in 2006, and downgrade the vehicle to the MY 2005 level of safety; next, the device introduced, say in 1996, diminishing the vehicle to the MY 1995 level, and so on until the vehicle is degraded to 1950s technologies without any of the modern safety devices. At each step into the past, the model tallies the lives [or fractions of lives] saved by the latest safety technology – i.e., the additional fatalities that would have occurred if that technology had been removed.

The model produces unbiased estimates of the lives saved by the various technologies, and it is not an exercise in double counting, because each of the effectiveness estimates in Part 1 is based on analyses of vehicles produced **just after** versus **just before** the introduction of the technology in question.[574] For example, the evaluation of frontal air bags was limited to data on MY 1985 and later cars, some without air bags and some with frontal air bags, but all equipped with 3-point belts and energy-absorbing steering columns. Thus, the above effectiveness estimate is no more than the incremental effect of frontal air bags, given that a car already has energy-absorbing steering columns and that the driver buckled up. Similarly, the effectiveness estimate for 3-point belts was based on MY 1975-to-1986 cars always equipped with energy-absorbing steering columns but almost never with air bags. It measured the incremental effect of belts, given that cars already had the columns, but not air bags. The evaluation of energy-absorbing steering columns was limited to data on MY 1966-to-1968 cars, without air bags or 3-point belts, and measured the effect of the column for an (almost always) unrestrained driver of a pre-standard car. In other words, these effectiveness estimates are each incremental, and may be applied in sequence, as shown above, to estimate the total fatality reduction for the combination of the three technologies.[575]

One factor that simplifies the model is that in most cases only a few technologies apply to any specific crash situation. For example, the energy-absorbing steering column only benefits drivers in frontal crashes, and its effect will never need to be combined with, say, the benefit of rear seat belts. In addition, the safety technologies that have little or no effect on fatalities (even though they significantly reduced nonfatal injuries or crashes), such as head restraints or CHMSL, do not need to be addressed in this model.

The model requires enough information about each FARS case of an occupant fatality in a passenger car or LTV to determine which safety technologies were present in the vehicle, and what effect, if any, each of these technologies would have had, given the type of crash and the type of occupant. In other words, the following data elements are needed to apply the model to an individual fatality case.

Vehicle

- Vehicle type: car or LTV (pickup, SUV, CUV, minivan or full-size van)
- Model year
- Make-model, if possible
- Impact locations – principal and initial
- Most harmful event

Occupant

- Seating position
- Age
- Restraint system use
- Was the occupant ejected?

[574] Even though the analyses are based on vehicles produced just after versus just before the FMVSS, they usually include crashes involving these vehicles over a number of calendar years after the FMVSS. Specifically, in the case of crash avoidance standards, vehicles have been on the road long enough for drivers to adapt to the technologies, if that is an issue.
[575] Kahane (1996, August), pp. 7-9; Kahane (2000, December), pp. 5-10; Kahane, (1981, January), pp. 197-203.

Crash

- Calendar year
- Single- or multivehicle
- First harmful event/manner of collision
- Light condition

Crash avoidance technologies are more complicated because their life-saving benefits are not limited to the occupants of the vehicles equipped with them. Dual master cylinders and front disc brakes in passenger cars and LTVs benefit not only the occupants of the vehicles equipped with these technologies but also the pedestrians, bicyclists and motorcyclists who are not struck by those vehicles as a result of their safety contributions; ESC in cars and LTVs also similarly benefits motorcyclists. Conspicuity tape has only been installed on heavy truck trailers, but it saves occupants of cars and LTVs who, as a consequence, do not strike the trailers. This "full" accounting of the benefits of the FMVSS and other safety technologies for cars and LTVs includes not only the lives saved in cars and LTVs by car/LTV technologies or child safety seats (which turn out to be 99 percent of the total), but also the non-occupants and motorcyclists saved by car/LTV technologies and the car/LTV occupants saved by technologies in other vehicles (heavy trailers) – any technology where cars/LTVs produce and/or receive benefits. For that purpose it is necessary to know, for each non-occupant or motorcyclist fatality, the model year/type of the vehicle that struck it, and for each car/LTV occupant fatality in impacts with heavy trucks, the model year and impact location on the heavy truck, and the light conditions at the time of the crash.

The model does not address the benefits of safety technologies in vehicles other than cars and LTVs aside from the benefits to occupants of the cars/LTVs struck by those other vehicles. For example, it does not include motorcyclist lives saved by motorcycle helmets.

The model also does not estimate fatality reductions (or increases) due to shifts between existing vehicle types or seating positions such as: between cars and LTVs, large cars and small cars, 2-door and 4-door cars, or between the front seat and the rear seat. They are not "new safety technologies" but merely shifts between existing vehicle designs. However, the effects of these shifts on safety may account for some of the year-to-year changes in the "base" of actual and potential fatalities.

The model consists of three principal sections:

Preprocessor to adjust for missing data elements: As listed above, the model requires complete information for a core group of data elements to determine which safety equipment was in the case vehicle and the effect, if any, this equipment had on fatality risk, given the type of crash, the occupant's seat position, and other factors. However, FARS cases may have "unknown" codes for one or more of these data elements, in which case the original FARS data need to be transformed to a file that has complete information on the core data elements and whose case weights add up to the same number of fatalities as in the original file. There are two strategies to adjust for missing data:

- Vehicle type and vehicle model year are rarely missing. In the well under 1 percent of occupant fatality cases where they are missing, the remaining data elements rarely provide clues for an educated guess at the vehicle type or model year. The strategy here is to omit the cases with missing data and to give the leftover cases a weight factor slightly higher than 1 so that their weights add up to the original fatality total.

- More frequently unknown are the vehicle impact location/crash type (2% of car/LTV occupant fatalities), occupant seating position (2%), and restraint use (14%). Other variables and knowledge of their typical distributions can help to determine, case-by-case, the likely distributions of the unknowns. For example, if the "manner of collision" is front-to-rear (multivehicle), the impact location/crash type is most likely a frontal or a rear impact and unlikely to be a side impact or rollover. If the most harmful event is a collision with a tree, the impact location is very likely frontal, possibly a side impact, but unlikely to be a rear impact. A passenger with unknown seating position was more likely to have been in the rear seat if he or she was a child than if an adult and more likely to have occupied an "unenclosed part of the vehicle" if the vehicle was a pickup truck than if it was a minivan. An adult with unknown restraint use from a crash that happened in 2012 was more likely to have been belted than if the crash happened in 1980.

Several regression analyses estimate the distribution of impact type, seating position and belt use as a function of other core variables, based on the calibration dataset of cases with known values on all the core variables. For example, when the fatality is a non-ejected driver 50 or older, the vehicle is a passenger car, and the first harmful event is an impact with a tree or highway sign, the distribution of these fatalities by impact type is 76 percent frontal, 19 percent side, 3 percent rollover and 2 percent rear/other. The strategy here is to replace the FARS fatality case of the 50+ year-old car driver who hit a tree with unknown vehicle-impact location by four new cases, each of which retain the values of the other core variables: one with a frontal impact, one with a side impact, one rollover and one rear/other impact. If the original case had a weight factor of 1, the new cases will have weight factors of .76, .19, .03, and .01, respectively.

The two strategies generate a file of fatality cases with non-missing values on all the core variables. Data inconsistencies are also corrected – e.g., "lap and shoulder belts used" is changed to "lap belt used" if a seat was only equipped with lap belts.

Calculation of lives saved, 1975-2012: The model runs through each of the actual fatality cases and removes the safety technologies from the vehicle in the reverse chronological order that they were implemented in the fleet, inflating the case weight factor as each technology is removed. In the example at the beginning of this discussion, if the case of the belted driver fatality in the MY 2001 car in a directly frontal, multivehicle crash has a case weight of 1, that case weight would have been inflated to 1.34 after removing the frontal air bag, 2.31 after removing the seat belts, and 2.63 after removing the energy-absorbing column, because the combination of energy-absorbing columns, seat belts and frontal air bags are estimated to reduce 2.63 fatalities to 1 fatality in this type of crash. Thus, this actual fatality case contributes evidence of .34 lives saved by air bags, .97 by seat belts and .32 by energy-absorbing columns, totaling up to 1.63 lives saved by all the technologies. Benefits are summed and tabulated by technology (sometimes grouped by associated FMVSS), by vehicle type, by CY, and by whether the technology was compliant with a standard already in effect or was voluntarily furnished by the manufacturer at the time the vehicle was built.

The chronological order of the safety technologies is based on their **median installation** (or implementation) **years**, generally the first model year in which 50 percent or more of new vehicles were equipped with the technology (but in a few cases, such as child safety seats, the first CY in which the use rate reached 50%). Table 2-1 shows the chronological order of the 31 safety improvements for passenger cars that NHTSA has evaluated to date and the analysis showed a statistically significant reduction of fatality risk.

Table C-1 in Appendix C of this report shows the percentages of new cars, in each model year, equipped with the various technologies. It pinpoints (in bold red print) the median installation year. For example, lap belts for outboard front seat occupants were offered on some new cars as early as 1956, and were required on all new cars after FMVSS No. 208 took effect on January 1, 1968. However, NCSS and NASS data show that 1962 is the first MY in which 50 percent of new cars [involved in towaway crashes] were equipped with lap belts. A description, regulatory history and effectiveness estimate for every safety improvement in Table 2-1 may be found in Part 1 of this report, within the chapter whose FMVSS number matches the code number for that technology (or in the "NCAP" chapter).

NHTSA's initial safety standards took effect on January 1, 1968, but the manufacturers had already implemented some of the safety technologies several years earlier. Three-point seat belts and side door beams were the major innovations of the 1970s. Frontal air bags and the side-impact upgrade by structure and padding highlighted improvements in the 1990s. Major technologies reaching 50 percent of the new-car market between 2000 and 2010 include the head-impact upgrade, curtain and side air bags, seat belt pretensioners/load limiters, and ESC.

Three subsequent enhancements to frontal air bags – manual on-off switches, the 1998-to-1999 redesign (sled-certification), and advanced air bags (automatic suppression or low-risk deployment) – are treated by the model's chronological listing as if they are parts of a single technology, frontal air bags, whose median installation year was 1992. After the model estimates the number of lives saved by frontal air bags, it then allocates those savings to first-generation, redesigned, or advanced air bags and also computes the effects of on-off switches on fatalities. Similarly, the model treats curtain and side air bags as a single technology in the chronological listing, but then separately calculates lives saved for the various types of side air bags.

Two of the 31 technologies are not applied to the cars themselves. Child safety seats are add-on equipment and conspicuity tape is applied to heavy trailers to help car drivers see the trailers at night and avoid collisions with them. For these two, rather than a median installation year, Table 2-1 identifies a median implementation year: the first CY when over 50 percent of children 4 or younger rode in safety seats (1985), and the first CY when over 50 percent of heavy trailers on the road were treated with tape (1996).

Table 2-1: Installation Dates of Safety Technologies in Passenger Cars

		First Offered In	**Median Installation Year**[576]	FMVSS Effective Date[577]
208A	Lap belts for outboard front seat occupants	1956	**1962**	1/1/68
208B	Lap belt use by children age 1-4	1956	**1965 early**	1/1/68
206	Improved door locks	1962 (?)[578]	**1965**	1/1/68
208C	Lap belts for outboard rear seat passengers	1961 (?)	**1965 late**	1/1/68
212	Adhesive windshield bonding	1963	**1966 early**	1/1/70[579]
208D	Lap belts for center front seat passengers	1961 (?)	**1966**	1/1/68
105A	Dual master cylinders	1962	**1966 late**	1/1/68
208E	Lap belts for center rear seat passengers	1961 (?)	**1967 early**	1/1/68
203	Energy-absorbing steering assemblies	1967	**1967**	1/1/68
201	Voluntary instrument panel improvements	1967 (?)	**1968**	1/1/68[580]
105B	Front disc brakes	1965	**1971**	1/1/76
214A	Side door beams	1969	**1973 early**	1/1/73
216	Roof crush resistance, eliminate hardtops	1970	**1973**	9/1/73
208F	3-point belts for outboard front seat occupants	1963	**1974**	9/1/73
NCAP	NCAP-related improvements (w/o air bags)	1982	**1984**	N.A.
213	Child safety seats	Pre-1970[581]	**1985**[582]	4/1/71
208G	3-point belts for outboard rear seat passengers	1971	**1989**	12/11/89
208H	Automatic 2-point belts	1975	**1991**[583]	9/1/86-9/1/89
208I	Frontal air bags	1985	**1992**	1987-1990
	Manual on-off switches for passenger air bags			
	Redesigned air bags (1998-1999)			
	Advanced air bags			
214B	TTI(d) red. in 2 & 4-door cars (214 upgrade)	1986 (?)	**1996 early**	1994-1997
108	Conspicuity tape – heavy trailers	1991 (?)	**1996**	12/1/93
201B	Head impact upgrade (padding)	1999	**2001 early**	1999-2003
208J	3-point belts for center rear seat passengers	1994	**2001**	2006-2008
208K	Pretensioners & load limiters	1995	**2002**	N.A.
214C	Curtain and side air bags	1996	**2006**	2011-2015
301	Fuel system integrity: rear impact upgrade	2006	**2008**	2007-2009
126	ESC	1998	**2010**	2009-2012
226	Rollover curtains	2003	**>2011**	2014-2017

[576] Unless otherwise noted, first MY that over 50 percent of new vehicles were equipped with this safety technology. "Early" = close to 50 percent were already equipped in the preceding year and/or much more than 50 percent were equipped in this year or the following year. "Late" = far fewer than 50 percent were equipped in the preceding year and/or barely over 50 percent were equipped in this year and the following year.
[577] Or range of MY for phase-in period.
[578] (?): approximate date
[579] FMVSS No. 212 did not specifically require adhesive bonding; some cars continued to have rubber gaskets (meeting FMVSS No. 212) after the effective date.
[580] FMVSS No. 201 did not require these improvements to middle and lower instrument panels; these improvements were not necessarily introduced before the effective date.
[581] Effective seats were offered before 1970; child passenger protection laws took effect in all States, 1978-85.
[582] Safety seat use first exceeded 50 percent in 1985.
[583] Phased out of new cars after 1996; never reached 50 percent of new vehicles; 1991 was the peak installation year.

"Reverse chronological order" is just one of several general methods that could have been used to allocate lives saved among the safety technologies in those crashes where more than one technology is beneficial (e.g., frontal air bags, seat belts and energy-absorbing steering columns for drivers in frontal crashes). Furthermore, "median installation year" is just one of several specific methods that could have been used to order the standards chronologically. However, in considering other allocation methods or orderings, it is important to note that all methods should produce the **same estimate of overall lives saved** (the primary objective of this report), only changing the allocation of the lives saved among the individual standards. In the example at the beginning of this section, all methods would agree that the combination of frontal air bags, seat belts, and energy-absorbing steering columns saved 163 lives in the crashes where drivers were protected by all three. They would only differ on how to allocate these 163 lives among air bags, belts, and energy-absorbing columns – a more theoretical issue because these drivers are being saved by the combination of all three devices, and there is no obvious way to pinpoint who was saved by what.

The reverse-chronological method is intuitively straightforward. It views each (at that time) new safety technology as building upon the baseline of previously existing technologies, and it allocates to the new technology only the benefits relative to that baseline: it computes how many lives are saved if technology Z is added to cars that already have X and Y. Another advantage is that the effectiveness estimates in NHTSA evaluations are computed on that basis and enter directly into the model this report uses to estimate total lives saved.

A less attractive feature of the reverse-chronological method is that the allocation between technologies depends on their chronological order. In general, moving a standard earlier in the chronological order will increase the benefits allocated to that standard and take some away from the standards that follow (leaving unchanged, however, the total lives saved by the combination of these standards). Two technologies might, in some intuitive way, be equally effective, but the model would allocate more lives saved to the earlier one.

An alternative approach that could allocate independently of chronological order is based on the effectiveness of each technology acting alone. For example, X alone might reduce fatality risk by 30 percent and Y alone by 10 percent. If the combination of X and Y saves 1,000 lives, 750 of them are allocated to X and 250 to Y (based on the ratio of their free-standing effectiveness estimates). That approach is feasible if there are data on vehicles that have only X and other vehicles that have only Y (e.g., seat belts without frontal air bags, and air bags with unrestrained drivers). But it is essentially impossible for most of the non-belt technologies in this report, because they were introduced in nearly all vehicles in the same sequence: first X, then Y. For example, we know the effectiveness of energy-absorbing columns without frontal air bags, but it is impossible to estimate, from crash data, the effectiveness of air bags without energy-absorbing columns, because there are no vehicles with air bags and rigid columns.

Even within the reverse-chronological method, there are alternatives to using the median installation year. The median year is fine if technologies X and Y were each introduced over relatively short, non-overlapping timeframes – e.g., energy-absorbing steering columns (1967-to-1968) and frontal air bags (1985-to-1996). It also works for the non-belt technologies in Tables 2-1 and 2-2, because even though some technologies were introduced at about the same time, they usually do not apply to the same occupant or crash type – e.g., energy-absorbing steering columns for drivers and improved instrument panels for passengers.

A problem arises with seat belts, whose use has gradually increased over the years. Some people began to buckle up long before cars had air bags but others only started a few years ago. Theoretically, we should ascertain when each individual started buckling up to decide the "order" of seat belts and frontal air bags for that individual. FARS, however, only tells us if a fatality was belted, but it does not say in what year that person first started buckling up. We only know that 3-point belts became available in all new cars in MY 1974, that most States had buckle-up laws by 1987, and that on-the-road belt use exceeded 50 percent by 1991. Whatever year we use as the "median" implementation year for seat belts, it is before the median installation year for frontal air bags (1992) and after the median installation years for all the early "built-in" safety technologies up to side door beams, preserving the sequence in Table 2-1.

Another issue with the reverse-chronological method is that new technologies may eclipse older technologies to some extent. For example, curtain air bags may have made some of the earlier energy-absorbing padding unnecessary for head impact protection and may even have resulted in removal of some of the padding (see the discussion in the FMVSS Nos. 201 and 214 chapters in Part 1). NHTSA's evaluations estimate (1) the fatality reduction with curtains (plus whatever padding remains in the vehicle) relative to a vehicle without the curtains but with all the padding needed to certify to FMVSS No. 201; and (2) the fatality reduction with padding relative to a vehicle with neither curtains nor padding. The reverse-chronological method first "transforms" a vehicle with curtains into a vehicle without curtains but with FMVSS No. 201 padding; then it "removes" the padding. The "lives saved" model will attribute a benefit to curtains based on effectiveness estimate (1) and a benefit to padding based on estimate (2). This method, in theory, may understate the lives saved by the curtains and overstates lives saved by padding (although the two add up to the right total), because in many cases it is the curtains that cushion the head impacts while the padding is not significantly contacted or is not even in the vehicle at that impact location – but it would be difficult to quantify how many of the lives saved should be reallocated from the padding to the curtains. Thus, as in the preceding issues, we will stay with the reverse-chronological method, which directly applies the effectiveness estimates based on the statistical analyses.

Similar situations where new technologies may partially eclipse older ones (although in these cases the older technology remains in the vehicle and usually continues to contribute to the overall life-saving effect) include:

- Side air bags and the padding introduced to certify to FMVSS No. 214,
- Frontal air bags and energy-absorbing steering columns, and
- 3-point belts and redesigned mid- and lower instrument panels at the RF seating position.

Here, too, the lives-saved model uses the reverse-chronological method.

NHTSA's 2004 report, which estimated lives saved from CY 1960 through 2002, only includes 22 of the 31 technologies listed in Table 2-1. Seven of the nine technologies not included in the 2004 report were already available in some production vehicles of MY 2002 or earlier – ESC, curtain and side air bags, the head-impact upgrade of FMVSS No. 201, belt pretensioners and load limiters, manual switches for passenger air bags, redesigned frontal air bags, and rollover curtains – but NHTSA did not yet have estimates of fatality reduction based on crash data. The other two technologies – advanced frontal air bags and the 50 mph rear-impact test for FMVSS No. 301 – were still in the future. Furthermore, the earlier report's effectiveness estimate for side-impact structures and padding is superseded by a 2007 analysis.

The estimates of lives saved in the current report will be identical to the 2004 report from CY 1960 through 1985. Small differences will begin in 1986: the current model has new estimates of the effects of side-impact structures and padding, improvements that began gradually on a voluntary basis in MY 1986, even though the upgrade to FMVSS No. 214 did not phase in until MY 1994 to 1997. Because technologies whose effects are included here but not in the earlier report – ESC, curtain and side air bags, etc. – proliferated after 1995, the current model's estimates of lives saved will become, year by year, progressively somewhat higher than the earlier report's. The next chapter ("Findings") will show that the current report estimates 332,459 lives saved cumulative from 1960 through 2002, which is slightly higher than the 328,551 estimated in NHTSA's 2004 report. CY by CY, the increases range from 8 additional lives saved in 1986 (8,531 in the current report, 8,523 in the 2004 report) to 1,130 in 2002 (25,691 versus 24,561).

These increments in lives saved, however, are not limited to the seven newer safety measures, but will even accrue to some of the 22 original technologies. This can be demonstrated by reconsidering the earlier example of 100 driver fatalities, wearing seat belts, in MY 2001 cars equipped with frontal air bags, involved in 12 o'clock impacts in multivehicle crashes. The previous model estimated that the 100 actual fatalities corresponded to 263 potential fatalities without the FMVSS, of which frontal air bags saved 34 lives, belt use saved 97 lives, and energy-absorbing steering columns saved 32 lives: adding up to 163 lives saved.

But these particular MY 2001 cars were also equipped with ESC (not considered in the previous model) and they were the culpable vehicles in these crash involvements. ESC reduces the risk of culpable involvements in fatal collisions with other vehicles by an estimated 16 percent. If the cars had not been ESC-equipped, there would have been not 100 but

$$100/(1 - .16) = 119 \text{ potential fatalities.}$$

If the cars had also not been equipped with frontal air bags, there would have been not 119 but

$$119/(1 - .253) = 159 \text{ potential fatalities.}$$

If the drivers had not been belted, that would have increased to

$$159/(1 - .42) = 275 \text{ potential fatalities.}$$

If rigid columns had replaced the energy-absorbing steering columns that would have increased to

$$275/(1 - .121) = 313 \text{ potential fatalities.}$$

In other words, the new model will estimate 213 lives saved (i.e., 313 potential minus 100 actual fatalities) rather than 163 lives saved. The new total includes not only the 19 lives saved by ESC, but also 40 rather than 34 lives saved by frontal air bags, 116 rather than 97 lives saved by belts, and 38 rather than 32 lives saved by energy-absorbing steering columns.

Table 2-2 shows the chronological order of the 27 life-saving improvements for LTVs. Table C-3 in Appendix C lists percentages of new LTVs, by MY, equipped with the various technologies, identifying the median installation year in bold red print. The 27 technologies for LTVs are the same improvements as for cars, but excluding

- Automatic belts (never installed in LTVs);
- NCAP-related improvements in LTVs without frontal air bags (not evaluated for LTVs); and
- The original FMVSS No. 216, "Roof crush resistance" and the dynamic-test upgrade of FMVSS No. 214, "Side impact protection." NHTSA has little evidence that LTVs required or received substantial modifications to meet those regulations.

Many of the earlier FMVSS were not extended to LTVs until several years after they had been in effect for cars. More recently, some technologies became widely available a few years earlier in LTVs than in cars (ESC, rollover curtains) or vice-versa (side air bags, 3-point belts for center rear seats). As a result, the chronological order of the technologies in LTVs is slightly different from cars. In both LTVs and cars, though, 3-point belts for drivers and RF passengers were installed before frontal air bags but after energy-absorbing steering columns and voluntary instrument-panel improvements.

Tables C-2 (cars) and C-4 (LTVs) of Appendix C show the percentages of vehicles on the road, by calendar year, equipped with the various safety technologies. There is a multiyear lag from when a safety improvement first appears in new vehicles until the majority of vehicles on the road will have it; older vehicles without the device may continue in service many years before they are retired. As of CY 2012, for example, 95 percent of cars on the road had frontal air bags, but only 42 percent had some kind of curtain or side air bags, and only 20 percent had ESC.

If two technologies were implemented at the same time and benefited the same people in the same types of crashes, there is a danger of double-counting the benefits – i.e., attributing the joint benefit to each of the individual technologies. However, the history of the safety measures, as shown in Tables 2-1 and 2-2 and the analysis methods in most NHTSA evaluations (with control groups) minimize that danger. Major technologies usually came in several years apart, but even when two were introduced at once, they did not benefit the same people because:

- They applied to different seating positions (e.g., front seat belts and rear seat belts);
- They applied to different crash types (e.g., side impacts and frontal impacts);
- Belt technologies only benefit belted occupants, while other technologies can benefit unrestrained occupants; or
- 100-series FMVSS can be evaluated for their crash avoidance benefits, while 200-series FMVSS do not have such benefits.

Table 2-2: Installation Dates of Safety Technologies in LTVs

		First Offered In	**Median Installation Year**[584]	FMVSS Effective Date[585]
208A	Lap belts for outboard front seat occupants	1956 (?)[586]	**1964**	7/1/71
208B	Lap belt use by children age 1-4	1956 (?)	**1966**	7/1/71
105A	Dual master cylinders	1962 (?)	**1966 late**	9/1/83
206	Improved door locks	1962 (?)	**1967**	1/1/72
208C	Lap belts for outboard rear seat passengers	?	**1967 late**	7/1/71
208D	Lap belts for center front seat passengers	1965 (?)	**1968**	7/1/71
208E	Lap belts for center rear seat passengers	?	**1968**	7/1/71
105B	Front disc brakes	1965 (?)	**1971**	9/1/83
201	Voluntary instrument panel improvements	1969 (?)	**1972**	9/1/81[587]
203	Energy-absorbing steering assemblies	1970	**1975**	9/1/81
208F	3-point belts for outboard front seat occupants	1969	**1977**	9/1/76
212	Adhesive windshield bonding	1978 (?)	**1980**	9/1/78[588]
213	Child safety seats	Pre-1970[589]	**1985**[590]	4/1/71
208G	3-point belts for outboard rear seat passengers	1987	**1992**	9/1/91
214A	Side door beams	1991	**1994**	9/1/93
208I	Frontal air bags	1991-92	**1995**	9/1/94-9/1/97
	Manual on-off switches for passenger air bags			
	Redesigned air bags (1998-1999)			
	Advanced air bags			
108	Conspicuity tape – heavy trailers	1991 (?)	**1996**[591]	12/1/93[592]
201B	Head impact upgrade (padding)	1999	**2002 early**	1999-2003
208K	Pretensioners & load limiters	1998	**2002**	N.A.
208J	3-point belts for center rear seat passengers	1998	**2003**	2006-2008
301	Fuel system integrity: rear impact upgrade	2006	**2007**	2006-2009
126	ESC	1999	**2008 early**	2009-2012
214C	Curtain and side air bags	1998	**2008**	2011-2015
226	Rollover curtains	2002	**2009**	2014-2017

584 Unless otherwise noted, first MY that over 50 percent of new vehicles were equipped with this safety technology. “Early” = close to 50 percent were already equipped in the preceding year and/or much more than 50 percent were equipped in this year or the following year. “Late” = far fewer than 50 percent were equipped in the preceding year and/or barely over 50 percent were equipped in this year and the following year.
585 Or range of MY for phase-in period.
586 (?): approximate date
587 FMVSS 201 did not require these improvements to middle and lower instrument panels.
588 FMVSS 212 did not specifically require adhesive bonding; some LTVs continued to have rubber gaskets (meeting FMVSS 212) after the effective date.
589 Effective child safety seats were offered before 1970; child passenger protection laws took effect in all States, 1978-85.
590 Safety seat use first exceeded 50 percent in 1985.
591 First CY when over 50 percent of heavy trailers on the road were equipped with the tape.
592 FMCSA retrofit requirement effective 6/1/2001.

Postprocessor to estimate lives saved in 1960-1974: FARS data only exists from 1975. However, the FMVSS date back to 1968 and some of them incorporate technologies available well before that. The postprocessor extends the estimation model back to the years before FARS existed, specifically 1960 to 1974.

The National Safety Council's *Accident Facts* tally the number of fatalities in motor vehicle crashes each year in the United States and apportion the fatalities among car occupants, "truck" occupants, motorcyclists, pedestrians/bicyclists, and several other categories.[593] For CY 1975 to 1980, when FARS and *Accident Facts* are both available, it is possible to compare the total fatalities for the two data sources (which use slightly different definitions of "motor vehicle crash fatality") and the number in each category and thereby establish ratios of FARS to *Accident Facts* case counts. These ratios are applied to the *Accident Facts* counts for each earlier year to estimate a hypothetical number of FARS fatality cases if FARS had existed that year.

The postprocessor essentially recreates a FARS file for each year from 1960 to 1974, with just the core variables needed to operate the model. It runs these files through the basic model to estimate how many additional people would have died had it not been for the FMVSS and other vehicle safety technologies affecting passenger cars and LTVs.

The core variables are the number of vehicles in the crash (1, 2+); the vehicle's impact type (front, side, rollover, rear/other) and MY; and the occupant's age group (0, 1-4, 5+), seating position, belt/safety seat use, and ejection status. The joint distribution of the core variables is inferred from 1975-to-1980 FARS. Specifically, all the variables except MY, belt use, and safety seat use are assumed to have the same distribution in earlier years as on 1975-to-1980 FARS. The distribution of vehicle age is also assumed not to change, and the distribution of vehicles by model year is obtained by noting that MY = CY – vehicle age.

Belt use depends on the vehicle's MY and the occupant's seating position, based on trends seen in 1975-to-1980 FARS data; safety seat use depends on the child's age and the CY. The various assumptions add uncertainty to this part of the model, but it does not matter so much because, as we shall see, fewer than 3 percent of the lives saved from 1960 to 2012 were saved during 1960 to 1974. A file is created with one cell for each possible combination of values of the core variables, and with cell fatality counts that add up to the number of FARS cases if FARS had existed that year.

For example, suppose this process had created a cell count of 100 "would-have-been" FARS cases of unbelted drivers in frontal crashes of MY 1968 cars in CY 1972. All MY 1968 cars were equipped with energy-absorbing steering assemblies that reduce drivers' fatality risk in frontal collisions by 12.1 percent. If the energy-absorbing steering assemblies in these cars had been replaced by pre-1968 rigid columns, there would have been not 100 but $100/(1 - .121) = 114$ potential fatalities. The energy-absorbing columns saved an implicit $114 - 100 = 14$ lives in this cell.

Appendix A of this report contains step-by-step descriptions of the preprocessor and the main model. It also discusses the auxiliary programs needed to run the model.

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[593] For example, (1978). *Accident facts 1978 edition*. Chicago: National Safety Council, pp. 56 and 58.

FINDINGS

Estimates of lives saved

Table 2-3 shows that safety technologies regulated by the FMVSS or introduced on a voluntary basis saved an estimated 613,501 lives during the 53 years from 1960 to 2012. The annual number of lives saved grew from 115 in 1960, when a small number of people used lap belts, to 27,621 in 2012, when most cars and LTVs were equipped with numerous modern safety technologies and belt use on the road achieved 86 percent.[594] The number of lives saved grew every year except 1974, 1981 to 1982, and 2008 to 2011 when, among other things, transient phenomena (possibly triggered by an energy crisis, a fuel-price increase, or an economic slowdown) substantially reduced baseline crashes from the previous year.

The total of 613,501 includes 65,563 lives saved by voluntary improvements and 547,938 saved by technologies compliant with FMVSS that were in effect at the time. "Voluntary" improvements include those introduced before the actual effective date of a FMVSS (e.g., energy-absorbing steering assemblies before January 1, 1968) and distinct technologies that were never required for meeting a FMVSS (such as belt pretensioners and load limiters).

On the other hand, technologies compliant with a specific FMVSS in effect at the time are credited in Table 2-3 to the "FMVSS in effect," even if the manufacturer selected a technology that excelled the minimum requirements of the FMVSS. For example, lives saved by a frontal air bag in a 1998 car are credited to the air bag FMVSS, regardless of whether that car scored a HIC of 1000 (the minimum requirement) or 200 (exceptionally good performance) on the FMVSS No. 208 test. The number of lives saved is computed from fatality-reducing effectiveness estimates based on statistical analyses of crash data involving production vehicles as actually equipped. In almost all cases, the statistical analyses did not (and could not) differentiate between the basic benefit of minimally complying with a FMVSS and the additional benefits when actual vehicles excelled the minimum requirements. Thus, both benefits are included in "FMVSS in effect" column of Table 2-3 and subsequent tables – but it is implicit that these columns may include portions, of unknown magnitude, that are also voluntary in a sense.

Furthermore, if the FMVSS was phased in over several model years (the customary NHTSA practice since the mid-1980s), the <u>beginning</u> of the phase-in is considered the "actual effective date of the FMVSS" in these computations.

[594] Every number in Tables 2-3 through 2-54 has been rounded to the nearest integer to make it look like counts of people, even though the lives-saved model can generate fractions of lives saved. Because of the rounding, the columns of printed numbers might not always add exactly to the totals at the ends of tables.

Table 2-3: Lives Saved by Vehicle Safety Technologies, 1960-2012
(Car and LTV occupants saved + non-occupants and motorcyclists saved by car/LTV techs)

		L I V E S S A V E D	
CY	TOTAL	BY VOLUNTARY IMPROVEMENTS	BY FMVSS IN EFFECT
1960	115	115	0
1961	117	117	0
1962	135	135	0
1963	160	160	0
1964	203	203	0
1965	251	251	0
1966	339	339	0
1967	509	509	0
1968	816	709	107
1969	1,179	831	348
1970	1,447	866	581
1971	1,774	957	817
1972	2,226	1,096	1,130
1973	2,576	1,168	1,408
1974	2,518	1,005	1,513
1975	3,058	1,073	1,986
1976	3,240	1,089	2,151
1977	3,671	1,156	2,515
1978	4,040	1,185	2,855
1979	4,299	1,198	3,101
1980	4,540	1,219	3,321
1981	4,455	1,167	3,288
1982	4,057	1,060	2,997
1983	4,248	1,003	3,244
1984	4,835	963	3,872
1985	6,389	1,086	5,303
1986	8,531	1,224	7,307
1987	9,992	1,263	8,729
1988	11,292	1,326	9,965
1989	11,522	1,330	10,192
1990	11,761	1,332	10,429
1991	12,250	1,320	10,931
1992	12,573	1,346	11,228
1993	13,902	1,417	12,486
1994	15,263	1,514	13,749
1995	16,265	1,563	14,701
1996	17,956	1,624	16,332
1997	18,751	1,646	17,106
1998	19,613	1,582	18,031
1999	20,256	1,543	18,714
2000	22,280	1,583	20,696
2001	23,364	1,557	21,807
2002	25,691	1,612	24,079
2003	27,174	1,718	25,456
2004	28,253	1,776	26,477
2005	29,936	1,825	28,111
2006	30,242	1,977	28,266
2007	30,312	2,153	28,159
2008	27,941	2,168	25,773
2009	26,770	2,090	24,680
2010	26,695	2,112	24,583
2011	26,098	2,054	24,045
2012	27,621	2,250	25,370
	===========	===========	===========
	613,501	**65,563**	**547,938**

Of course, before January 1, 1968, every life saved was due to a “voluntary” improvement – or at least one not required by the Federal government, although some States required seat belts in new cars well before 1968. After 1968, lives saved by voluntary improvements have gradually escalated from approximately 1,000 to just over 2,000 per year, comprising modifications to instrument panels, pretensioners and load limiters, TTI(d) reductions before the FMVSS No. 214 upgrade, NCAP-related changes, and numerous improvements introduced before, sometimes well before a FMVSS took effect. Specifically, ESC and curtain and side air bags became available in the late 1990s but the corresponding FMVSS did not phase in until MY 2009 to 2015. The benefits of voluntary improvements continue as long as the vehicles remain on the road, long past the FMVSS effective date. For example, the energy-absorbing columns in MY 1967 cars, produced before the January 1, 1968, effective date, started generating “voluntary” benefits in late 1966, when those cars first began to sell, and continued to generate them as long as any of those cars were still on the road, even in 2012.

By contrast, the number of lives saved by technologies compliant with FMVSS in effect has grown dramatically from a modest start of 107 in 1968. They accounted for 25,370 of the 27,621 total lives saved in 2012.

Any non-belt technology “built into” new cars or LTVs takes years to build up substantial benefits. At first, only the newest vehicles on the road have the technology. Only after 6 years (for the initial FMVSS) to 12 years (for the most recent technologies, because vehicles last longer now) are they in the majority of vehicles on the road. By contrast, any program to increase belt use, such as buckle-up laws, can have an immediate large effect on lives saved. The belts are already in the vehicles; the program immediately increases the number of people who use them.

If the estimated lives saved in Table 2-3 are added up from 1960 through just 2002, the total is 332,459. This is slightly higher than the 328,551 estimated in NHTSA’s 2004 report, which only went up to CY 2002.[595] As explained in the preceding chapter, estimates increased from CY 1986 onwards, especially toward 2002, because the current report includes technologies such as ESC, curtain and side air bags, and head impact protection, for which effectiveness had not yet been fully evaluated in 2004. Essentially, the new numbers correct a slight underestimate in the earlier report. But the principal difference between the 613,501 lives saved in Table 2-3 and the 328,551 in the 2004 report is what happened from CY 2003 through 2012 (not included in the earlier report): an average of 28,104 lives saved per year.

[595] Kahane (2004, October), p. xii.

Figure 2-1 graphs the year-by-year trend in lives saved (the first column in Table 2-3). It took until 1969 to reach 1,000. Throughout the 1970s, new vehicles meeting the early FMVSS gradually superseded the older on-road fleet, contributing to steady growth in lives saved, but that was offset by declining belt use in the late 1970s, prior to national buckle-up campaigns. The largest gains in both absolute and relative terms came with the buckle-up laws: lives saved rose from 4,835 in 1984 to 11,292 in 1988. Until 2007, continued increases in belt use, frontal and, later, side air bags, ESC, other recent technologies, and a steadily escalating "base" of more vehicles and more VMT helped the fatality reduction grow steadily, reaching a peak in absolute terms of 30,312 in 2007. The base of VMT and exposure declined from 2008 to 2011, more than offsetting the continued improvement of vehicle safety: lives saved dropped each year, down to 26,098 in 2011. However, as we shall soon see, the percentage of potential fatalities saved continued to rise in those years. In 2012, lives saved once again increased to 27,621, as VMT and the proportion of vehicles equipped with safety technologies both expanded.

Table 2-4 compares the lives saved, year-by-year, by vehicle or person type. Car occupants are the largest group, comprising 385,408 of the 613,501 lives saved. However, commensurate with the growth in LTV sales relative to cars, the number of lives saved in LTVs has almost caught up with cars in recent years, reaching 13,500 in 2012, compared to 14,018 car occupants. By contrast, in 1980, safety technologies saved only 608 LTV occupants versus 3,848 car occupants.

The effect of car/LTV braking improvements and ESC on pedestrian, bicyclist and motorcyclist fatalities is small relative to the effect of all the FMVSS on car/LTV occupants. Non-occupants accounted for 2,211 and motorcyclists, 725 of the 613,501 lives saved. Once dual master cylinders and front disc brakes were in most of the cars and LTVs on the road, in the mid-1970s, non-occupant and motorcyclist lives saved stopped increasing and have, in fact, declined as the "base" of pedestrian and motorcyclist exposure decreased until about 2009 (pedestrians) or 1998 (motorcyclists). In the last few years, ESC in cars and LTVs has helped them avoid hitting motorcycles and saved an increasing number of motorcyclists (but ESC has not had a significant effect on car/LTV collisions with pedestrians, to date).

FIGURE 2-1: LIVES SAVED PER YEAR BY VEHICLE SAFETY TECHNOLOGIES, 1960 TO 2012

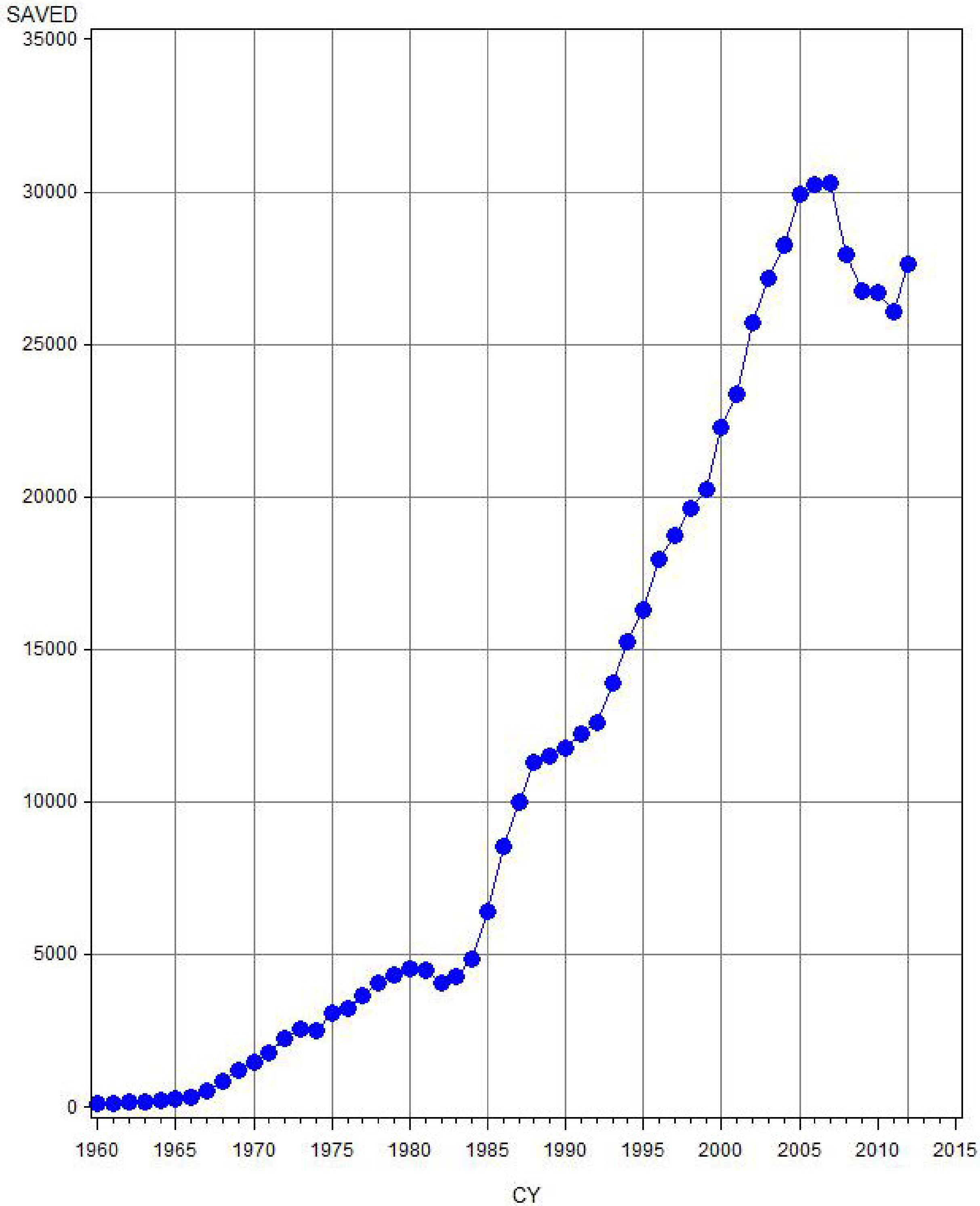


Table 2-4: Lives Saved by Vehicle Safety Technologies, 1960-2012, by Vehicle/Person Type

CY	TOTAL	CAR OCCUPANTS	LTV OCCUPANTS	PEDESTRIANS BICYCLISTS	MOTOR-CYCLISTS
1960	115	92	22	0	0
1961	117	95	22	0	0
1962	135	110	25	0	0
1963	160	131	28	1	0
1964	203	168	34	1	0
1965	251	211	38	2	0
1966	339	288	46	4	1
1967	509	444	55	9	1
1968	816	719	80	15	2
1969	1,179	1,042	114	21	2
1970	1,447	1,279	136	28	4
1971	1,774	1,574	161	35	4
1972	2,226	1,984	194	42	6
1973	2,576	2,282	238	48	8
1974	2,518	2,220	244	45	9
1975	3,058	2,723	272	53	10
1976	3,240	2,852	324	54	11
1977	3,671	3,190	409	58	14
1978	4,040	3,501	462	60	16
1979	4,299	3,657	561	64	18
1980	4,540	3,848	608	65	18
1981	4,455	3,758	614	64	18
1982	4,057	3,394	585	62	16
1983	4,248	3,534	641	57	15
1984	4,835	3,943	815	60	17
1985	6,389	5,196	1,118	59	17
1986	8,531	6,828	1,626	60	17
1987	9,992	7,788	2,128	60	15
1988	11,292	8,752	2,464	61	14
1989	11,522	8,706	2,746	58	12
1990	11,761	8,727	2,963	58	12
1991	12,250	8,996	3,191	53	11
1992	12,573	9,079	3,435	50	9
1993	13,902	10,005	3,836	52	10
1994	15,263	10,725	4,479	50	9
1995	16,265	11,252	4,952	51	9
1996	17,956	12,212	5,685	50	9
1997	18,751	12,335	6,359	49	9
1998	19,613	12,549	7,007	48	9
1999	20,256	12,698	7,503	45	9
2000	22,280	13,491	8,733	43	12
2001	23,364	14,131	9,174	45	13
2002	25,691	15,053	10,581	44	13
2003	27,174	15,482	11,632	43	16
2004	28,253	15,608	12,585	43	17
2005	29,936	16,305	13,564	46	22
2006	30,242	16,400	13,771	45	26
2007	30,312	16,287	13,950	43	33
2008	27,941	14,752	13,113	41	35
2009	26,770	13,960	12,738	39	33
2010	26,695	13,746	12,871	40	38
2011	26,098	13,285	12,726	42	45
2012	27,621	14,018	13,500	45	58
	===========	===========	===========	===========	===========
	613,501	**385,408**	**225,158**	**2,211**	**725**

Net effectiveness for car/LTV occupants

Table 2-5 concentrates on the occupant fatalities in cars and LTVs. The first column is the actual number of occupant fatalities. There were an estimated 1,712,855 actual occupant fatalities in cars and LTVs from CY 1960 through 2012.[596] The next column estimates how many fatalities would have happened from 1960 to 2012 if none of the safety technologies had existed: 2,323,421.[597] The third column, equal to column 2 minus column 1, is the lives saved by the safety technologies: 610,566 from 1960 through 2012. The fourth column is the overall effectiveness of the existing safety technologies in each calendar year: the lives saved divided by the number of fatalities there would have been without any safety improvements. The effectiveness grew in **every** year from 1960 to 2012, from a humble 0.40 percent in 1960 to a very substantial 55.92-percent fatality reduction in 2012. There were 21,696 actual car/LTV occupant fatalities in 2012, but there would have been 49,214 without the safety technologies. The 27,518 lives saved represent 55.92 percent of the potential fatalities.

Three graphs help to illustrate the trends in actual fatalities, potential fatalities and effectiveness. Figure 2-2 compares the actual car/LTV occupant fatalities (blue circles) to the potential fatalities that could have happened without the safety technologies (red diamonds). Actual fatalities remained fairly level, usually in the low 30,000s, throughout 1960 to 2006. Only in 1968 to 1972, when large numbers of baby-boomers were young drivers, did they crest just over 40,000. But from 2006 to 2011, actual fatalities dropped from 30,633 to 21,331. By contrast, potential fatalities doubled from 28,298 in 1960 to a peak of 61,408 in 2005. They have experienced a long-term rising trend, with transient interruptions in the mid-1970s, the early 1980s, from 1990 to 1992 and from 2008 to 2011. The interruptions were perhaps triggered by external events such as an energy crisis, a fuel-price increase, an economic slowdown, or a societal drive for health and safety (e.g., when the post-war baby-boomers reached their 40s, circa 1990). Periods of prosperity such as the later 1980s and most of the 1990s saw large rises in potential fatalities, commensurate with rising VMT, vehicle sales, and trips for both work and recreation.

Until the mid-1970s, there is little distance between the blue circles and the red diamonds on Figure 2-2. Then a gap opens between them, and it really widens after buckle-up laws were enacted in the mid-1980s. From that time until 2005, the potential fatalities continue to grow, but the FMVSS and other safety technologies have held the line on actual fatalities, working a little harder each year, keeping them in the low 30,000s year after year. From 2005 to 2011, potential fatalities dropped from 61,408 to 47,342, but the proportional reduction in actual fatalities was even larger. In 2012, potential fatalities resumed their historical upward trajectory (from 47,342 to 49,214) but actual fatalities increased only slightly (from 21,331 to 21,696).

[596] This is the sum of the ORIGWT values in the programs LS2004 and OLDFA24 (see Appendix A).
[597] This is the sum of WEIGHTFA in LS2004 and OLDFA24, the inflated values of ORIGWT after all the safety technologies are "removed," one-by-one, from the vehicles (see Appendix A).

Table 2-5: Actual Occupant Fatalities, Potential Fatalities Without The Vehicle Safety Technologies, and Lives Saved in Cars/LTVs

	CAR+LTV OCCUPANT FATALITIES			
CY	ACTUAL	W/O SAFETY TECHS.	LIVES SAVED	PERCENT SAVED
1960	28,183	28,298	115	0.40
1961	28,087	28,204	117	0.41
1962	30,544	30,679	135	0.44
1963	32,664	32,823	159	0.49
1964	35,603	35,805	202	0.56
1965	36,518	36,767	249	0.68
1966	39,130	39,465	334	0.85
1967	39,327	39,826	499	1.25
1968	41,019	41,818	799	1.91
1969	42,117	43,273	1,156	2.67
1970	39,556	40,972	1,415	3.45
1971	38,916	40,651	1,735	4.27
1972	40,103	42,281	2,178	5.15
1973	38,739	41,258	2,520	6.11
1974	31,145	33,608	2,463	7.33
1975	31,361	34,355	2,995	8.72
1976	32,222	35,398	3,176	8.97
1977	33,173	36,772	3,599	9.79
1978	34,988	38,951	3,964	10.18
1979	35,108	39,325	4,217	10.72
1980	35,097	39,554	4,456	11.27
1981	33,911	38,284	4,373	11.42
1982	29,855	33,834	3,979	11.76
1983	29,209	33,384	4,176	12.51
1984	30,177	34,935	4,758	13.62
1985	30,044	36,357	6,314	17.37
1986	32,394	40,849	8,454	20.70
1987	33,334	43,251	9,916	22.93
1988	34,245	45,461	11,216	24.67
1989	33,725	45,177	11,452	25.35
1990	32,844	44,534	11,690	26.25
1991	30,939	43,126	12,187	28.26
1992	29,557	42,071	12,514	29.75
1993	30,192	44,033	13,840	31.43
1994	30,995	46,200	15,204	32.91
1995	32,067	48,271	16,204	33.57
1996	32,541	50,438	17,897	35.48
1997	32,515	51,208	18,693	36.50
1998	31,955	51,512	19,557	37.97
1999	32,171	52,373	20,202	38.57
2000	32,241	54,465	22,225	40.81
2001	32,021	55,327	23,306	42.12
2002	32,872	58,506	25,634	43.81
2003	32,297	59,411	27,114	45.64
2004	31,871	60,064	28,193	46.94
2005	31,539	61,408	29,869	48.64
2006	30,633	60,804	30,171	49.62
2007	29,009	59,246	30,236	51.04
2008	25,423	53,287	27,864	52.29
2009	23,417	50,115	26,698	53.27
2010	22,235	48,852	26,617	54.49
2011	21,331	47,342	26,011	54.94
2012	21,696	49,214	27,518	55.92
	===========	===========	===========	
	1,712,855	**2,323,421**	**610,566**	

FIGURE 2-2: ACTUAL VERSUS POTENTIAL CAR/LTV OCCUPANT FATALITIES, 1960-2012

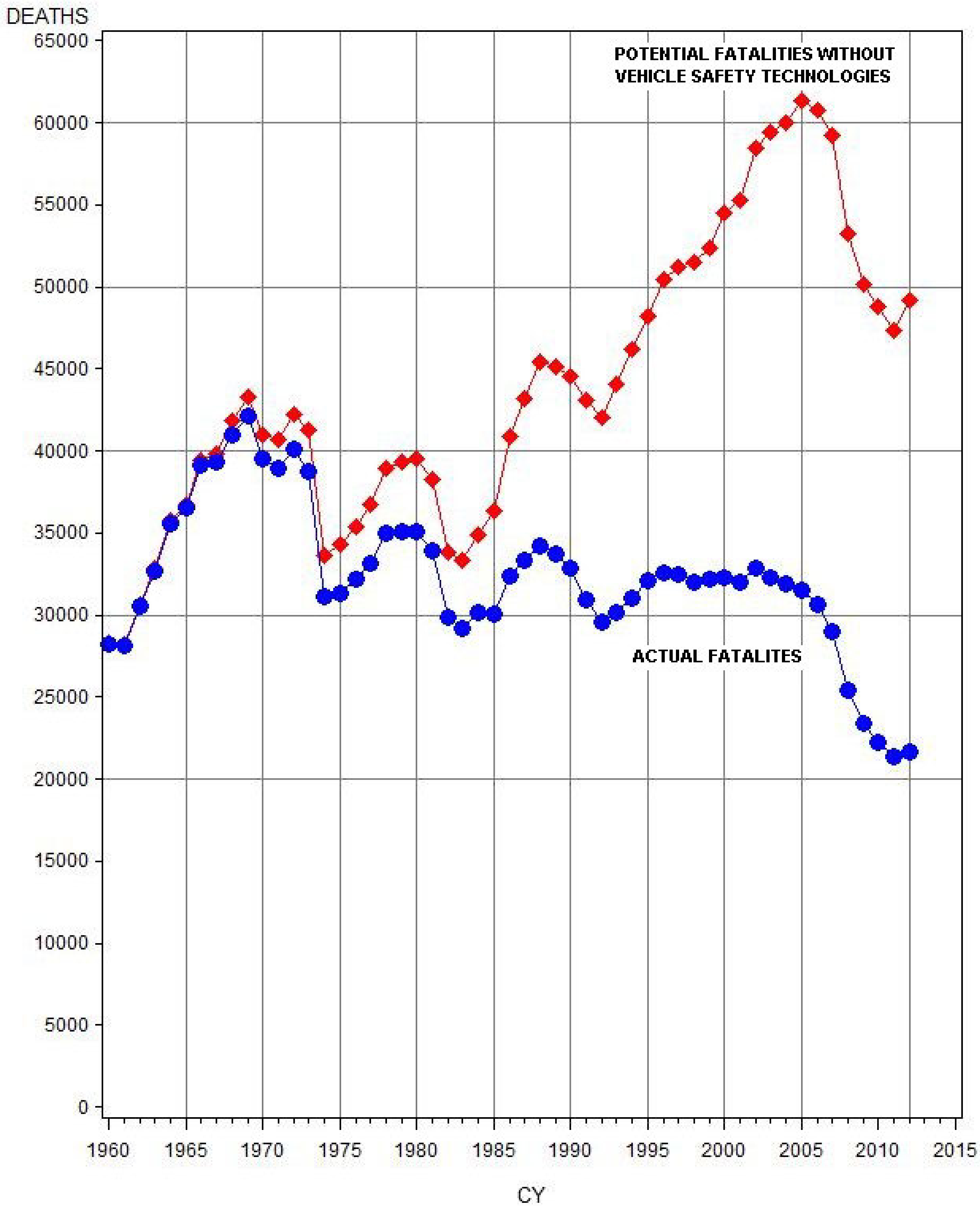


Figure 2-3 graphs the **percentage** of potential fatalities saved by the safety technologies. It resembles Figure 2-1, a graph of the absolute number of lives saved. The difference is that Figure 2-3 essentially controls for VMT and other factors that make the "base" grow or shrink. The trend of the effectiveness of the vehicle safety technologies becomes even clearer:

- Not much effect until the late 1960s.
- Steady growth in the early-to-mid 1970s as new vehicles meeting the early FMVSS gradually phased in.
- Little progress from 1978 to 1982, when belt use declined, prior to national buckle-up campaigns.
- The largest absolute and relative gains came with the buckle-up laws in the mid-to-late 1980s.
- Steady, uninterrupted progress from the late 1980s through 2012 thanks to continued increases in belt use, frontal air bags, curtain and side air bags, ESC, and other recent FMVSS. The trend remains steadily upward because new technologies have been introduced every few years and because the vehicles equipped with these technologies are gradually replacing older, pre-standard vehicles.

Figure 2-4 tracks a **vehicular fatality-risk index** for occupants of cars or LTVs that isolates the effects of vehicle safety improvements. The index is obtained by subtracting the percentage of potential fatalities saved from 100. The index was 100 in 1955 and had declined to 44 by 2012. In other words, given the same mileage by the same driver on the same roads, the average vehicle on the road in 2012 would have 56 percent lower fatality risk for its occupants than the average vehicle on the road in 1955. The index can be used to identify the contribution of vehicle safety improvements to the overall reduction in occupant fatalities per 100 million VMT, which will be discussed next.

FIGURE 2-3: PERCENT OF POTENTIAL FATALITIES SAVED
BY VEHICLE SAFETY TECHNOLOGIES, 1960-2012

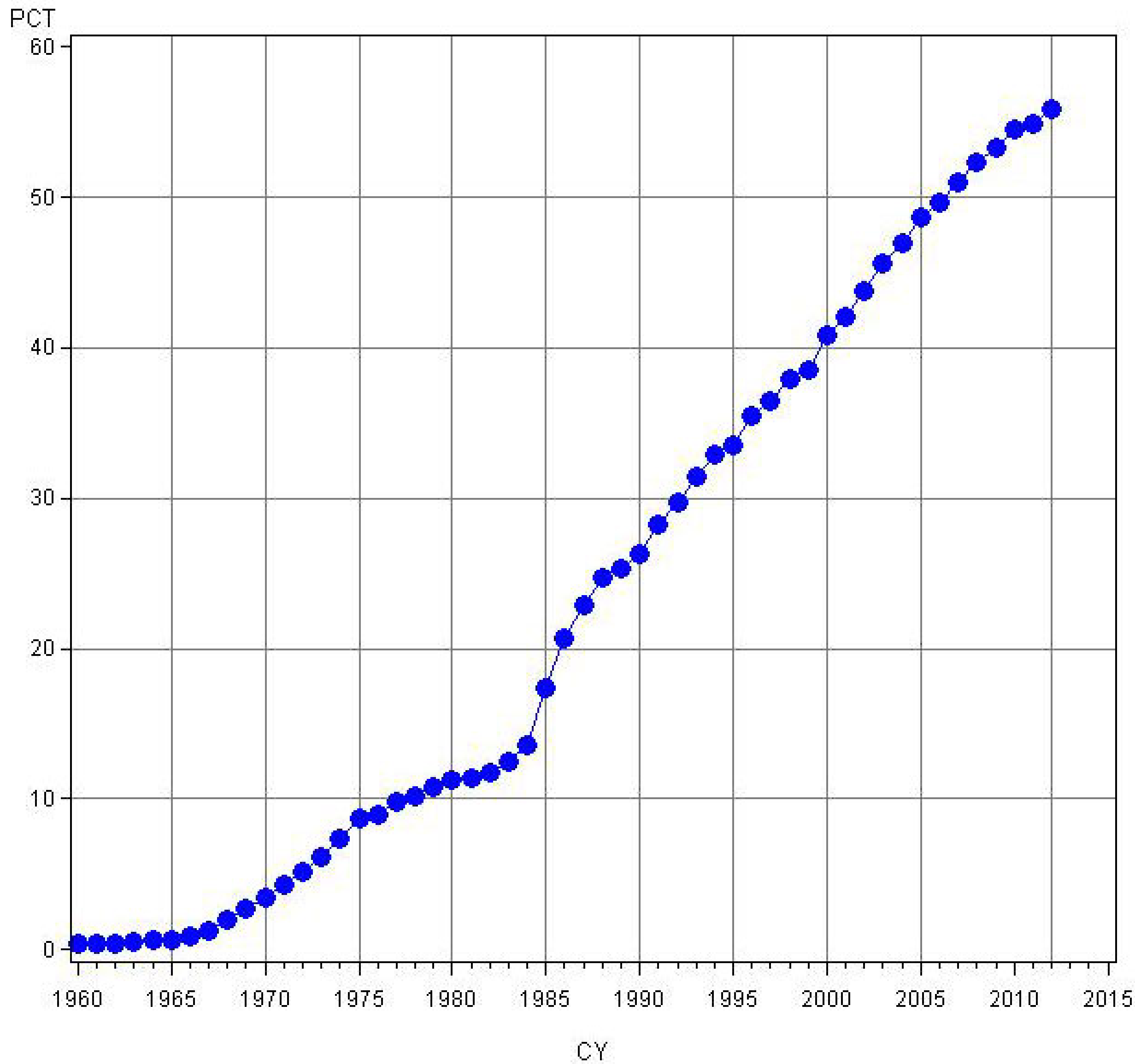
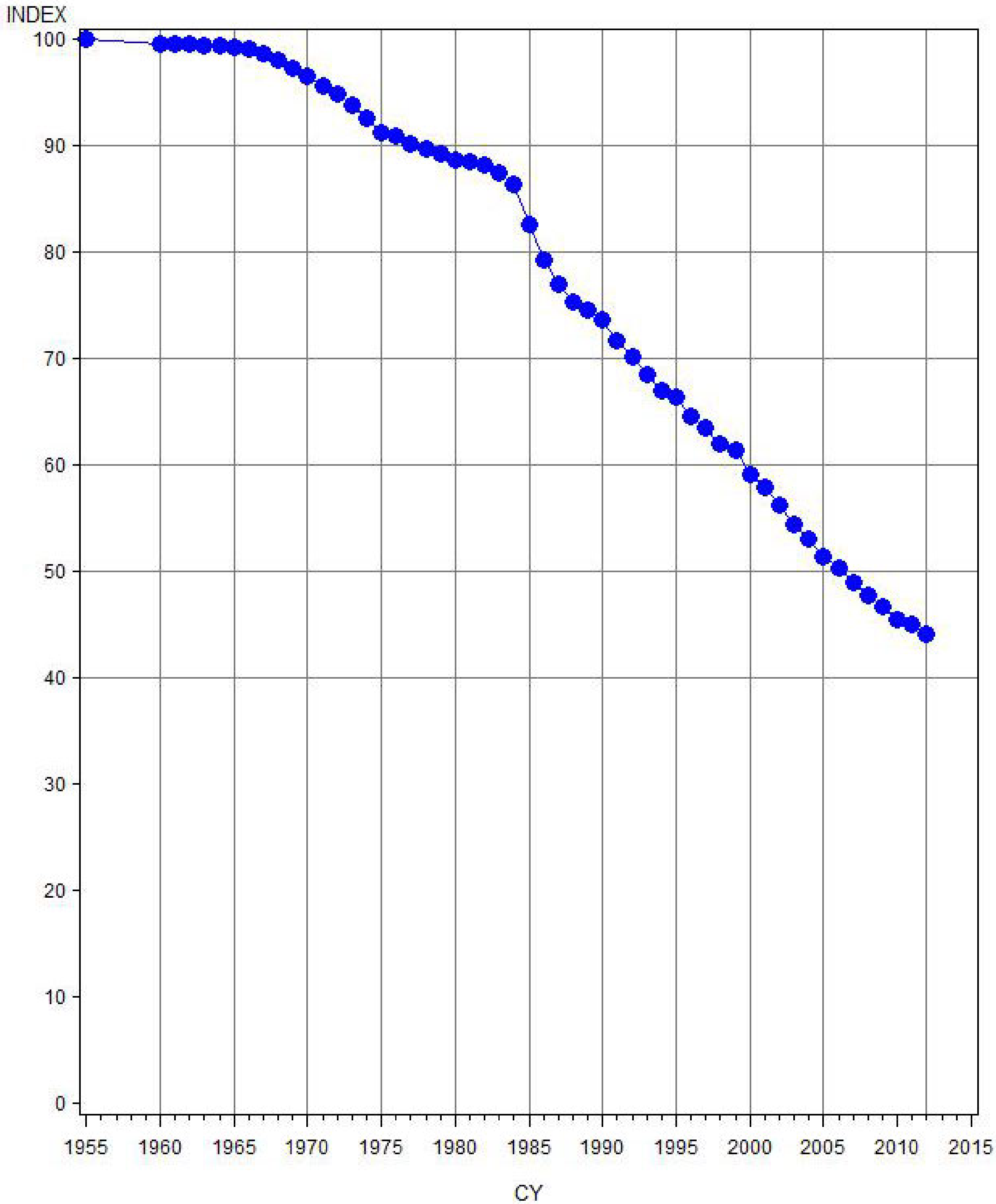


FIGURE 2-4: VEHICULAR FATALITY-RISK INDEX BY CALENDAR YEAR (1955 = 100)
BASED ON PERCENT OF POTENTIAL FATALITIES SAVED BY VEHICLE SAFETY TECHNOLOGIES



Car/LTV occupant fatalities per 100,000,000 VMT

A detailed analysis of fatality rates per 100,000,000 VMT comparing the strength of vehicle, behavioral, environmental, and demographic factors is beyond the scope of this report, which concentrates on estimating the lives saved by vehicle safety technologies. Nevertheless, it is interesting to look at the trends in occupant fatality rates per 100,000,000 VMT – with and without the vehicle safety technologies.

Table 2-6 shows the VMT of passenger cars plus LTVs in 1960 to 2012 and computes the rates of actual and potential fatalities per 100,000,000 miles in each calendar year.[598] America has become an increasingly mobile society and VMT has grown every year except the energy-crisis years of 1974 and 1979-to-1980 and from 2007 to 2011. Even in those years it decreased just slightly. The actual fatality rate of car/LTV occupants has dramatically fallen from 4.26 fatalities per 100,000,000 miles in 1960 to 0.82 in 2012: a reduction of **almost 81 percent**. Without the vehicle safety technologies, the potential fatality rates would have been 4.28 in 1960 and 1.86 in 2012, a reduction of 57 percent – the combined effect of "everything else" other than vehicle safety improvements that might have influenced VMT fatality rates between 1960 and 2012. "Everything else" includes the effects of actual safety or health improvements outside the vehicle, such as safer roads, programs to reduce drunk driving, or better trauma care; it also includes effects of demographic shifts such as reductions in the young-driver population or greater urbanization. Vehicle safety improved by 56 percent over that time span, as demonstrated by the percentage of potential fatalities saved and the vehicular risk index (Figures 2-3 and 2-4). In other words, over the entire time span from 1960 to 2012, vehicle safety improvements and "everything else" made almost identical contributions to the overall 81-percent reduction in the VMT fatality rate.

$$.81 = 1 - [(1-.57) \times (1-.56)]$$

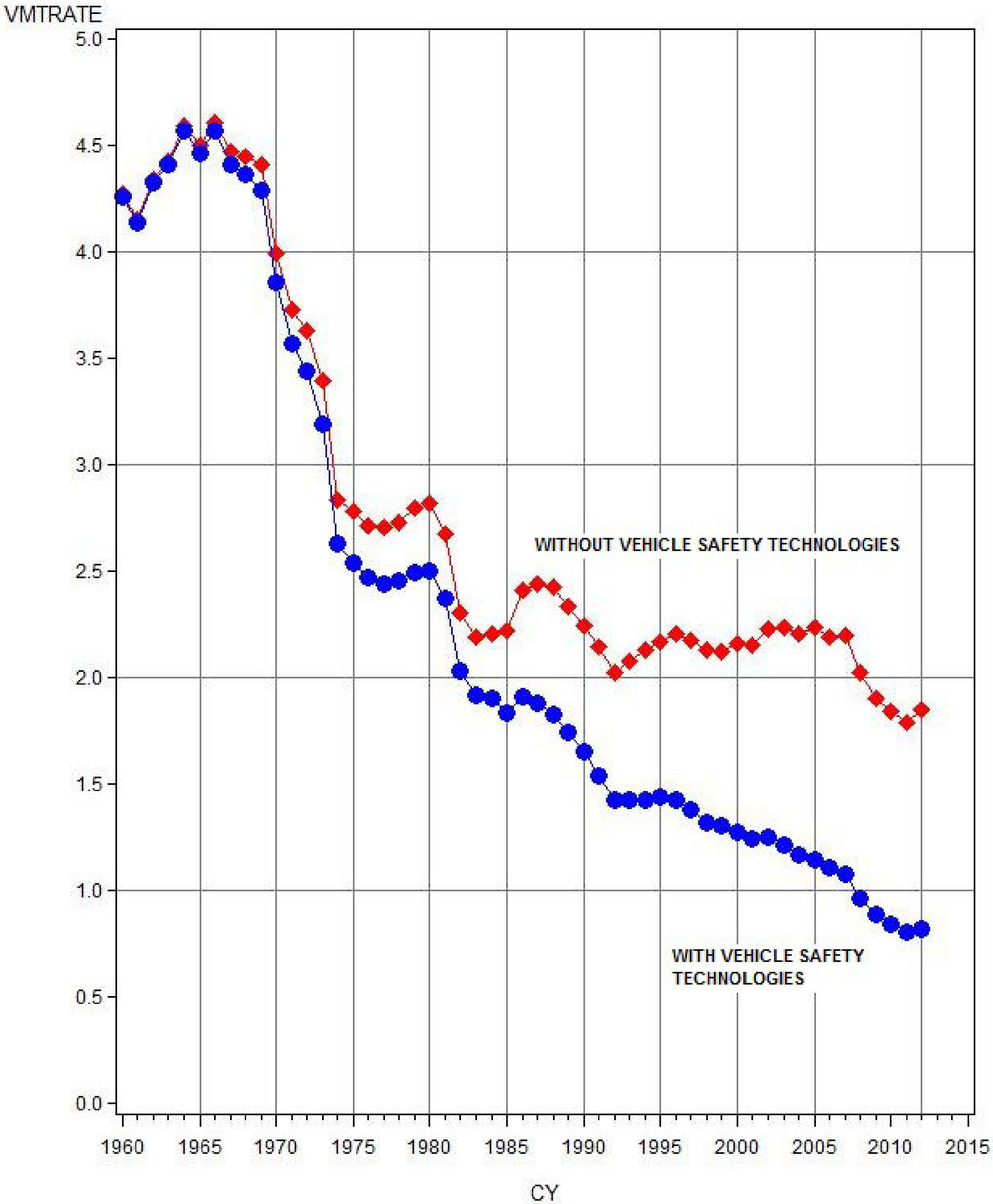
But these contributions came at different times: most of the benefits of vehicle safety improvements came after 1984 and a large portion of "everything else" had arrived by 1983. Figure 2-5 shows the difference in the trends of the actual and potential fatality rates. From 1960 to the mid-1970s there was little difference between the actual and potential rates, because the vehicle technologies were not yet saving that many lives. There were large changes in the fatality rate for reasons unrelated to the vehicle safety technologies. From 1960 to 1964, the fatality rate actually increased as the first great cohort of baby-boomers, born immediately after World War 2, began to drive.

[598] *Traffic safety facts 2011*, p. 24 specifies VMT for cars in 1975 to 2011 and p. 26 for LTVs; add them to obtain the left column of Table 2-6. VMT estimates were obtained from FHWA. P. 17 shows VMT for all vehicles on the road in 1966 to 2011, also obtained from FHWA. In 1975 to 80, cars + LTVs accounted for 92.4 percent of total VMT, and this percentage is assumed also for years before 1975. *Accident facts 1974 edition*, p. 59 tabulates VMT back to 1960 and earlier, also obtained from FHWA but with a slightly different definition. In 1966 to 1973 the *Traffic safety facts* VMT is 99.6 percent of the *Accident facts* VMT and this percentage is also assumed for years before 1966. Total VMT for 2012 is estimated in NHTSA (2013, November) *Traffic safety facts research note – 2012 motor vehicle crashes*. (Report No. DOT HS 811 856). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/811856.pdf. It has been allocated to cars, LTVs, and other vehicles based on the 2010-to-2011 trends.

Table 2-6: Actual and Potential Occupant Fatalities in Cars/LTVs per 100,000,000 Miles VMT

CY	VMT (10^8 MILES)	ACTUAL FATALITIES N	RATE	POTENTIAL FATALITIES W/O SAFETY TECHNOLOGIES N	RATE
1960	6,617	28,183	4.26	28,298	4.28
1961	6,791	28,087	4.14	28,203	4.15
1962	7,058	30,544	4.33	30,679	4.35
1963	7,408	32,664	4.41	32,823	4.43
1964	7,794	35,603	4.57	35,805	4.59
1965	8,172	36,518	4.47	36,767	4.50
1966	8,560	39,131	4.57	39,465	4.61
1967	8,911	39,327	4.41	39,825	4.47
1968	9,392	41,019	4.37	41,818	4.45
1969	9,817	42,117	4.29	43,273	4.41
1970	10,260	39,556	3.86	40,972	3.99
1971	10,898	38,916	3.57	40,650	3.73
1972	11,647	40,103	3.44	42,280	3.63
1973	12,137	38,739	3.19	41,258	3.40
1974	11,841	31,145	2.63	33,608	2.84
1975	12,347	31,360	2.54	34,356	2.78
1976	13,040	32,222	2.47	35,397	2.71
1977	13,598	33,173	2.44	36,772	2.70
1978	14,259	34,988	2.45	38,952	2.73
1979	14,055	35,108	2.50	39,325	2.80
1980	14,025	35,098	2.50	39,554	2.82
1981	14,297	33,911	2.37	38,284	2.68
1982	14,679	29,855	2.03	33,834	2.30
1983	15,227	29,209	1.92	33,384	2.19
1984	15,850	30,177	1.90	34,934	2.20
1985	16,378	30,043	1.83	36,357	2.22
1986	16,941	32,394	1.91	40,849	2.41
1987	17,729	33,335	1.88	43,250	2.44
1988	18,725	34,246	1.83	45,461	2.43
1989	19,377	33,725	1.74	45,176	2.33
1990	19,828	32,843	1.66	44,535	2.25
1991	20,076	30,940	1.54	43,126	2.15
1992	20,784	29,557	1.42	42,071	2.02
1993	21,205	30,192	1.42	44,033	2.08
1994	21,707	30,995	1.43	46,200	2.13
1995	22,283	32,067	1.44	48,271	2.17
1996	22,864	32,541	1.42	50,438	2.21
1997	23,533	32,515	1.38	51,208	2.18
1998	24,179	31,955	1.32	51,513	2.13
1999	24,701	32,171	1.30	52,373	2.12
2000	25,233	32,240	1.28	54,465	2.16
2001	25,700	32,021	1.25	55,327	2.15
2002	26,245	32,872	1.25	58,507	2.23
2003	26,560	32,297	1.22	59,411	2.24
2004	27,271	31,871	1.17	60,064	2.20
2005	27,495	31,539	1.15	61,408	2.23
2006	27,730	30,633	1.10	60,804	2.19
2007	26,910	29,009	1.08	59,246	2.20
2008	26,302	25,422	.97	53,287	2.03
2009	26,332	23,417	.89	50,115	1.90
2010	26,485	22,235	.84	48,852	1.84
2011	26,466	21,331	.81	47,343	1.79
2012	26,530	21,696	.82	49,214	1.86

FIGURE 2-5: LIGHT-VEHICLE OCCUPANT FATALITIES PER 100 MILLION MILES WITH AND WITHOUT THE VEHICLE SAFETY TECHNOLOGIES, 1960 TO 2012



From 1966 to 1977, the actual and potential rates fell dramatically (the potential rate from 4.61 to 2.70), partly because of major infrastructure improvements such as the Interstate Highway System,[599] but also because of demographic and external factors that began to act at various times, such as:

- An increasingly urbanized and suburban population, with an increasing share of the VMT involved in relatively low-risk commuting and urban trips;[600]
- A rising proportion of female drivers, who have lower fatal crash rates (specifically, a lower incidence of drunk driving);[601]
- In the 1970s, the first cohort of baby-boomers passed age 25, their most dangerous driving years behind them;[602] and
- Toward the end of that period, the 55 mph speed limit,[603] the energy crisis, and an economic slowdown.[604]

From about 1983 until 2007, the paradigm shifts. The potential fatality rate stayed rather flat at about 2.2, whereas the actual fatality rate improved from 1.92 to 1.08. In other words, in the absence of vehicle safety technologies and belt-use increases, if all other factors influencing the

[599] Interstate highways accounted for 3.7 percent of the nation's VMT in 1960 (www.fhwa.dot.gov/policyinformation/statistics/vm03.cfm?vm_year=1960), 14.4 percent in 1970 (www.fhwa.dot.gov/policyinformation/statistics/vm03.cfm?vm_year=1970), 19.4 percent in 1980, and 24.3 percent in 2010 (www.fhwa.dot.gov/policyinformation/statistics/2010/vm202.cfm); the fatality rate per VMT is 50 percent lower on Interstate highways than on principal arterial roads (www.fhwa.dot.gov/policyinformation/statistics/2009/fi30.cfm).

[600] The proportion of the United States population living in non-metropolitan areas decreased from 37 percent in 1960 (www2.census.gov/prod2/statcomp/documents/1961-02.pdf) to 17 percent in 2010 (www.census.gov/prod/2011pubs/12statab/pop.pdf); the fatality rate per VMT is 50 percent lower on urban roads than on rural roads of the same functional class (www.fhwa.dot.gov/policyinformation/statistics/2009/fi30.cfm).

[601] The percentage of licensed drivers who are females increased from 41.8 percent in 1965 (*Highway statistics 1965*. Washington, DC: Federal Highway Administration) to 50.3 percent in 2010 (www.fhwa.dot.gov/policyinformation/statistics/2010/pdf/dl20.pdf); the fatal-crash involvement rate per VMT of female drivers (50 or younger) is 40 percent lower than for male drivers of the same age (Kahane, C. J. (2003, October). *Vehicle weight, fatality risk and crash compatibility of model year 1991-99 passenger cars and light trucks*. (Report No. DOT HS 809 662, p. 71). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/809662.PDF).

[602] The percentage of licensed drivers younger than 25 was 18.4 percent in 1960 (*Accident facts, 1961*. Chicago: National Safety Council), reached 22.1 percent in 1969 (Gish, R. E. (1973, April). *National Personal Transportation Survey – Characteristics of licensed drivers*. Washington, DC: Federal Highway Administration. Available at www.fhwa.dot.gov/ohim/1969/s.pdf.), but had dropped to 13.3 percent by 2009 (www.census.gov/compendia/statab/2012/tables/12s1114.pdf); the fatal-crash involvement rate per VMT is 2.5 times as high for an 18-year-old driver as for a 30-year-old driver of the same gender (Kahane [2003, October], p. 71).

[603] Kahane, C. J. (1975). *Lower speed limits, reduced speeds, fewer deaths*. (Report No. DOT HS 801 667). Washington, DC: National Highway Traffic Safety Administration; Johnson, P., Klein, T. M., Levy, P., & Maxwell, D. (1980, October). *The effectiveness of the 55 mph national maximum speed limit as a life saving benefit*. (Report No. DOT HS 805 694). Washington, DC: National Highway Traffic Safety Administration. Available at ntl.bts.gov/lib/30000/30300/30319/805694.pdf; NHTSA. (1989, January). *The effects of the 65 mph speed limit during 1987*. (Report No. DOT HS 807 369). Washington, DC: National Highway Traffic Safety Administration. Available at ntl.bts.gov/lib/25000/25800/25819/DOT-HS-807-369.pdf.

[604] Partyka, S. C. (1984a). Simple models of fatality trends using employment and population data. *Accident Analysis and Prevention*, *16*, pp. 211-222; Partyka, S. C. (1991). Simple models of fatality trends revisited seven years later. *Accident Analysis and Prevention*, *23*, pp. 423-430.

fatality rate had stayed the same, the fatality rate would also have stayed about the same. During those years, there were some factors that tended to reduce the potential fatality rate while other offsetting factors increased it:

- Effective programs to reduce drunk driving helped to reduce the fatality rate;[605]
- A growing and increasingly mobile population of crash-prone, physically vulnerable older drivers contributed to increasing the rate;[606]
- A reduction in the average size and mass of passenger cars on the road as pre-downsized vehicles were retired, followed by an influx of rollover-prone and aggressive LTVs may have contributed to increasing the rate;[607] and
- An increasingly prosperous society, with more recreational driving destinations and a greater hurry to get there, may have increased the rate.[608]

The effects of significant improvements in behavioral safety during this period are not clearly reflected in this analysis for several reasons. First, it is important to note that the effects of the sharp increase in seat belt use during this period, from less than 60 percent in 1984 to 86 percent in 2012, are incorporated in the vehicular risk index rather than in the "everything else" index. Second, the effects of other traffic safety behavioral improvements such as the reduction in the proportion of alcohol-impaired driving fatalities from more than 40 percent in 1984 to 31 percent in 2012 and other improvements such as safer roadways and improvements to the emergency medical system are obscured by changes in demographic and socioeconomic trends.

But the steady increase in belt use, air bags, and other vehicle safety technology helped preserve the long-term downward trend in the actual fatality rate. From 2007 to 2011 the potential fatality rate dropped from 2.20 to 1.79 and the actual fatality rate from 1.08 to 0.81, proportionally an even greater decrease.

It is evident from trend lines such as Figures 2-2 and 2-5 that there have been several periods lasting approximately 2 to 5 years during which fatalities in crashes decreased substantially more than the decrease (if any) in VMT: the mid-1970s, the early 1980s, the early 1990s, and from 2007 to 2011. A detailed investigation of these transient phenomena is outside the scope of this report. They were possibly triggered by events such as an energy crisis, a fuel-price increase, or an economic slowdown. For some years afterwards, fatalities drop faster than VMT, perhaps because: (1) The reduction in high-risk VMT such as nighttime driving in search of recreation is greater than the reduction in low-risk VMT such as driving to work or basic shopping; (2) The reduction in VMT among higher-risk young and old drivers is greater than for adults 25 to 60 years old, who are less affected by the events; or (3) Some individuals could be influenced by the events to drive more carefully.

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[605] Dang, J. N. (2008, May). *Statistical analysis of alcohol-related driving trends, 1982-2005*. (Report No. DOT HS 810 942). Washington, DC: National Highway Traffic Safety Administration. Available at www-nrd.nhtsa.dot.gov/Pubs/810942.PDF.

[606] The percentage of licensed drivers 65 and older was 6.7 percent in 1960 (*Accident facts, 1961*) and had climbed to 15.6 percent by 2009 (www.census.gov/compendia/statab/2012/tables/12s1114.pdf); the fatal-crash involvement rate per VMT is 1.6 times as high for a 70-year-old driver and 2.5 times as high for an 80-year-old driver as for a 50-year-old driver of the same gender (Kahane (2003, October), p. 71).

[607] Kahane, (1988, January), pp. 187-190; Kahane (2003, October), Chapters 3, 5, and 6.

[608] Partyka (1984a); Partyka (1991).

Suffice it to say that, after 2007, vehicle-safety technologies combined with other factors to bring light-vehicle occupant fatalities down to low levels not seen since the 1940s – and that these vehicle-safety technologies will continue protecting occupants even if the other factors should at some point return to the trends seen before 2007.

Estimates of lives saved by each technology (grouped by associated FMVSS)

Tables 2-7, 2-8 and 2-9 apportion the 613,501 lives saved from 1960 to 2012 among the various safety technologies (grouped by the FMVSS with which they are most closely associated).

Table 2-7 indicates that seat belts saved 329,715 occupants of cars and LTVs in 1960 to 2012, including 15,485 in 2012. The estimate comprises seat belts of all types – lap/shoulder, lap only, and automatic 2-point – at all seating positions, front and rear, outboard and center. It also includes the effects of voluntary NCAP-related belt improvements and voluntarily installed pretensioners and load limiters.

Lap belts were saving about 500 lives a year in the early 1970s. The transition to 3-point belts in the mid-1970s increased that to about 800. In the mid-1980s, buckle-up laws had a huge impact, raising lives saved to 6,000 per year by 1989 and, for the first time since 1970, putting belts far ahead of any other FMVSS in number of lives saved. From 1990 to 2005, continuing, successful programs to increase belt use, and the expanding "base" of VMT, vehicles, and potentially fatal crashes has kept the "saved by the belt" number growing every year; it leveled off after 2005 because the "base" of potentially fatal crashes shrank, even though belt use continued to rise. Furthermore, belts are especially effective in LTVs (because many potentially fatal crashes are rollovers and/or ejections); the growing LTV population means belts are saving more people. The 329,715 lives saved by belts are just over half of the total of 613,501; the 15,485 saved in 2012 are likewise somewhat over half of the total of 27,621 saved in that year.

It is important to note that the estimates in Table 2-7 **do not supersede** the agency's **official** estimates of lives saved by seat belts, frontal air bags, and safety seats, generated by NHTSA's National Center for Statistics and Analysis in its annual compendia of *Traffic Safety Facts – Occupant Protection*. The official numbers measure the lives **directly** saved by belts, frontal air bags, and safety seats – namely, the additional fatalities that would have occurred if nobody had used belts or safety seats and if all frontal air bags had been removed, but otherwise the cars and LTVs on the road had remained unchanged.[609]

[609] Glassbrenner & Starnes (2009, December).

Table 2-7: Car/LTV Occupants Saved by Seat Belts, Air Bags, and Safety Seats, 1960 to 2012

CY	SEAT BELTS	FRONTAL AIR BAGS	CURTAIN & SIDE AIR BAGS	CHILD SAFETY SEATS
1960	115	0	0	0
1961	116	0	0	0
1962	129	0	0	0
1963	140	0	0	0
1964	160	0	0	0
1965	174	0	0	0
1966	195	0	0	0
1967	205	0	0	0
1968	240	0	0	1
1969	298	0	0	1
1970	332	0	0	4
1971	379	0	0	9
1972	470	0	0	14
1973	546	0	0	19
1974	591	0	0	20
1975	843	0	0	36
1976	755	0	0	17
1977	791	0	0	34
1978	797	0	0	24
1979	707	0	0	49
1980	706	0	0	43
1981	666	0	0	70
1982	657	0	0	73
1983	823	0	0	112
1984	1,151	0	0	131
1985	2,370	0	0	166
1986	3,979	1	0	157
1987	5,075	2	0	209
1988	5,971	3	0	226
1989	6,190	8	0	239
1990	6,373	44	0	234
1991	6,915	77	0	252
1992	7,269	104	0	283
1993	8,235	210	0	278
1994	9,125	310	0	326
1995	9,461	542	0	331
1996	10,569	764	0	394
1997	11,022	984	1	373
1998	11,556	1,232	2	346
1999	11,717	1,488	9	396
2000	12,999	1,796	11	429
2001	13,564	2,093	26	330
2002	14,919	2,523	48	340
2003	15,795	2,769	68	437
2004	16,307	2,956	105	442
2005	17,373	3,170	122	425
2006	17,287	3,340	172	456
2007	17,296	3,423	190	433
2008	15,763	3,199	220	334
2009	15,118	3,064	233	357
2010	15,229	2,906	319	346
2011	14,766	2,919	339	336
2012	15,485	2,930	389	357
	===========	===========	===========	===========
	329,715	**42,856**	**2,252**	**9,891**

Table 2-8: Lives Saved by Technologies Associated With FMVSS Nos. 105/135, 108, 126, 201, 203/204, and 206, 1960 to 2012

CY	FMVSS 105/135 BRAKES	FMVSS 108 TRAILER CONSPICUITY	FMVSS 126 ESC	FMVSS 201 INTERIOR PROTECTION	FMVSS 203/204 STEERING ASSEMBLY	FMVSS 206 DOOR LOCKS
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	2	0	0	0	0	4
1963	4	0	0	0	0	15
1964	7	0	0	0	0	34
1965	9	0	0	0	0	60
1966	24	0	0	1	3	98
1967	54	0	0	14	68	141
1968	92	0	0	45	201	198
1969	129	0	0	88	346	258
1970	157	0	0	128	449	293
1971	189	0	0	179	563	337
1972	232	0	0	247	706	396
1973	262	0	0	305	808	427
1974	242	0	0	307	760	378
1975	278	0	0	366	894	385
1976	300	0	0	408	989	435
1977	330	0	0	458	1,113	566
1978	360	0	0	528	1,262	620
1979	377	0	0	548	1,334	753
1980	387	0	0	600	1,381	838
1981	380	0	0	602	1,351	795
1982	344	0	0	535	1,231	692
1983	338	0	0	522	1,210	702
1984	357	0	0	553	1,294	730
1985	369	0	0	605	1,469	763
1986	408	0	0	700	1,615	908
1987	429	0	0	734	1,718	1,012
1988	449	0	0	783	1,836	1,098
1989	442	0	0	793	1,878	1,036
1990	439	0	0	793	1,888	1,045
1991	421	10	0	768	1,821	1,025
1992	409	21	0	766	1,805	981
1993	428	34	0	793	1,924	992
1994	444	51	0	808	2,033	1,058
1995	463	72	0	852	2,164	1,110
1996	480	82	0	886	2,242	1,154
1997	487	114	0	916	2,307	1,151
1998	489	130	1	880	2,345	1,176
1999	495	156	3	849	2,332	1,236
2000	513	161	26	945	2,447	1,301
2001	523	134	55	978	2,614	1,299
2002	549	165	56	1,099	2,707	1,413
2003	560	169	110	1,183	2,776	1,359
2004	566	149	198	1,254	2,838	1,440
2005	583	186	267	1,309	2,916	1,564
2006	578	188	376	1,387	2,947	1,525
2007	564	150	511	1,431	2,950	1,454
2008	513	146	674	1,356	2,741	1,295
2009	480	134	708	1,297	2,635	1,183
2010	471	133	849	1,282	2,368	1,152
2011	460	115	973	1,247	2,300	1,116
2012	482	161	1,362	1,350	2,407	1,127
	===========	===========	===========	===========	===========	===========
	18,350	**2,660**	**6,169**	**34,477**	**79,989**	**42,135**

Table 2-9: Lives Saved by Technologies Associated With FMVSS Nos. 212, 214, 216, 226, and 301, 1960 to 2012

CY	FMVSS 212 WINDSHIELD BONDING	FMVSS 214 SIDE IMPACT PROTECTION	FMVSS 216 ROOF CRUSH STRENGTH	FMVSS 226 ROLLOVER CURTAINS	FMVSS 301 FUEL SYSTEM INTEGRITY	TOTAL FOR 13 NON-BELT FMVSS
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	6
1963	0	0	0	0	0	20
1964	2	0	0	0	0	43
1965	8	0	0	0	0	78
1966	18	0	0	0	0	144
1967	28	0	0	0	0	304
1968	39	0	0	0	0	576
1969	53	7	0	0	0	880
1970	62	21	2	0	0	1,112
1971	72	40	5	0	0	1,387
1972	86	63	11	0	0	1,742
1973	94	96	18	0	0	2,010
1974	83	115	22	0	0	1,907
1975	85	142	29	0	0	2,179
1976	94	209	34	0	0	2,468
1977	104	218	59	0	0	2,847
1978	119	259	70	0	0	3,219
1979	121	308	103	0	0	3,543
1980	133	335	116	0	0	3,790
1981	133	343	115	0	0	3,719
1982	126	297	102	0	0	3,327
1983	131	311	98	0	0	3,312
1984	149	370	99	0	0	3,553
1985	169	370	108	0	0	3,853
1986	208	421	131	0	0	4,393
1987	238	437	137	0	0	4,706
1988	268	508	151	0	0	5,092
1989	259	533	144	0	0	5,084
1990	265	544	136	0	0	5,110
1991	262	561	138	0	0	5,006
1992	247	556	133	0	0	4,918
1993	263	611	133	0	0	5,178
1994	278	682	148	0	0	5,501
1995	295	827	147	0	0	5,930
1996	300	925	159	0	0	6,229
1997	298	950	149	0	0	6,372
1998	306	997	155	0	0	6,480
1999	315	1,113	153	0	0	6,655
2000	324	1,192	148	0	0	7,055
2001	336	1,286	150	0	0	7,376
2002	352	1,406	163	0	0	7,909
2003	338	1,527	149	2	0	8,173
2004	336	1,608	157	4	0	8,549
2005	352	1,607	174	7	0	8,967
2006	355	1,630	163	11	0	9,160
2007	347	1,574	160	15	3	9,160
2008	311	1,438	148	22	2	8,645
2009	287	1,353	127	22	2	8,230
2010	273	1,532	125	23	5	8,214
2011	259	1,454	120	28	4	8,077
2012	271	1,512	122	43	9	8,848
	===========	===========	===========	===========	===========	===========
	9,853	**32,288**	**4,913**	**178**	**26**	**231,039**

The somewhat more hypothetical estimates in Table 2-7, meaningful primarily within the context of this report, include some indirect as well as the direct savings. This report estimates the total additional fatalities that would have occurred if **all** safety technologies had been removed – not just the belts, safety seats and frontal air bags, but also, for example, ESC. It then **apportions** the total among the various individual technologies, based on a computational process that simulates the effect of "removing" the technologies one-by-one in reverse chronological order, as explained in the "Summary of the Estimation Method" at the beginning of Part 2 of this report.

The estimates in *Traffic Safety Facts* and in Table 2-7 track closely until the mid-1990s (with discrepancies on the order of 1% due to slight differences in the computational details) because, until then, 3-point belts, frontal air bags, and child safety seats were essentially the most recent safety technologies. After 1995, even more recent technologies such as ESC, curtain and side air bags, and head impact protection cause the estimates in Table 2-7 to gradually pull away from those in *Traffic Safety Facts*. As explained in the "Summary of the Estimation Method," the new technologies not only save lives themselves but also indirectly augment this report's estimates of lives saved by earlier technologies such as seat belts (because "removing" the newer technology augments the baseline fatalities prior to estimating the effect of removing the earlier technology). For a simple example, in a type of crash where ESC and belts each reduce fatality risk by 50 percent, *Traffic Safety Facts* would infer from the presence on FARS of a single belted fatality in a vehicle, that there would have been two fatalities if belts were removed – i.e., one life saved directly by belts, regardless of whether this vehicle had been equipped with ESC or not. But in this report, ESC is removed first, leaving two belted fatalities without ESC (augmented baseline), which in turn become four unbelted fatalities if the belts are also removed – i.e., two lives saved by belts. Furthermore, as stated above, Table 2-7 includes (and *Traffic Safety Facts* does not include) the effects of pretensioners and load limiters in its computation of lives saved by seat belts.

Thus, in 1996, the official estimate of 10,414 lives directly saved by belts is close to the 10,569 in Table 2-7; by 2003, they have diverged to 15,095 and 15,795; and by 2012, to 12,174 lives directly saved versus 15,485 lives directly or indirectly saved by belts.[610]

According to Table 2-7, the various types of frontal air bags saved 42,856 lives from 1986 through 2012, including 2,930 in 2012. These are the net lives saved – i.e., the benefits for adults and adolescents (13 and older) are to a small extent offset by increased risk to certain subgroups of child passengers from air bags that do not have suppression or low-risk deployment features; see Tables 2-49 through 2-54. By CY 2012, about 95 percent of the passenger cars on the road and 91 percent of the LTVs were equipped with frontal air bags (see Tables C-2 and C-4 in Appendix C). In other words, when the proportion of vehicles with air bags gets close to 100 percent, air bags will save somewhat over 3,000 lives per year, if the "base" of potential fatalities remains similar to 2012 levels.

[610] *Traffic safety facts 2001 – Occupant protection*. (Report No. DOT HS 809 474). Washington, DC: National Highway Traffic Safety Administration. Available www-nrd.nhtsa.dot.gov/Pubs/809474.pdf; *Traffic safety facts 2012 data – Occupant protection*.

The various types of curtain and side air bags have saved an estimated 2,252 lives from 1996 to 2012, including 389 in 2012. In that year, 42 percent of cars and 28 percent of LTVs on the road were equipped with some type of curtain and/or side air bags.

Child safety seats (including infant, toddler, convertible, and booster seats) have been saving 326 to 456 lives per year since 1994. They have been available and have saved 9,891 lives since the late 1960s. Benefits really began to increase after the States enacted child passenger protection laws in 1978 to 1985 and followed them up with campaigns to increase use.

Tables 2-8 and 2-9 estimate the lives saved by all the vehicle technologies other than seat belts, frontal air bags and safety seats, grouping them into 11 columns based on the 13 FMVSS associated with them (FMVSS Nos. 105/135 and 203/204 each constitute a single column). Importantly, the right column of Table 2-9 shows that, together, these "built-in," non-belt technologies saved an estimated 231,039 lives from 1960 through 2012, a substantial portion of the 613,501 lives saved by all the technologies. (The "FMVSS 214" column in Table 2-9 includes curtain and side air bags; without them, the total for FMVSS No. 214 would decrease from 32,288 to 30,036 and the total for the 13 FMVSS from 231,039 to 228,787).

The right column of Table 2-9 shows these technologies were saving 3,000 lives per year by the late 1970s, by which time most cars of the pre-FMVSS era had been retired. The savings continued to grow, reaching a peak of 9,160 in both 2006 and 2007, as new technologies were introduced, most pre-FMVSS LTVs were retired, and the "base" of vehicles, VMT and potentially fatal crashes continued to grow. The estimate had fallen back to 8,077 by 2011, despite vehicles with new technologies replacing less protective vehicles, because the base of potential fatalities shrank, but it had returned to 8,848 by 2012. Each of the 11 individual columns exhibit years of strong increases in lives saved when the FMVSS is introduced or upgraded, followed by more gradual increases until about 2007 and some decline after that until 2011 unless new technologies under that FMVSS rapidly entered the fleet in recent years (e.g., FMVSS No. 126, "Electronic stability control").

Braking improvements directly or indirectly associated with FMVSS Nos. 105 and 135 include dual master cylinders, implemented in the early-to-mid 1960s, and front disc brakes, introduced during 1965 to 1977. The first column of Table 2-8 shows these technologies began saving lives in 1962. Benefits grew rapidly from 1967 to 1980 as vehicles with dual master cylinders replaced older vehicles without them in the on-road fleet. Benefits continued to grow from 1980 to 2005 as the "base" of potentially fatal crashes kept expanding. They saved an estimated 18,350 lives in 1962 to 2012, including 482 in 2012. The people who owe their lives to these safety improvements are not limited to occupants of the cars and LTVs equipped with them. When a car or LTV, as a consequence of these improvements, avoids hitting another car/LTV, a pedestrian, bicyclist, or motorcyclist, it may prevent a fatality among any of those groups.

The life-saving technology associated with FMVSS No. 108 is the red-and-white conspicuity tape on heavy truck trailers. Although this device is furnished on heavy trailers, not cars or LTVs, it is the occupants of cars and LTVs who primarily benefit, because it helps them avoid hitting the trailers in the dark. The tape began to appear on substantial numbers of trailers by 1991, and it has saved an estimated 2,660 car/LTV occupants, including 161 in 2012.

ESC, voluntarily introduced as standard equipment on one make-model in 1998 and required on all new vehicles in MY 2012 by FMVSS No. 126, saved 6,169 lives from 1998 through 2012, including 1,362 in 2,012. ESC on cars and LTVs benefits not only the occupants of those vehicles but also some motorcyclists when ESC on a car or LTV helps the driver avoid hitting the motorcycle. In CY 2012, only 20 percent of cars and 22 percent of LTVs on the road were ESC-equipped. Thus, ESC will likely save far more than 1,362 lives per year as those percentages rise.

Improvements to middle and lower instrument panels, not actually required by FMVSS No. 201, "Occupant protection in interior impact" but historically and functionally associated with that standard to some extent, began to appear in cars in the later 1960s and in LTVs a few years after that. Then, in MY 1999 to 2003, NHTSA upgraded the standard's head impact protection. Table 2-8 shows an initial surge in lives saved in the 1970s and another surge after 2000. The two technologies have saved an estimated 34,477 lives, including 1,350 in 2012.

Energy-absorbing steering assemblies meeting FMVSS Nos. 203 and 204 were one of the most important "built-in" early safety technologies. They significantly reduced the fatality risk of drivers in frontal crashes, and have saved an estimated 79,989 lives in cars and LTVs, including 2,407 in 2012. Energy-absorbing column and well-designed instrument panels continue to be important components of the overall occupant protection system in today's vehicles with frontal air bags and they continue to save lives. Specifically, as explained in the "Summary of the Estimation Method," our model first computes by how much fatalities would increase if the most recent technologies such as air bags were "removed" from today's vehicles, and then by how much more they would increase if the earlier technologies such as energy-absorbing columns were also "removed."

Improvements to door locks, latches, hinges and other components regulated by FMVSS No. 206 have significantly reduced door ejections in rollover crashes, saving an estimated 42,135 lives from 1962 to 2012, including 1,127 in 2012. Increases in the population of then relatively rollover-prone LTVs expanded the "base" of potentially fatal crashes addressed by this technology between 1999 and 2005.

FMVSS No. 212, "Windshield mounting," is the first standard addressed in Table 2-9. The introduction of adhesive windshield bonding extended from 1963 in some cars until approximately 1985 in some LTVs. As a result, the benefits for FMVSS No. 212 built up more gradually than some other standards. Adhesive bonding has significantly reduced occupant ejections via the windshield portal, saving an estimated 9,853 lives from 1964 to 2012, including 271 in 2012.

The estimates of benefits associated with FMVSS No. 214, "Side impact protection," are based on technologies that entered at different times: side door beams for passenger cars (1969 to 1973); TTI(d) reduction by structure and padding in passenger cars (related to the FMVSS upgrade that phased in during MY 1994 to 1997, but including voluntary improvements back to 1986); side door beams for LTVs (mostly 1994); and curtain and side air bags (available on some vehicles since 1996). Each new technology increased benefits, reaching 1,512 lives saved in 2012, and a total of 32,288 from 1969 to 2012.

FMVSS No. 216, "Roof crush resistance," is associated with the redesign of true hardtops as pillared hardtops or sedans during the 1970s. The elimination of these hardtops with low, flat, vulnerable roofs saved lives; if cars were still built that way there would have been 4,913 additional fatalities, including an estimated 122 in 2012.

Curtains that deploy in rollovers began to appear on LTVs in 2002, well in advance of FMVSS No. 226, "Ejection mitigation." They were still fairly rare on passenger cars as of MY 2012. They had saved 178 lives from 2002 to 2012, including 43 in 2012.

The most recent rear-impact upgrade of FMVSS No. 301, "Fuel system integrity," phased in during MY 2007 to 2009. It had saved an estimated 26 lives by 2012, including 9 in that year. Although it is the smallest total among these 11 FMVSS, it is unique because every one of those fatalities was due to burns. Ranked by their estimates of lives saved from 1960 through 2012, 14 groups of safety technologies line up as follows:

		Lives Saved in 1960 to 2012
208/209/210	Seat belts	329,715
203/204	Energy-absorbing steering assemblies	79,989
208	Frontal air bags	42,856
206	Door locks, latches and hinges	42,135
201	Occupant protection in interior impact	34,477
214	Side impact protection (incl. side air bags)	32,288
105/135	Dual master cylinders/front disc brakes	18,350
213	Child safety seats	9,891
212	Adhesive windshield bonding	9,853
126	ESC	6,169
216	Roof crush resistance	4,913
108	Trailer conspicuity tape	2,660
226	Rollover curtains	178
301	Fuel system integrity	26
		613,501

Seat belts are first by far, followed by an early occupant-protection standard dating back to January 1, 1968, for passenger cars. Frontal air bags, a substantially later arrival ranks third despite not having had nearly as many years of accumulated benefits. Ranked by their estimates of lives saved in 2012 alone, the 14 groups line up as follows:

		Lives Saved in 2012
208/209/210	Seat belts	15,485
208	Frontal air bags	2,930
203/204	Energy-absorbing steering assemblies	2,407
214	Side impact protection (incl. side air bags)	1,512
126	ESC	1,362
201	Occupant protection in interior impact	1,350
206	Door locks, latches and hinges	1,127
105/135	Dual master cylinders/front disc brakes	482
213	Child safety seats	357
212	Adhesive windshield bonding	271
108	Trailer conspicuity tape	161
216	Roof crush resistance	122
226	Rollover curtains	43
301	Fuel system integrity	9
		27,621

Seat belts and frontal air bags account for a large proportion of the total in recent years. They ranked first and second in 2012. ESC already ranks fifth despite being on just over 20 percent of the vehicles on the road and it will likely move up to second place in the future.

As stated in the "Summary of the Estimation Method," our model comprises any technology where cars/LTVs produce and/or receive benefits: not only (1) the lives saved in cars and LTVs by car/LTV technologies (plus child safety seats), but also (2) the non-occupants and motorcyclists saved by car/LTV technologies, and (3) the car/LTV occupants saved by technologies in other vehicles (heavy trailers). We can now estimate the sizes of these three groups: 99 percent of the benefits estimated by the model are car/LTV occupant lives saved by car/LTV technologies (plus child safety seats)[611]:

Car/LTV occupant lives saved by car/LTV technologies	607,905
Non-occupants/motorcyclists saved by car/LTV brake improvements/ESC	2,936
Car/LTV occupant lives saved by heavy-trailer conspicuity tape	2,660
	613,501

Benefits for occupants of passenger cars

Table 2-10 is a summary of the benefits of safety technologies for passenger car occupants. Actual fatalities in passenger cars increased from 24,689 in 1960 to an all-time high of 36,406 in 1969. They have greatly declined since then to 11,949 in 2012, partly reflecting cars' gradual loss of market share to LTVs. But safety improvements greatly contributed to the decline; with-

[611] The non-occupant/motorcyclist lives saved are the sum of the last two columns (1,782 + 398) on Table 2-4; the car/LTV occupant lives saved by trailer conspicuity tape is the total for FMVSS No. 108 in Table 2-8. (Trailer conspicuity tape also has the potential to save lives of motorcyclists and heavy-truck occupants, but these are not tallied by our model, as explained in the "Summary of the Estimation Method.")

out them, fatalities would only have fallen from 37,449 in 1969 to 25,967 in 2012. Safety technologies saved 385,408 car occupants from 1960 through 2012, including 14,018 in 2012. Voluntary improvements such as better instrument panels, TTI(d) reductions in 2-door cars and designs to new FMVSS before their effective date have been saving between 600 and 1,300 lives a year since 1968; however, most of the lives saved (340,451) are by safety technologies compliant with FMVSS in effect at that time.

The proportion of potential fatalities saved by safety technologies has grown from 0.37 percent in 1960, when 92 car occupants were saved by lap belts, to 53.98 percent in 2012. The largest boost (from 14.32 to 25.35%) came from 1984 to 1988, when buckle-up laws took effect in most of the States, but there have been continued, steady gains since with belt use increasing and important non-belt technologies phasing in one after another, including frontal air bags, side impact protection, head impact protection, and ESC.

VMT data is available for passenger cars from 1975 to 2012.[612] They make it possible to compute occupant fatality rates per 100,000,000 VMT, as shown in Table 2-11 and Figure 2-6. Without the safety technologies, the fatality rate would potentially have remained nearly flat, close to 2.2, from about 1983 until 2007 (with possibly a rising trend in the mid-1980s as new, downsized cars continued to replace the pre-downsized fleet). But thanks to the safety improvements, the actual fatality rate trended steadily downward from 1.93 in 1983 to 1.06 in 2007. Specifically, the buckle-up laws enacted in the mid-1980s more than cancelled any upward trend in the potential fatality rate. From 2007 to 2011, the potential fatality rate dropped from 2.10 to 1.67 and the actual fatality rate from 1.06 to 0.78 (proportionately, an even steeper decline). The rates were 1.74 and 0.80 in 2012.

At this point, we can review the lives saved by 31 individual safety technologies for passenger cars. Table 2-1 lists them in a chronological order based on the “median installation year”: the first year that at least 50 percent of new cars had the technology. Our presentation will follow the same order: from oldest to newest (even though the computer models generating the estimates actually analyze the technologies in reverse chronological order). Table 2-12 covers the two earliest technologies, 208A – lap belts for outboard front seat occupants (age 5 and older), and 208B – lap belt use (at any seating position) by children 1 to 4 years old.

[612] *Traffic safety facts 2011*, p. 24 specifies VMT for cars in 1975 to 2011; the estimate of total VMT in *Traffic safety facts research note – 2012 motor vehicle crashes* has been allocated to cars, LTVs, and other vehicles based on the 2010-to-2011 trends.

Table 2-10: Passenger Car Summary – Actual Occupant Fatalities, Potential Fatalities Without the Safety Technologies, and Lives Saved

	CAR OCCUPANT FATALITIES		LIVES SAVED			
CY	ACTUAL	W/O SAFETY TECHS.	BY VOLUNTARY IMPROVEMENTS	BY FMVSS IN EFFECT	TOTAL	PERCENT SAVED
1960	24,689	24,782	92	0	92	0.37
1961	24,605	24,699	95	0	95	0.38
1962	26,757	26,867	110	0	110	0.41
1963	28,614	28,745	131	0	131	0.46
1964	31,189	31,357	168	0	168	0.54
1965	31,991	32,202	211	0	211	0.66
1966	34,346	34,634	288	0	288	0.83
1967	34,542	34,986	444	0	444	1.27
1968	35,720	36,439	614	105	719	1.97
1969	36,406	37,449	700	342	1,042	2.78
1970	34,051	35,331	711	568	1,279	3.62
1971	33,463	35,036	778	796	1,574	4.49
1972	34,444	36,427	899	1,084	1,984	5.45
1973	32,874	35,155	957	1,325	2,282	6.49
1974	26,103	28,322	809	1,411	2,220	7.84
1975	26,601	29,325	873	1,851	2,723	9.29
1976	26,803	29,655	864	1,988	2,852	9.62
1977	27,337	30,527	881	2,310	3,190	10.45
1978	28,438	31,940	878	2,624	3,501	10.96
1979	28,069	31,725	857	2,800	3,657	11.53
1980	27,709	31,557	839	3,009	3,848	12.20
1981	26,945	30,703	789	2,970	3,758	12.24
1982	23,390	26,783	686	2,708	3,394	12.67
1983	22,932	26,466	646	2,889	3,534	13.35
1984	23,596	27,538	626	3,317	3,943	14.32
1985	23,217	28,413	684	4,512	5,196	18.29
1986	24,957	31,785	841	5,987	6,828	21.48
1987	25,091	32,879	867	6,921	7,788	23.69
1988	25,718	34,469	910	7,842	8,752	25.39
1989	25,013	33,719	911	7,795	8,706	25.82
1990	24,086	32,814	917	7,810	8,727	26.60
1991	22,333	31,328	918	8,077	8,996	28.71
1992	21,296	30,375	944	8,136	9,079	29.89
1993	21,536	31,541	1,004	9,000	10,005	31.72
1994	21,943	32,668	1,063	9,662	10,725	32.83
1995	22,339	33,591	1,117	10,135	11,252	33.50
1996	22,495	34,707	1,145	11,067	12,212	35.19
1997	22,142	34,477	1,165	11,170	12,335	35.78
1998	21,210	33,760	1,099	11,450	12,549	37.17
1999	20,903	33,601	1,046	11,652	12,698	37.79
2000	20,710	34,201	1,092	12,399	13,491	39.45
2001	20,320	34,451	1,077	13,054	14,131	41.02
2002	20,564	35,618	1,096	13,957	15,053	42.26
2003	19,682	35,164	1,167	14,315	15,482	44.03
2004	19,134	34,742	1,153	14,455	15,608	44.93
2005	18,443	34,748	1,181	15,123	16,305	46.92
2006	17,790	34,190	1,249	15,151	16,400	47.97
2007	16,407	32,694	1,307	14,979	16,287	49.82
2008	14,446	29,198	1,228	13,524	14,752	50.52
2009	12,897	26,857	1,165	12,796	13,960	51.98
2010	12,235	25,981	1,226	12,520	13,746	52.91
2011	11,736	25,022	1,174	12,111	13,285	53.10
2012	11,949	25,967	1,216	12,802	14,018	53.98
	==========	==========	==========	==========	==========	
	1,292,205	**1,677,614**	**44,957**	**340,451**	**385,408**	

Table 2-11

Cars: Actual and Potential Occupant Fatalities per 100,000,000 Miles VMT

		ACTUAL FATALITIES		POTENTIAL FATALITIES W/O SAFETY TECHNOLOGIES	
CY	VMT (10^8 MILES)	N	RATE	N	RATE
1975	10,304	26,601	2.58	29,325	2.85
1976	10,707	26,803	2.50	29,655	2.77
1977	11,027	27,337	2.48	30,527	2.77
1978	11,365	28,438	2.50	31,940	2.81
1979	11,117	28,069	2.52	31,725	2.85
1980	11,071	27,709	2.50	31,557	2.85
1981	11,221	26,945	2.40	30,703	2.74
1982	11,458	23,390	2.04	26,783	2.34
1983	11,878	22,932	1.93	26,466	2.23
1984	12,265	23,596	1.92	27,538	2.25
1985	12,490	23,217	1.86	28,413	2.27
1986	12,776	24,957	1.95	31,785	2.49
1987	13,285	25,091	1.89	32,879	2.47
1988	13,840	25,718	1.86	34,469	2.49
1989	14,152	25,013	1.77	33,719	2.38
1990	14,272	24,086	1.69	32,814	2.30
1991	14,117	22,333	1.58	31,328	2.22
1992	14,360	21,296	1.48	30,375	2.12
1993	14,451	21,536	1.49	31,541	2.18
1994	14,592	21,943	1.50	32,668	2.24
1995	14,784	22,339	1.51	33,591	2.27
1996	14,991	22,495	1.50	34,707	2.32
1997	15,284	22,142	1.45	34,477	2.26
1998	15,559	21,210	1.36	33,760	2.17
1999	15,695	20,903	1.33	33,601	2.14
2000	15,831	20,710	1.31	34,201	2.16
2001	15,966	20,320	1.27	34,451	2.16
2002	16,137	20,564	1.27	35,618	2.21
2003	16,135	19,682	1.22	35,164	2.18
2004	16,300	19,134	1.17	34,742	2.13
2005	16,169	18,443	1.14	34,748	2.15
2006	16,163	17,790	1.10	34,190	2.12
2007	15,547	16,407	1.06	32,694	2.10
2008	15,243	14,446	.95	29,198	1.92
2009	15,103	12,897	.85	26,857	1.78
2010	15,077	12,235	.81	25,981	1.72
2011	14,953	11,736	.78	25,022	1.67
2012	14,900	11,949	.80	25,967	1.74

FIGURE 2-6: CAR OCCUPANT FATALITIES PER 100 MILLION MILES
WITH AND WITHOUT THE VEHICLE SAFETY TECHNOLOGIES, 1975 TO 2012

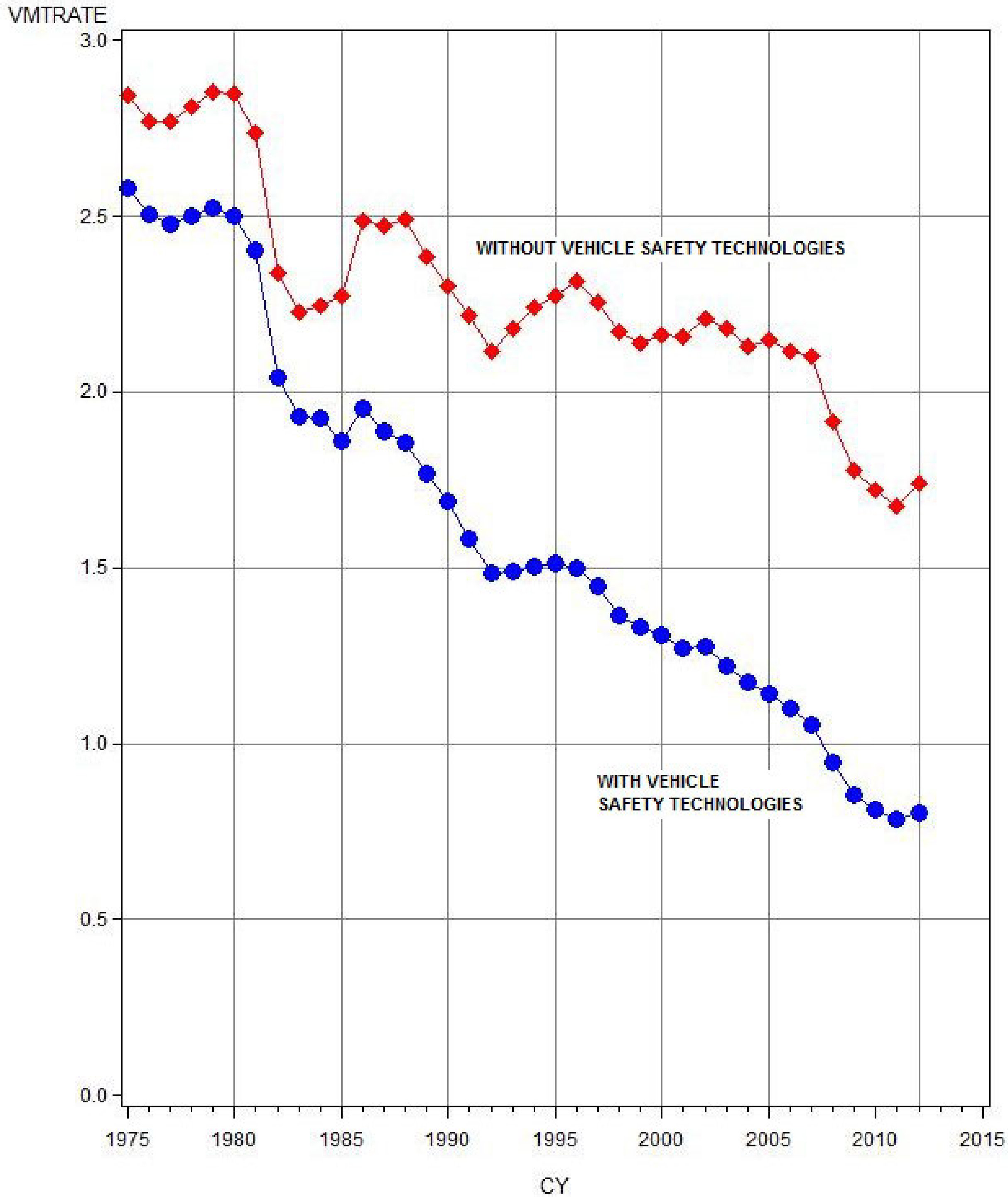

Table 2-12: Car Occupant Lives Saved by Outboard-Front-Seat Lap Belts
And Lap Belts for Children 1-4 Years Old, 1960-2012

	208A: LAP BELTS FOR OUTBOARD FRONT OCCS (MEDIAN INSTALL YR 1962, FMVSS 1/1/68)			208B: LAP BELT USE BY CHILDREN AGE 1-4 (MEDIAN INSTALL YR EARLY 65, FMVSS 1/1/68)		
CY	**VOLUNTARY**	**POST-FMVSS**	**TOTAL**	**VOLUNTARY**	**POST-FMVSS**	**TOTAL**
1960	92	0	92	1	0	1
1961	94	0	94	1	0	1
1962	104	0	104	1	0	1
1963	114	0	114	1	0	1
1964	131	0	131	1	0	1
1965	142	0	142	1	0	1
1966	160	0	160	1	0	1
1967	169	0	169	1	0	1
1968	176	12	188	2	0	2
1969	168	48	216	1	0	2
1970	145	83	228	1	1	2
1971	130	118	249	1	1	2
1972	122	180	303	1	1	2
1973	104	233	337	1	1	2
1974	72	194	266	1	1	2
1975	64	188	253	0	1	1
1976	44	140	184	0	2	3
1977	33	109	142	0	3	3
1978	30	95	125	1	2	3
1979	21	62	83	1	3	4
1980	15	45	59	1	5	5
1981	7	39	46	0	4	4
1982	10	25	34	0	7	7
1983	7	22	28	0	7	8
1984	8	23	30	0	11	11
1985	11	35	46	0	14	14
1986	20	51	71	0	23	23
1987	17	41	58	0	27	27
1988	17	36	53	0	28	28
1989	16	23	40	0	30	30
1990	12	26	38	0	20	20
1991	8	19	27	0	19	19
1992	8	16	24	0	25	25
1993	9	14	23	0	26	26
1994	11	15	26	0	42	42
1995	4	12	16	0	30	30
1996	7	13	20	0	33	33
1997	5	8	13	0	29	29
1998	5	10	15	0	35	35
1999	6	9	15	0	19	19
2000	6	6	12	0	15	15
2001	5	6	11	0	22	22
2002	6	9	15	0	19	19
2003	5	5	10	0	18	18
2004	5	3	8	0	13	13
2005	3	4	7	0	12	12
2006	3	2	5	0	12	12
2007	4	3	7	0	10	10
2008	2	2	3	0	9	9
2009	3	2	6	0	8	8
2010	4	1	5	0	6	6
2011	2	2	4	0	8	8
2012	2	1	3	0	8	8
	===========	===========	===========	===========	===========	===========
	2,367	**1,988**	**4,356**	**21**	**611**	**632**

Lap belts at the driver and RF seats were offered in some new cars as early as 1956 and were retrofitted into some cars even older than that. (Part 1 of this report discusses the availability and effectiveness of each safety technology, in this case the section on "lap belts for front seat occupants" in the chapter on FMVSS No. 208.) By MY 1962, over half of new cars were equipped with lap belts; States were passing laws requiring lap belts on new cars sold there. Lap belts reduce fatality risk by an average of 27 percent. FMVSS No. 208, like other initial safety standards, went into effect on January 1, 1968. Any lap-belt installation before January 1, 1968 – i.e., before mid-model year 1968 – is considered a "voluntary" installation, at least from a Federal point of view (although State laws might have required it) and any life saved by belts in a pre-MY 1968 or early-MY 1968 car is counted as a voluntary save in Table 2-12. Voluntary saves grow from 92 in 1960 to 176 in 1968 as more cars became equipped with belts. These cars, however, remained on the road after 1968 and their lap belts continued to accrue voluntary saves every year up to and including 2012, but in ever dwindling numbers as more and more were retired.

Most cars built from January 1, 1968, until August 31, 1973, had separate lap and shoulder belts. Here, our model counts fatality reductions among people who wore only the lap belt as "saved by the lap belt" and tallies them in the "post-FMVSS" column of Table 2-12. But fatality reductions among people who wore both belts are counted with "saved by lap/shoulder belts" in Table 2-18, technology 208F. The number of post-FMVSS saves grew from 12 in 1968 to 233 in 1973 and generally declined after that as the MY 1968-to-1973 cars were retired. The sum of voluntary and post-FMVSS saves, in the third column of Table 2-12, peaked at 337 in 1973 and totaled 4,356 from 1960 to 2012. Relatively low use and low effectiveness limited the number of lives saved by lap belts.

NHTSA **strongly urges** that children 1 to 4 years old ride in child safety seats appropriate for their weight, size, and age, in the rear seat of the vehicle. Nevertheless, there have historically been some parents or caregivers who placed small children in seat belts without a safety seat. While that is not nearly as safe as a child safety seat, it does reduce fatality risk, to some extent, relative to an unrestrained child. Technology 208B counts any child 1 to 4 years old saved by belts (but not in a child safety seat) at any seating position. It counts them as "saved by lap belts" regardless of whether that seat was equipped with a lap belt only, a 3-point belt, or separate lap and shoulder belts, because the shoulder portion of the belt is of little value to a small child who is not in a safety seat. Lap belts reduce the fatality risk of 1-to-4 year old children by an average of 33 percent. Belts, without a safety seat, are assumed to have little or no value for infants (less than 1 year old); the model calculates no savings for infants. Lives saved in cars built before January 1, 1968, are "voluntary" saves, and they can accrue as long as such cars remain in service; savings in cars built on or after January 1, 1968, are counted as "post-FMVSS." This technology had quite limited benefits before States enacted child passenger protection laws in the early 1980s. From then until 2002, belts saved 15 to 42 lives a year. Some early State laws specifically permitted a belt in lieu of a safety seat for young children; in other cases, the adults transporting the child may simply have decided on their own to use belts rather than a safety seat. After 2000, more and more States revised their laws to disallow premature graduation; belt use by small children declined relative to safety seats. In cars, belts have saved a total of 632 children 1 to 4 years old.

Table 2-13 tallies savings by FMVSS No. 206 (improved door locks) and by technology 208B (lap belts for outboard rear seat passengers 5 and older). A series of improvements to door locks in approximately 1962 to 1968 makes that the earliest non-belt technology evaluated by NHTSA. The evaluation estimated a 15-percent reduction of fatalities in rollovers. Benefits grew rapidly to about 500 lives saved per year as cars with the new technology replaced older cars; after that they gradually escalated to 713 in 2005 as the "base" of VMT and potentially fatal crashes grew larger and as smaller, more rollover-prone cars replaced full-size cars. As explained in the "Summary of the Estimation Method," our model first "removes" all safety technologies that came after FMVSS No. 206, most importantly 3-point belts. The 713 lives saved in 2005 are an estimate of the difference between a hypothetical fleet of cars equipped only with lap belts for outboard front seat occupants, lap belts for children, and improved door locks (208A, 208B, and 206) and another fleet with lap belts for children and front-outboard occupants, but not improved door locks (only 208A and 208B) – i.e., the benefit of FMVSS No. 206 in a fleet where nobody has 3-point belts. As with the other technologies, all lives saved in cars built before the January 1, 1968, effective date are "voluntary" saves. Benefits declined after 2005 as the on-road vehicle fleet gradually shifted from cars to LTVs. Improved door locks saved an estimated 25,377 car occupants from 1960 to 2012.

Lap belts were available at the outboard rear seats of most new cars by 1965 or 1966 and were required effective January 1, 1968. In the 1980s, 3-point belts increasingly superseded lap belts. FMVSS No. 208 required lap/shoulder belts effective December 11, 1989. Lap belts are estimated to reduce fatality risk by an average of 32 percent for rear seat occupants 5 and older. They achieved their largest benefit, 116 lives saved, in 1988, just before the shift to 3-point belts but after buckle-up laws, although primarily applicable to front seat occupants, began to have a favorable influence on the rear seat occupants as well. These lap belts saved an estimated 1,420 lives from 1960 to 2012. By 2012, most vehicles equipped with lap belts had been retired.

Table 2-13: Car Occupant Lives Saved by Improved Door Locks And Lap Belts for Outboard Rear Seat Occupants, 1960-2012

	206: IMPROVED DOOR LOCKS (MEDIAN INSTALL YR 1965, FMVSS 1/1/68)			208C: LAP BELTS FOR OUTBOARD REAR SEAT OCCS (MEDIAN INSTALL YR LATE 65, FMVSS 1/1/68)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	4	0	4	0	0	0
1963	13	0	13	0	0	0
1964	30	0	30	1	0	1
1965	52	0	52	2	0	2
1966	86	0	86	3	0	3
1967	123	0	123	4	0	4
1968	152	21	173	4	0	5
1969	157	67	224	4	1	6
1970	143	110	253	4	2	6
1971	139	151	291	4	3	7
1972	141	199	340	4	6	10
1973	129	232	361	4	9	13
1974	95	221	316	3	10	13
1975	74	248	322	5	12	17
1976	68	290	357	2	13	15
1977	69	392	461	4	21	25
1978	60	445	505	3	20	22
1979	53	536	589	0	12	12
1980	41	609	650	0	10	10
1981	29	590	619	1	13	13
1982	24	506	530	0	13	13
1983	20	511	532	0	29	30
1984	15	533	549	0	30	30
1985	15	553	568	0	65	65
1986	12	652	664	0	87	88
1987	10	710	721	1	88	89
1988	9	769	778	1	115	116
1989	5	703	708	1	109	109
1990	5	704	709	0	83	83
1991	5	675	681	0	77	77
1992	3	626	628	1	64	65
1993	2	629	631	0	65	65
1994	3	650	653	2	64	65
1995	2	679	681	1	67	68
1996	2	686	687	0	47	47
1997	2	643	644	0	42	42
1998	1	636	637	0	39	39
1999	1	665	666	0	18	18
2000	1	678	679	0	39	39
2001	1	672	673	0	15	15
2002	0	710	711	0	12	12
2003	1	633	633	0	6	6
2004	1	647	647	0	16	16
2005	1	712	713	0	6	6
2006	0	690	690	0	10	10
2007	0	656	656	0	3	3
2008	0	569	570	0	1	1
2009	1	513	514	0	5	5
2010	1	489	489	3	2	5
2011	0	477	477	0	2	2
2012	0	486	486	0	2	2
	===========	===========	===========	===========	===========	===========
	1,802	**23,575**	**25,377**	**62**	**1,357**	**1,420**

Table 2-14 considers adhesive windshield bonding and lap belts for center front seat passengers. Adhesive windshield bonding is a technology that was often employed to comply with the performance requirements set forth by FMVSS No. 212, but not explicitly mandated by that standard. Its introduction extended from MY 1963 through the effective date of January 1, 1970 until approximately 1980, although the majority of new cars had it by MY 1966. Adhesive bonding significantly reduces the risk of ejection through the windshield portal. Lives saved in cars built before January 1, 1970 are counted as voluntary saves, all others as post-FMVSS saves. The number of lives saved gradually rose over 200 per year as the "base" of VMT and potentially fatal crashes increased, but dropped back after 2005 with the shift from cars to LTVs. Adhesive bonding saved an estimated 7,268 lives from 1960 to 2012.

The center front seat, like all designated seating positions, had to be equipped with lap belts by January 1, 1968, and often was equipped before that. Many cars do not have a center front seat, especially in recent years. Even when they do, it is usually unoccupied and belt use is low. Nevertheless, over five decades, an estimated 94 car occupants can thank this technology for saving their lives.

Table 2-15 addresses dual master cylinders (105A) and lap belts for center rear seat passengers (5 and older). Both technologies were required effective January 1, 1968, and often introduced a few years before that. Dual master cylinders reduce the risk of a fatal crash involvement by an estimated 0.7 percent. As the "base" of potentially fatal crashes grew, benefits also grew to a peak of 242 car occupants saved in 2002 and a total of 8,834 from 1960 to 2012.

Lap belts reduce the fatality risk of center rear seat passengers by about 32 percent. Benefits increased in the 1980s as belt use increased and in the 1990s as more children 5 to 12 years old moved to the rear seat. In the later 1990s, manufacturers began phasing in 3-point belts and the numbers for lap belts dwindled after that. Lap belts saved an estimated 259 center rear seat passengers from 1960 to 2012.

Table 2-16 analyzes two basic "built-in" protections for front seat occupants in frontal crashes: energy-absorbing/telescoping steering assemblies to protect drivers (FMVSS Nos. 203 and 204), and voluntary modifications to middle and lower instrument panels, protecting passengers (called "201A" in this report because it is the first of two technologies associated with FMVSS No. 201). Energy-absorbing columns were introduced in the majority of cars in MY 1967 – i.e., late CY 1966 – and FMVSS Nos. 203 and 204 took effect on January 1, 1968. Thus, lives saved in the MY 1967 and early MY 1968 cars are counted as voluntary saves. The technology reduced drivers' fatality risk in frontal crashes by an estimated 12.1 percent. NHTSA's evaluation report, using 1978 as the baseline year, said FMVSS Nos. 203 and 204 would be saving 1,300 lives per year when all cars on the road met the standards. In fact, estimated benefits reached 1,300 in 1986 and reached a peak of 1,724 in 2005 as the base of VMT and potentially fatal crashes expanded. Subsequent reduction in the exposure base, including the shift from cars to LTVs, had returned benefits to the 1,300 level by 2011 and 2012. Energy-absorbing and telescoping columns continue to be a critical component of the overall frontal energy-management and crash-protection system, even in today's cars with frontal air bags and high belt use. With 57,112 lives saved from 1966 through 2012, energy-absorbing steering assemblies clearly rank first in cumulative benefits among the non-belt technologies for passenger cars.

Table 2-14: Car Occupant Lives Saved by Adhesive Windshield Bonding And Lap Belts for Center Front Seat Passengers, 1960-2012

	212: ADHESIVE WINDSHIELD BONDING (MEDIAN INSTALL EARLY 66, FMVSS 1/1/70)			208D: LAP BELTS FOR CENTER FRONT SEAT OCCS (MEDIAN INSTALL YR 1966, FMVSS 1/1/68)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	2	0	2	0	0	0
1965	8	0	8	0	0	0
1966	18	0	18	0	0	0
1967	28	0	28	0	0	0
1968	39	0	39	0	0	1
1969	53	0	53	1	0	1
1970	56	6	62	0	1	1
1971	55	17	72	0	1	2
1972	56	31	86	0	1	2
1973	52	41	94	0	2	2
1974	40	42	83	0	2	2
1975	37	48	85	1	3	4
1976	35	58	94	0	3	3
1977	33	71	104	0	2	2
1978	31	87	118	0	3	3
1979	23	92	115	0	1	1
1980	20	104	124	0	2	2
1981	12	110	122	0	1	1
1982	10	103	113	0	2	2
1983	8	107	115	0	1	1
1984	7	120	127	0	1	1
1985	5	133	138	0	3	3
1986	5	164	170	0	2	2
1987	4	183	187	0	2	2
1988	3	206	209	0	3	3
1989	2	196	197	0	4	5
1990	1	196	198	0	4	4
1991	1	194	195	0	3	3
1992	1	184	185	0	2	2
1993	1	193	194	0	3	3
1994	1	201	202	0	3	3
1995	1	210	211	0	3	3
1996	0	213	214	0	4	4
1997	0	208	208	0	4	4
1998	1	207	208	0	3	3
1999	0	210	210	0	2	2
2000	1	215	215	0	2	2
2001	0	222	223	0	2	2
2002	0	233	233	0	1	1
2003	0	221	221	0	1	1
2004	0	218	218	0	2	2
2005	0	228	228	0	3	3
2006	0	226	226	0	1	1
2007	0	220	220	0	2	2
2008	0	199	199	0	1	1
2009	0	182	183	0	0	0
2010	0	175	175	0	0	0
2011	0	166	166	0	2	2
2012	0	177	177	0	1	1
	===========	===========	===========	===========	===========	===========
	653	**6,615**	**7,268**	**6**	**89**	**94**

Table 2-15: Car Occupant Lives Saved by Dual Master Cylinders
And Lap Belts for Center Rear Seat Occupants, 1960-2012

	105A: DUAL MASTER CYLINDERS (MEDIAN INSTALL YR LATE 66, FMVSS 1/1/68)			208E: LAP BELTS FOR CENTER REAR SEAT OCCS (MEDIAN INSTALL EARLY 67, FMVSS 1/1/68)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	1	0	1	0	0	0
1963	3	0	3	0	0	0
1964	5	0	5	0	0	0
1965	6	0	6	0	0	0
1966	16	0	16	0	0	0
1967	37	0	37	0	0	0
1968	51	10	61	0	0	0
1969	53	32	85	0	0	0
1970	47	53	100	0	0	0
1971	46	73	119	0	0	0
1972	47	96	143	0	0	1
1973	45	112	157	0	0	1
1974	34	107	141	0	0	1
1975	32	132	164	0	0	0
1976	29	146	175	0	0	0
1977	23	163	186	0	1	1
1978	19	182	201	3	1	4
1979	15	188	203	0	0	1
1980	12	194	205	0	0	0
1981	9	192	201	0	0	0
1982	7	170	176	0	4	4
1983	5	170	176	0	1	1
1984	4	180	184	0	5	5
1985	4	186	190	0	6	6
1986	3	209	212	0	4	4
1987	2	218	220	0	10	10
1988	2	229	231	0	4	4
1989	2	225	227	0	10	10
1990	1	220	221	0	10	10
1991	1	210	211	0	7	7
1992	1	205	205	0	8	8
1993	1	213	213	0	5	5
1994	1	220	221	0	8	8
1995	0	227	227	0	10	10
1996	0	235	235	0	17	17
1997	0	234	234	0	13	13
1998	0	229	229	0	12	12
1999	0	228	228	0	9	9
2000	0	232	232	0	13	13
2001	0	234	234	0	8	8
2002	0	242	242	0	13	13
2003	0	240	240	0	23	23
2004	0	237	237	0	14	14
2005	0	236	236	0	7	7
2006	0	232	233	0	2	2
2007	0	222	222	0	8	8
2008	0	199	199	0	4	4
2009	0	183	183	0	3	3
2010	0	177	177	0	1	1
2011	0	170	170	0	2	2
2012	0	177	177	0	6	6
	===========	===========	===========	===========	===========	===========
	566	**8,268**	**8,834**	**5**	**254**	**259**

Table 2-16: Car Occupant Lives Saved by Energy-Absorbing Steering Assemblies And Voluntary Instrument Panel Improvements, 1960-2012

	203: ENERGY-ABSORBING STEERING ASSEMBLIES (MEDIAN INSTALL YEAR 1967, FMVSS 1/1/68)			201A: VOLUNTARY INSTRUMENT PANEL IMPROVEMENTS (MEDIAN INSTALL YR 1968, FMVSS 1/1/68)
CY	VOLUNTARY	POST-FMVSS	TOTAL	TOTAL (VOLUNTARY)
1960	0	0	0	0
1961	0	0	0	0
1962	0	0	0	0
1963	0	0	0	0
1964	0	0	0	0
1965	0	0	0	0
1966	3	0	3	1
1967	68	0	68	14
1968	140	60	201	45
1969	154	192	346	87
1970	136	313	448	125
1971	131	431	562	172
1972	135	569	704	234
1973	133	663	795	286
1974	106	630	735	283
1975	100	764	864	339
1976	98	846	944	371
1977	78	964	1,043	410
1978	65	1,106	1,171	462
1979	54	1,168	1,222	475
1980	43	1,204	1,247	510
1981	31	1,178	1,209	510
1982	25	1,049	1,073	451
1983	19	1,029	1,047	439
1984	15	1,088	1,103	457
1985	13	1,211	1,224	502
1986	10	1,328	1,338	578
1987	8	1,388	1,396	593
1988	6	1,462	1,468	636
1989	6	1,460	1,465	626
1990	4	1,447	1,451	614
1991	5	1,372	1,377	591
1992	3	1,357	1,360	595
1993	2	1,427	1,430	612
1994	2	1,485	1,487	620
1995	2	1,534	1,535	646
1996	1	1,591	1,592	646
1997	2	1,601	1,603	677
1998	1	1,589	1,590	623
1999	1	1,546	1,547	589
2000	1	1,583	1,584	621
2001	0	1,673	1,673	615
2002	1	1,692	1,693	649
2003	1	1,689	1,690	638
2004	0	1,717	1,717	617
2005	0	1,724	1,724	592
2006	0	1,723	1,723	603
2007	0	1,689	1,690	573
2008	0	1,568	1,569	513
2009	0	1,472	1,472	459
2010	0	1,324	1,324	457
2011	1	1,282	1,283	413
2012	0	1,323	1,323	431
	===========	===========	===========	===========
	1,604	**55,508**	**57,112**	**22,000**

NHTSA proposed in 1966 and again in 1970 that FMVSS No. 201 regulate the force-deflection characteristics of middle and lower instrument panels, but those requirements were not included in any final rule.[613] Nevertheless, by the mid-1970s, manufacturers had voluntarily remodeled the panels, using newly available materials, to absorb passenger impacts at a safer and more controlled force level. That has resulted in a 15.9-percent fatality reduction for unrestrained RF passengers in frontal impacts. It saved an estimated 22,000 lives from late CY 1966 through 2012. The benefits for this technology are about one-third of the benefits for energy-absorbing steering assemblies principally because only one-third of crash-involved cars have a RF passenger, while all have a driver.

Table 2-17 addresses front disc brakes (105B) and side door beams (214A). Front disc brakes are well suited for meeting tests added to FMVSS No. 105 effective January 1, 1976, but were never explicitly required by that standard. Consumers preferred them to drum brakes. Their introduction extended from MY 1965 until 1977, but the majority of new cars had them by 1971. Front disc brakes reduce the risk of a fatal crash involvement by an estimated 0.17 percent. They have been saving approximately 50 car occupants per year (closer to 40 after 2008), and a total of 1,725 from 1960 to 2012.

Side door beams were introduced in some cars as early as MY 1969, four years before the January 1, 1973, effective date of FMVSS No. 214. This technology aims to enhance crashworthiness and structural integrity in side impacts. While there are significant injury reductions in all types of side impacts, fatality reduction has been limited to single-vehicle crashes, such as side impacts with poles or trees after a car has run off the road and gone out of control. Side door beams reduce these fatalities by 14 percent, saving an average of 450 lives per year after most cars on the road were equipped with them, and an estimated total of 15,602 from 1969 through 2012.

Table 2-18 covers FMVSS No. 216, roof crush resistance and the big one: 3-point belts for outboard front seat occupants, age 5+ (208F). The visible change associated with FMVSS No. 216 was the redesign of true hardtops as pillared hardtops or sedans. Nevertheless, many hardtops could and did meet FMVSS No. 216. The transition to pillared hardtops and sedans extended from approximately MY 1970 through the FMVSS No. 216 effective date of September 1, 1973, until about 1977. Pillared cars do a significantly better job of protecting non-ejected occupants in rollover crashes, saving a peak 174 lives in 2005 and an estimated 4,913 in 1960 to 2012.

[613] Kahane (1988, January), pp. 2-3; *Federal Register* 31 (December 3, 1966): 15212, 35 (September 25, 1970): 14936.

Table 2-17: Car Occupant Lives Saved by Front Disc Brakes and Side Door Beams, 1960-2012

	105B: FRONT DISC BRAKES (MEDIAN INSTALL YEAR 1971, FMVSS 1/1/76)			214A: SIDE DOOR BEAMS (MEDIAN INSTALL EARLY 73, FMVSS 1/1/73)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	1	0	1	0	0	0
1968	1	0	1	0	0	0
1969	3	0	3	7	0	7
1970	4	0	4	21	0	21
1971	7	0	7	40	0	40
1972	11	0	11	63	0	63
1973	15	0	15	75	21	96
1974	15	0	15	61	54	115
1975	19	0	19	66	76	142
1976	21	2	23	84	125	209
1977	21	6	27	65	153	218
1978	21	11	32	69	190	259
1979	19	16	35	68	240	308
1980	18	19	37	69	266	335
1981	15	22	38	53	290	343
1982	12	22	34	45	251	297
1983	11	24	35	41	270	311
1984	10	28	37	39	330	370
1985	8	32	40	23	347	370
1986	8	37	45	25	390	415
1987	6	42	47	20	398	418
1988	5	46	50	13	452	466
1989	3	46	50	9	457	466
1990	3	46	49	9	446	455
1991	2	45	47	6	450	456
1992	2	44	46	6	416	422
1993	1	46	47	4	425	428
1994	1	48	49	3	427	430
1995	1	50	51	3	481	484
1996	1	52	53	1	492	493
1997	1	52	52	1	452	453
1998	0	51	51	2	447	450
1999	0	51	51	1	453	454
2000	0	52	52	1	458	459
2001	0	52	52	0	466	466
2002	0	54	54	1	492	493
2003	0	54	54	1	510	511
2004	0	53	53	1	507	508
2005	0	53	53	0	487	487
2006	0	52	52	0	495	495
2007	0	50	50	0	463	463
2008	0	44	44	0	415	416
2009	0	41	41	0	385	385
2010	0	40	40	0	400	400
2011	0	38	38	0	367	367
2012	0	40	40	0	359	359
	===========	===========	===========	===========	===========	===========
	267	**1,458**	**1,725**	**1,000**	**14,602**	**15,602**

Table 2-18: Car Occupant Lives Saved by Roof Crush Resistance And 3-Point Belts for Outboard Front Seat Occupants, 1960-2012

CY	216: ROOF CRUSH RESISTANCE - ELIMINATE HARDTOPS (MEDIAN INSTALL YR 1973, FMVSS 9/1/73)			208F: 3-POINT BELTS FOR OUTBOARD FRONT OCCS (MEDIAN INSTALL YR 1974, FMVSS 9/1/73)		
	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	2	0	2
1969	0	0	0	12	0	12
1970	2	0	2	23	0	23
1971	5	0	5	38	0	38
1972	11	0	11	59	0	59
1973	18	0	18	77	9	86
1974	15	7	22	64	144	208
1975	14	15	29	85	363	448
1976	14	20	34	83	344	426
1977	19	41	59	88	384	472
1978	16	54	70	71	427	499
1979	19	84	103	53	398	451
1980	19	97	116	53	449	502
1981	16	99	115	31	429	460
1982	12	90	102	33	452	486
1983	9	89	98	33	563	596
1984	8	92	99	28	776	804
1985	5	103	108	57	1,685	1,742
1986	7	125	131	77	2,801	2,878
1987	4	133	137	70	3,512	3,582
1988	3	148	151	54	4,073	4,127
1989	2	141	144	44	4,005	4,049
1990	2	134	136	45	3,826	3,871
1991	1	137	138	45	4,009	4,055
1992	1	132	133	34	4,066	4,100
1993	1	133	133	34	4,556	4,589
1994	1	147	148	26	4,785	4,811
1995	0	147	147	32	4,885	4,917
1996	0	159	159	22	5,392	5,415
1997	0	149	149	22	5,468	5,490
1998	0	155	155	28	5,568	5,596
1999	0	153	153	7	5,611	5,618
2000	0	148	148	15	5,919	5,934
2001	0	150	150	12	6,364	6,375
2002	0	163	163	6	6,751	6,757
2003	0	149	149	7	7,048	7,055
2004	0	156	157	7	7,035	7,042
2005	0	174	174	13	7,448	7,461
2006	0	163	163	11	7,528	7,539
2007	0	160	160	8	7,628	7,636
2008	0	148	148	3	6,867	6,869
2009	0	127	127	7	6,555	6,563
2010	0	125	125	1	6,528	6,529
2011	0	120	120	4	6,177	6,181
2012	0	122	122	1	6,547	6,548
	===========	===========	===========	===========	===========	===========
	226	**4,687**	**4,913**	**1,527**	**157,373**	**158,900**

FMVSS No. 208 has required manual, integral 3-point belts at the driver's and RF seats in all cars without automatic protection since September 1, 1973, and in all cars since September 1, 1997. From January 1, 1972, until August 31, 1973, FMVSS No. 208 required lap and shoulder belts at these positions in all cars, but manufacturers could choose between integral 3-point belts or separate lap and shoulder belts. From January 1, 1968, until December 31, 1971, this requirement applied only to cars where a lap belt was insufficient to prevent a dummy from contacting the windshield header (but, in reality, manufacturers equipped all their cars with separate or integral lap/shoulder belts).

The model developed for this study counts as "voluntary" saves by technology 208F:

- All people (5 and older) saved by integral 3-point belts installed before September 1, 1973 – primarily in cars imported from Europe.
- Lives saved among occupants who used both the lap and the shoulder belts, in cars with separate lap and shoulder belts built before September 1, 1973.

However, as stated earlier, people who wore only the lap belt in cars with separate belts are counted as "saved by lap belts" (208A).

The model counts as "post-FMVSS" saves by technology 208F:

- All people (5 and older) saved by manual, integral 3-point belts installed on or after September 1, 1973, regardless of whether these integral belts were used correctly or incorrectly (e.g., wearing the shoulder portion of the belt behind the back, essentially obtaining protection from the lap portion only).
- Lives saved by automatic 3-point belts. Although they are automatic belts, they have had use patterns and effectiveness nearly identical to manual 3-point belts.

As stated above, any child 1 to 4 years old saved by a belt, without a safety seat, is counted as "saved by lap belts" (208B), even if the belt was a 3-point belt, because the shoulder portion is intrinsically of little value to a child that small.

Three-point belts are the most important available occupant protection in most crash modes, reducing fatality risk by an average of 45 percent in passenger cars, when they are used. They were saving about 500 lives per year in 1977 to 1983 as declining belt use more or less offset the growing proportion of the fleet equipped with 3-point belts. Buckle-up laws in most States phenomenally increased the benefits of belts to 4,127 lives saved by 1988. Continued increases in belt use and moderate growth in the "base" of VMT and potentially fatal crashes raised that to a peak of 7,636 lives saved in 2007. After that, the shrinking base of car registrations and VMT offset further increases in belt use. Belts saved an estimated 6,548 lives in 2012 and a cumulative 158,900 from 1960 through 2012. Both numbers are somewhat under half the overall benefits of the FMVSS in passenger cars (14,018 and 385,408, respectively – see Table 2-10).

Table 2-19 estimates lives saved by voluntary NCAP-related improvements and child safety seats/booster seats (FMVSS No. 213). Since 1979, NCAP has advised the public about the injury performance of belted dummies in 35-mph frontal impact tests. During the early-to-mid 1980s, manufacturers substantially improved NCAP performance, modifying belt systems, steering assemblies, instrument panels and/or seat structures. For cars without air bags, NHTSA's evaluation estimated a 20-percent reduction of fatality risk for belted drivers in frontal impacts with other cars. NHTSA has not evaluated the relationship of NCAP scores with fatality risk in cars with air bags; the model limits its estimate of a benefit to cars without air bags. Lives saved by vehicle modifications associated with NCAP performance have saved an estimated 1,156 lives from 1983 to 2012; the estimates peaked at 79 in 1993 and had declined to almost nothing by 2012 because, by then, over 95 percent of cars on the road had driver air bags. Because NCAP is not a FMVSS and any modifications to improve performance were voluntary on the part of the manufacturers, all benefits are counted as voluntary saves.

FMVSS No. 213 regulates the performance of child safety seats, including booster seats. However, the seats themselves are usually not part of a new vehicle. They must be purchased or acquired separately. At first, that was a voluntary decision for parents. During 1978 to 1985, every State enacted laws requiring a safety seat for child passengers up to a certain age. Subsequently, most of the States revised their laws to increase the age up to which a child must be in a child safety seat or booster seat rather than merely buckled up with the car's seat belts. The model counts as a "voluntary" save by child safety seats:

- Any child saved before a child passenger protection law was in effect in that State; and
- Any child saved who was older than the range of ages included in that State's law.

The model counts as an "obligatory" save any child saved by a child safety seat or booster seat in a State where a law was in effect, and that law required a child of that age to be in a safety seat or booster seat.

However, any child saved by a belt, without a safety seat, is counted in one of the "saved by belts" categories, depending on the child's age and seating position, and is not counted as saved by a safety seat.

NHTSA's evaluation estimates that safety seats reduce fatality risk in passenger cars by 71 percent for infants and by 54 percent for toddlers; the model also assumes the latter effect for booster seats. Safety seats and booster seats saved an estimated 7,257 lives from 1960 through 2012, of which 6,163 were children obligated by a State law to be in a safety seat or booster seat, while 723 were voluntary saves before State laws or involving a child old enough that the law in effect at the time allowed belts in lieu of a safety seat. Benefits peaked at 336 in 2000, but dropped after 2001 because the exposure "base" of children in potentially fatal crashes shrank – in part because more and more children are placed in the safer rear seat to avoid exposure to air bags, and because many children are now transported in minivans or SUVs rather than cars.

Table 2-19: Car Occupant Lives Saved by Voluntary NCAP-Related Improvements and Child Safety Seats (Including Booster Seats), 1960-2012

CY	NCAP-RELATED VOLUNTARY IMPROVEMENTS (MEDIAN IMPLEMENTATION YEAR 1984) TOTAL (VOLUNTARY)	213: CHILD SAFETY SEATS (USE > 50% 1985, FMVSS 4/1/71, STATE LAWS 1978-85) VOLUNTARY	OBLIGATORY	TOTAL
1960	0	0	0	0
1961	0	0	0	0
1962	0	0	0	0
1963	0	0	0	0
1964	0	0	0	0
1965	0	0	0	0
1966	0	0	0	0
1967	0	0	0	0
1968	0	1	0	1
1969	0	1	0	1
1970	0	4	0	4
1971	0	8	0	8
1972	0	14	0	14
1973	0	18	0	18
1974	0	19	0	19
1975	0	34	0	34
1976	0	15	0	15
1977	0	32	0	32
1978	0	22	0	22
1979	0	48	0	48
1980	0	34	5	40
1981	0	66	2	69
1982	0	64	2	67
1983	2	59	48	107
1984	4	21	96	117
1985	16	18	128	145
1986	36	27	114	140
1987	52	35	140	175
1988	66	21	167	189
1989	65	25	184	209
1990	61	32	169	202
1991	71	26	182	208
1992	70	32	213	245
1993	79	13	229	242
1994	72	26	240	266
1995	68	26	234	260
1996	66	41	274	315
1997	67	27	262	289
1998	64	22	247	269
1999	50	33	262	295
2000	44	30	306	336
2001	41	27	210	237
2002	27	13	213	225
2003	34	39	291	330
2004	21	18	247	265
2005	19	15	271	286
2006	16	20	233	254
2007	12	16	230	246
2008	10	6	192	198
2009	7	11	196	206
2010	5	8	201	209
2011	5	11	175	185
2012	4	13	199	213
	===========	===========	===========	===========
	1,156	**1,094**	**6,163**	**7,257**

Table 2-20 considers two of the more recent belt technologies: 3-point belts for outboard rear seat occupants (208G) and automatic 2-point belts for outboard front seat occupants (208H). FMVSS No. 208 has required lap/shoulder belts at outboard rear seats since December 11, 1989[614] and quite a few make-models were voluntarily equipped with 3-point belts one year, two years, or even many years before that date. Three-point belts are quite effective for rear seat occupants, reducing fatality risk by an average of 44 percent (as compared to 32% for the lap belt only). Belt use, occupancy of the rear seat and the proportion of cars on the road equipped with 3-point belts have steadily increased since 1990, pushing benefits to a peak of 319 lives saved in 2002. Numbers decreased after 2005 with the shift from cars to LTVs, reaching 231 lives saved in 2012 and a total of 4,612 from 1960 to 2012.

Automatic 2-point belts were introduced on a voluntary basis in the Volkswagen Rabbit (non-motorized) starting in 1975 and the Toyota Cressida (motorized) starting in 1981. Quite a few make-models were equipped with them during the MY 1987-to-1989 phase-in period for automatic protection under FMVSS No. 208 and in the early 1990s. Consumers indicated a clear preference for the more effective combination of air bags and manual 3-point belts; automatic 2-point belts were gone from new cars by MY 1996, two years before FMVSS No. 208 required air bags and manual 3-point belts in all cars.

Automatic 2-point belts are less effective than 3-point belts, in part because the manual lap belt that accompanies them is often not used. Fatality reduction is an estimated 32 percent with automatic 2-point belts (versus 45% with 3-point belts). During the 1980s the lower effectiveness was more than offset by a much higher use rate for the 2-point belts; by 2002, use of 3-point belts had largely caught up with the automatic use rate. Lives saved by automatic 2-point belts peaked at 985 in CY 1996 and subsequently declined as no new cars were equipped with them and the existing fleet was retired. Through 2012, automatic 2-point belts had saved an estimated 14,068 lives.

[614] A choice of 3-point belts or separate lap and shoulder belts was allowed from December 11, 1989, to August 31, 1990, whereas 3-point belts were required starting September 1, 1990; in reality, all cars have been equipped with 3-point belts since before December 11, 1989.

Table 2-20: Car Occupant Lives Saved by 3-Point Belts for Outboard Rear Seat Occupants And Automatic 2-Point Belts, 1960-2012

	208G: 3-POINT BELTS FOR OUTBOARD REAR SEAT OCCS (MEDIAN INSTALL YR 1989, FMVSS 12/11/89)			208H: AUTOMATIC 2-POINT BELTS (PEAK YEAR 1991, PHASE-IN BEGAN 9/1/86)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	1	0	1
1977	0	0	0	5	0	5
1978	0	0	0	6	0	6
1979	1	0	1	5	0	5
1980	0	0	0	5	0	5
1981	0	0	0	7	0	7
1982	0	0	0	5	0	5
1983	1	0	1	8	0	8
1984	3	0	3	11	0	11
1986	8	0	8	16	0	16
1987	15	0	15	9	28	37
1988	13	0	13	16	102	118
1989	23	4	27	14	191	205
1990	23	18	41	16	418	434
1991	36	46	83	7	556	563
1992	26	58	84	15	620	636
1993	28	69	97	15	771	786
1994	23	115	138	15	913	928
1995	23	125	148	7	923	930
1996	29	149	178	5	979	985
1997	23	157	180	6	912	917
1998	32	212	244	10	859	869
1999	19	152	171	5	873	878
2000	22	216	239	5	822	827
2001	17	236	253	3	766	769
2002	14	286	299	9	736	746
2003	17	239	255	2	645	647
2004	6	254	260	2	581	583
2005	11	308	319	4	504	508
2006	7	260	267	1	438	439
2007	2	258	260	0	329	329
2008	2	205	207	0	234	235
2009	3	200	203	1	211	211
2010	2	175	177	0	152	152
2011	1	205	206	1	139	140
2012	1	230	231	0	114	114
	===========	===========	===========	===========	===========	===========
	433	**4,178**	**4,612**	**252**	**13,816**	**14,068**

Table 2-21 estimates **net** lives saved by frontal air bags (208I), including separate estimates for the three major types or "generations" of air bags: barrier-certified (until the late 1990s), sled-certified (late 1990s to mid-2000s), and certified-advanced (since the mid-2000s). Frontal air bags are effective in reducing the fatality risk of adults and adolescents (13 and older) in frontal and partially frontal crashes. Benefits are to a numerically small extent offset by increased risk to certain subgroups of child passengers (12 and younger). Some of the vehicles have manual on-off switches for passenger air bags, which can also affect net benefits in several ways. NHTSA's evaluations indicate that the three major types of air bags are about equally effective for adults and adolescents, but can differ substantially for child passengers. Effectiveness for adults and adolescents varies by crash type and seating position, but averaged over all crashes, driver air bags reduce the fatality risk of belted occupants by 11 percent, and unbelted occupants by 14 percent. At the end of this chapter, Tables 2-49 through 2-54 furnish more detailed analyses that estimate effects separately by type of air bag, occupant age group, and seating position; they also explore the effects of the manual switches.

Mercedes offered air bags on a voluntary basis in MY 1985 and 1986. After the FMVSS No. 208 phase-in of automatic protection began on September 1, 1986, other manufacturers began to offer driver or dual air bags, building up to 100 percent of new cars by MY 1997. Only the 1985 and 1986 Mercedes air bags are included in the voluntary saves on Table 2-21. All other air bags, supplied either during or after the phase-in period, have their benefits listed in the "Post-FMVSS" column. The number of lives saved by air bags grew rapidly, commensurate with the proportion of registered cars equipped with air bags, peaking at 2,110 in 2006. It then gradually decreased to 1,738 in 2012 after the downturn in VMT and the market shift from cars to LTVs. Frontal air bags had saved an estimated 27,765 lives in passenger cars from 1985 through 2012.

Initially, all frontal air bags were barrier-certified. In late CY 1997 (i.e., early MY 1998), sled-certified air bags begin to appear and, after 2005, lives saved by barrier-certified air bags dwindle as cars with those early systems are retired. The first advanced air bags show up in 2004. Eventually, advanced air bags will supersede barrier-certified and sled-certified in the on-road fleet, and all the benefits will gradually shift to advanced air bags.

Table 2-21: Car Occupant Lives Saved by Frontal Air Bags (208I), 1960-2012
(Median Installation Year 1992, Phase-In Began September 1, 1986)

CY	VOLUNTARY	POST-FMVSS	TOTAL	BARRIER-CERTIFIED	SLED-CERTIFIED	ADVANCED
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	0	0	0	0
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	0
1983	0	0	0	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	1	0	1	1	0	0
1987	1	0	2	2	0	0
1988	0	2	3	3	0	0
1989	1	7	8	8	0	0
1990	0	44	44	44	0	0
1991	0	76	76	76	0	0
1992	0	100	100	100	0	0
1993	1	196	198	198	0	0
1994	0	286	286	286	0	0
1995	1	458	459	459	0	0
1996	0	612	612	612	0	0
1997	0	749	749	746	3	0
1998	1	901	902	822	80	0
1999	0	1,054	1,055	832	223	0
2000	1	1,256	1,257	885	371	0
2001	1	1,409	1,410	873	536	0
2002	0	1,671	1,671	935	736	0
2003	1	1,761	1,762	904	857	0
2004	0	1,932	1,932	896	1,016	19
2005	0	1,999	1,999	871	1,056	72
2006	0	2,109	2,110	789	1,137	184
2007	1	2,102	2,103	686	1,078	339
2008	0	1,967	1,967	567	1,012	388
2009	0	1,855	1,855	465	939	452
2010	0	1,738	1,738	404	827	506
2011	0	1,732	1,732	379	793	560
2012	0	1,738	1,738	323	779	636
	===========	===========	===========	===========	===========	===========
	13	**27,752**	**27,765**	**13,164**	**11,444**	**3,157**

Table 2-22 addresses two technologies that came in a few years after frontal air bags: side impact protection by structure and padding (214B) and conspicuity tape for heavy trailers (108). Conspicuity tape is installed on heavy trailers, but benefits car occupants by helping car drivers to identify and avoid striking heavy vehicles at night.

A dynamic test for FMVSS No. 214 phased in from September 1, 1993, to September 1, 1996 to improve occupant protection when a car is struck in the side by another vehicle. The crash test measures a thoracic trauma index TTI(d) on the dummy seated in the vehicle adjacent to the impact location. NHTSA's evaluation quantifies the fatality-reducing effectiveness per unit reduction in the TTI(d) score. The new test procedure was the product of many years of research. During the decade before the phase-in manufacturers tried out the test procedure on their vehicles. From about MY 1986 onward they began to voluntarily modify vehicle structures in a way that gradually improved fleet-average TTI(d). A second, large increment of TTI(d) reduction by structure and padding came with certification to the upgraded standard in MY 1994 to 1997. NHTSA's evaluation estimates that, relative to MY 1985 baseline vehicles, voluntary and post-standard TTI(d) reductions by structure and padding had reduced fatality risk of front seat occupants in near-side impacts by other vehicles by a cumulative 17 percent in 4-door cars and by a cumulative 33 percent in 2-door cars. (NHTSA has not evaluated the effect for rear seat occupants.) The effect is greater in 2-door cars because they started from a substantially higher baseline TTI(d). The resulting estimated fatality reductions in MY 1986-to-1996 cars not yet certified to the new test requirement (which are fractions of the 17% or 33% effects) are tallied in the "voluntary" column of Table 2-22. They peaked at 301 in 1997 and then dwindled as all new cars certified to the new test requirement and pre-certified cars were retired. The reductions in MY 1994-to-2012 certified cars are tallied in the "post-FMVSS" column. Overall (voluntary plus post-FMVSS), structure and padding had saved 11,672 lives from 1986 through 2012, including 565 in 2012. Benefits peaked at 793 in 2005 and then declined with the market shift from cars to LTVs.

FMVSS No. 108 has required conspicuity tape on new heavy trailers (i.e., with GVWR over 10,000 pounds) since December 1, 1993. The Federal Motor Carrier Safety Administration required all heavy trailers on the road, even those built before December 1, 1993, to be equipped or retrofitted with tape by June 1, 2001. When trailers are equipped with tape, they are easier to see in the dark and cars are 29 percent less likely to hit them. The model[615] counts as a "voluntary" save by conspicuity tape:

- Any car occupant saved when his or her car, before June 1, 2001, avoided hitting a trailer built before December 1, 1993, yet equipped or retrofitted with tape.

The model counts as "post-standard" saves:

- Any car occupant saved when his or her car, at any time, avoided hitting a trailer built after December 1, 1993 and any car occupant saved when his or her car, after June 1, 2001, avoided hitting **any** trailer.

[615] Because FARS does not report the MY of trailers, the model can only assess the probability of the following three scenarios based on the CY and month of the crash.

Table 2-22: Car Occupant Lives Saved by Side Impact Protection [TTI(d) Reduction by Structure and Padding] and by Conspicuity Tape on Heavy Trailers, 1960-2012

	214B: TTI(d) REDUCTION BY STRUCTURE/PADDING (MEDIAN INSTALL YR EARLY 1996, FMVSS PHASE-IN BEGAN MY 1994)			108: CONSPICUITY TAPE ON HEAVY TRAILERS (ON-ROAD FLEET > 50% IN 1996, FMVSS 12/1/93, FMCSA RETROFIT 6/1/2001)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-STANDARD	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	0	0	0	0
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	0
1983	0	0	0	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	6	0	6	0	0	0
1987	19	0	19	0	0	0
1988	42	0	42	0	0	0
1989	67	0	67	0	0	0
1990	89	0	89	0	0	0
1991	105	0	105	7	0	7
1992	133	0	133	14	0	14
1993	179	0	179	22	0	22
1994	231	5	237	25	8	34
1995	271	39	310	29	19	48
1996	294	91	385	28	28	56
1997	301	149	450	30	40	70
1998	270	201	472	29	49	78
1999	282	268	550	31	61	92
2000	267	344	611	29	69	98
2001	251	417	668	10	76	86
2002	237	480	717	0	94	94
2003	225	558	784	0	94	94
2004	210	571	781	0	80	80
2005	167	626	793	0	104	104
2006	140	612	752	0	103	103
2007	119	578	697	0	79	79
2008	80	525	604	0	78	78
2009	67	469	536	0	67	67
2010	62	514	576	0	66	66
2011	50	492	542	0	64	64
2012	45	521	565	0	90	90
	===========	===========	===========	===========	===========	===========
	4,211	**7,461**	**11,672**	**254**	**1,270**	**1,524**

In 1991 to 1993, conspicuity tape applied to trailers in advance of any Federal requirement began saving car occupants. From December 1, 1993, through May 31, 2001, lives were saved by a mix of trailers built after FMVSS No. 108 required the tape and older trailers voluntarily equipped or retrofitted with tape. After June 1, 2001, every save is a post-standard save, because FMCSA requires every trailer on the road to have the tape. This technology has saved a total of 1,524 car occupants through 2012, including a peak of 104 in 2005.

NHTSA upgraded the head-injury protection requirements of FMVSS No. 201, "Occupant protection in interior impact" with a phase-in from MY 1999 to 2003. For a list of target areas in the vehicle's upper interior – including the A-, B- and other pillars, the front and rear roof header, the roof side rails, and the upper roof – FMVSS No. 201 specifies that HIC(d) may not exceed 1000 during an impact test with a headform. To comply with this, manufacturers applied energy-absorbing padding to the target areas. NHTSA's evaluation showed that the padding reduced AIS 4-to-6 head injuries involving contact with upper-interior components by an estimated 23.7 percent. That amounts to a 4.28-percent overall reduction of fatality risk, across all types of crashes, for all occupants seated within the occupant compartment. Table 2-23 shows that the padding has saved 2,779 car occupants from late CY 1998 (i.e., early MY 1999) through 2012, including a peak of 347 lives saved in 2012. As of CY 2012, only 64 percent of the cars on the road were certified to the upgrade, so benefits will likely increase as more pre-standard cars are retired. Because no vehicle was certified in advance of the phase-in period, all the lives saved in Table 2-23 are tallied in the "post-FMVSS" column.

Table 2-24 estimates lives saved by the two most recent seat-belt technologies evaluated by NHTSA: 3-point belts for center rear seats and pretensioners and load limiters for belts in the outboard front seats. Pursuant to Anton's Law, NHTSA issued a regulation requiring the phase-in of 3-point belts at center rear seats between September 1, 2005 and August 31, 2007. However, manufacturers had already furnished this technology voluntarily on numerous make-models, especially from MY 1998 onwards (see Table C-1 in Appendix C). Three-point belts reduce fatality risk, on the average, by 44 percent. It is estimated that they had saved 90 lives by the end of 2012.

Pretensioners and load limiters are technologies designed to make seat belts more effective. Pretensioners retract the seat belt to remove excess slack almost instantly upon sensing the vehicle has crashed, typically by firing a pyrotechnic device. When forces on the shoulder belt rise above a predetermined level, load limiters allow the belt to give or yield while controlling the tension in the belt, typically by spooling it out of the retractor, to avoid concentrating too much force on the occupant's chest. NHTSA has long encouraged but never required installation of these technologies. By MY 2002, the majority of new cars and by MY 2007, all new cars sold in the United States were equipped with pretensioners and load limiters at the driver's and RF passenger's seats. A belted driver or RF passenger has an estimated 12.8-percent lower fatality risk if the belt is equipped with a pretensioner and a load limiter than if it is not equipped with either. However, the model will apply this effect only in frontal impacts, because they were the only individual impact type where the effect was statistically significant. Table 2-24 shows that pretensioners and load limiters have saved 1,855 lives through 2012, including a peak of 249 in that year. As of CY 2012, only 56 percent of the cars on the road had pretensioners and load limiters; benefits will likely increase in future years.

Table 2-23: Car Occupant Lives Saved by the Head Impact Upgrade Of FMVSS No. 201, 1960-2012

201B: HEAD-IMPACT UPGRADE (PADDING)
(MEDIAN INSTALLATION YEAR EARLY 2001, FMVSS PHASE-IN BEGAN MY 1999)

CY	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0
1961	0	0	0
1962	0	0	0
1963	0	0	0
1964	0	0	0
1965	0	0	0
1966	0	0	0
1967	0	0	0
1968	0	0	0
1969	0	0	0
1970	0	0	0
1971	0	0	0
1972	0	0	0
1973	0	0	0
1974	0	0	0
1975	0	0	0
1976	0	0	0
1977	0	0	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	0	0	0
1984	0	0	0
1985	0	0	0
1986	0	0	0
1987	0	0	0
1988	0	0	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	0	0	0
1993	0	0	0
1994	0	0	0
1995	0	0	0
1996	0	0	0
1997	0	0	0
1998	0	1	1
1999	0	8	8
2000	0	26	26
2001	0	54	54
2002	0	86	86
2003	0	130	130
2004	0	171	171
2005	0	219	219
2006	0	258	258
2007	0	287	287
2008	0	294	294
2009	0	287	287
2010	0	301	301
2011	0	310	310
2012	0	347	347
	===========	===========	===========
	0	**2,779**	**2,779**

Table 2-24: Car Occupant Lives Saved by 3-Point Belts for Center Rear Seat Passengers And by Belt Pretensioners and Load Limiters, 1960-2012

	208J: 3-POINT BELTS FOR CENTER REAR SEAT OCCS (MEDIAN INSTALL YR 2001, PHASE-IN BEGAN MY 2006)			208K: PRETENSIONERS & LOAD LIMITERS (MEDIAN INSTALLATION YEAR 2002)
CY	VOLUNTARY	POST-FMVSS	TOTAL	TOTAL (VOLUNTARY)
1960	0	0	0	0
1961	0	0	0	0
1962	0	0	0	0
1963	0	0	0	0
1964	0	0	0	0
1965	0	0	0	0
1966	0	0	0	0
1967	0	0	0	0
1968	0	0	0	0
1969	0	0	0	0
1970	0	0	0	0
1971	0	0	0	0
1972	0	0	0	0
1973	0	0	0	0
1974	0	0	0	0
1975	0	0	0	0
1976	0	0	0	0
1977	0	0	0	0
1978	0	0	0	0
1979	0	0	0	0
1980	0	0	0	0
1981	0	0	0	0
1982	0	0	0	0
1983	0	0	0	0
1984	0	0	0	0
1985	0	0	0	0
1986	0	0	0	0
1987	0	0	0	0
1988	0	0	0	0
1989	0	0	0	0
1990	0	0	0	0
1991	0	0	0	0
1992	0	0	0	0
1993	0	0	0	0
1994	0	0	0	0
1995	0	0	0	0
1996	0	0	0	0
1997	0	0	0	1
1998	1	0	1	4
1999	2	0	2	8
2000	3	0	3	17
2001	3	0	3	34
2002	3	0	3	49
2003	3	0	3	73
2004	3	0	3	93
2005	9	0	9	123
2006	3	1	5	151
2007	13	2	16	196
2008	10	1	12	199
2009	6	1	6	213
2010	10	3	13	221
2011	5	5	9	224
2012	2	1	3	249
	===========	===========	===========	===========
	76	**14**	**90**	**1,855**

Table 2-25 enumerates the lives saved by the four major types of curtain and side air bags for drivers and RF passengers in near-side impacts. Starting MY 1996, manufacturers voluntarily introduced curtain and/or side air bags to improve on the head and/or side impact protection offered by structure and padding to meet the upgrades of FMVSS Nos. 201 and 214. Torso bags were first offered in MY 1996, head curtains plus torso bags in 1998, combination head-torso bags in 1999, and curtains alone in 2001. In 2007, NHTSA further upgraded FMVSS No. 214 by adding a crash test of a 20 mph oblique side impact with a pole, with phase-in scheduled for MY 2011 to 2015. NHTSA anticipated that head-protection air bags would generally be installed to meet the new requirement, because they are the principal technology available for cushioning an occupant in an oblique impact. By MY 2006, the majority of new cars had curtain and/or side air bags. By far the greatest number of these was equipped with curtains plus torso bags. By 2010, torso bags alone had phased out and combination bags were limited to convertibles where there is no roof to place a curtain. In MY 2011, 93 percent of new cars were equipped with curtains plus torso bags.

NHTSA's evaluation measures the fatality-reducing effect of curtain and side air bags above and beyond the structures and padding already in the vehicle for meeting FMVSS Nos. 201 and 214. Each of the four major types of air bags significantly reduces fatality risk for drivers and RF passengers in near-side impacts: curtain plus torso bags by an estimated 31 percent, combination bags by 25 percent, curtains only by 16 percent, and torso bags only by 8 percent. Table 2-25 estimates that curtain and side air bags saved 1,697 lives from 1996 through 2012, including 272 in 2012. That includes 1,626 by voluntary installations before the phase-in of the pole test in FMVSS No. 214 began in MY 2011 and 71 "post-FMVSS" saves in MY 2011-to-2013 cars. Curtain plus torso bags accounted for the large majority of the lives saved (1,035) because they are the most effective type and also the most common type since MY 2004; their benefits continue to increase, while the numbers for the other three types have begun tapering down.

Table 2-26 addresses the benefits of the rear impact upgrade of FMVSS No. 301, "Fuel system integrity" and the lives saved by ESC. The 50 mph offset-rear impact test phased into FMVSS No. 301 in MY 2007 to 2009; however, manufacturers voluntarily certified that some of their cars already met the new requirement in MY 2006 (benefits for these MY 2006 cars are counted in the "voluntary" column). NHTSA's evaluation finds a statistically significant 35-percent fatality reduction in rear-impact crash involvements with post-crash fires. All of the lives saved are people who would have died from burns. The upgrade saved an estimated 14 lives through 2012, including 5 in that year. Benefits are likely to increase, because only 23 percent of the cars on the road in 2012 were post-standard.

ESC is a crucial life-saving technology that had already prevented an estimated 2,415 fatalities through CY 2012. BMW first offered ESC as standard equipment on its 700-series cars in 1998 and, subsequently, the manufacturers voluntarily introduced ESC on steadily increasing numbers of cars. In 2007, NHTSA issued FMVSS No. 126 to require ESC on all new cars and LTVs, with a phase-in from MY 2009 to 2012. By MY 2010, the majority, in fact 75 percent of new cars had ESC.

Table 2-25: Car Occupant Lives Saved by Curtain and Side Air Bags in Near-Side Impacts (214C), 1960-2012 (Median Installation Year 2006, Phase-In of Pole Test in FMVSS No. 214 Began MY 2011)

CY	VOLUNTARY	POST-FMVSS	TOTAL	TORSO BAG ONLY	COMBINATION BAG	CURTAIN ONLY	CURTAIN + TORSO
1960	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0
1997	1	0	1	1	0	0	0
1998	2	0	2	2	0	0	0
1999	7	0	7	4	3	0	0
2000	9	0	9	5	3	0	2
2001	22	0	22	8	9	0	5
2002	41	0	41	11	18	1	11
2003	57	0	57	14	19	1	23
2004	83	0	83	13	29	1	40
2005	95	0	95	15	31	1	48
2006	135	0	135	14	46	4	71
2007	146	0	146	15	44	9	78
2008	167	0	167	13	50	11	93
2009	168	0	168	12	40	10	106
2010	236	2	237	12	50	11	164
2011	231	24	255	13	40	14	188
2012	226	46	272	11	43	12	207
	===========	===========	===========	===========	===========	===========	===========
	1,626	**71**	**1,697**	**162**	**424**	**75**	**1,035**

Table 2-26: Car Occupant Lives Saved by Fuel System Integrity/ Rear Impact Upgrade and by ESC, 1960-2012

	301: FUEL SYSTEM INTEGRITY/REAR IMPACT UPGRADE (MEDIAN INSTALL YR 2008, PHASE-IN BEGAN MY 2007)			126: ELECTRONIC STABILITY CONTROL (MED INSTALL YR 2010, PHASE-IN BEGAN 2009)		
CY	**VOLUNTARY**	**POST-FMVSS**	**TOTAL**	**VOLUNTARY**	**POST-FMVSS**	**TOTAL**
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	0	0	0	0
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	0
1983	0	0	0	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	0	0	0	0	0	0
1987	0	0	0	0	0	0
1988	0	0	0	0	0	0
1989	0	0	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	0	0
1992	0	0	0	0	0	0
1993	0	0	0	0	0	0
1994	0	0	0	0	0	0
1995	0	0	0	0	0	0
1996	0	0	0	0	0	0
1997	0	0	0	0	0	0
1998	0	0	0	1	0	1
1999	0	0	0	3	0	3
2000	0	0	0	19	0	19
2001	0	0	0	34	0	34
2002	0	0	0	40	0	40
2003	0	0	0	63	0	63
2004	0	0	0	87	0	87
2005	0	0	0	126	0	126
2006	0	0	0	156	0	156
2007	1	0	1	214	0	214
2008	0	0	0	235	3	238
2009	0	2	2	217	30	247
2010	1	1	2	215	101	316
2011	0	3	3	225	151	376
2012	1	5	5	237	263	500
	===========	===========	===========	===========	===========	===========
	2	**11**	**14**	**1,872**	**548**	**2,420**

NHTSA's evaluation indicates that ESC reduces first-event rollovers of cars by 60 percent, other single-vehicle crashes (not involving pedestrians or bicyclists) by 31 percent, and culpable involvements in multivehicle crashes by 16 percent. Table 2-26 estimates that ESC saved 2,420 lives from 1998 through 2012, including 500 in 2012. Benefits in cars up to MY 2008, before the phase-in of FMVSS No. 126 began are counted in the "voluntary" column; benefits in MY 2009 and later cars are in the "post-FMVSS" column. Because only 20 percent of the cars on the road in 2012 were equipped with ESC, benefits may be expected to increase rapidly in the coming years as new cars with ESC replace older cars without it.

Curtains that deploy in rollovers are the most recent technology evaluated by NHTSA. Manufacturers began to offer rollover curtains on selected LTVs in MY 2002 and selected cars in 2003. However, the installation of rollover curtains in cars has lagged behind LTVs, understandably so, because rollover crashes are more of an issue with LTVs. In 2011, 9 percent of new cars and 1 percent of cars on the road were equipped with rollover curtains. In that year, NHTSA issued FMVSS No. 226, "Ejection mitigation," with a phase-in scheduled for MY 2014 to 2017; the agency anticipates that rollover curtains will be the principal technology for meeting the new standard. NHTSA's evaluation estimates that rollover curtains reduce occupants' fatality risk by 41 percent in first-event rollovers. Table 2-27 shows that rollover curtains had saved 8 lives through 2012. All of the saves are in the "voluntary" column because the phase-in of FMVSS No. 226 did not begin until MY 2014. This concludes the review of the lives saved by the individual technologies in passenger cars.

Table 2-27: Car Occupant Lives Saved by Curtain That Deploy in Rollovers, 1960-2012

226: ROLLOVER CURTAINS
(MEDIAN INSTALLATION YEAR > 2011, FMVSS PHASE-IN BEGAN MY 2014)

CY	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0
1961	0	0	0
1962	0	0	0
1963	0	0	0
1964	0	0	0
1965	0	0	0
1966	0	0	0
1967	0	0	0
1968	0	0	0
1969	0	0	0
1970	0	0	0
1971	0	0	0
1972	0	0	0
1973	0	0	0
1974	0	0	0
1975	0	0	0
1976	0	0	0
1977	0	0	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	0	0	0
1984	0	0	0
1985	0	0	0
1986	0	0	0
1987	0	0	0
1988	0	0	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	0	0	0
1993	0	0	0
1994	0	0	0
1995	0	0	0
1996	0	0	0
1997	0	0	0
1998	0	0	0
1999	0	0	0
2000	0	0	0
2001	0	0	0
2002	0	0	0
2003	0	0	0
2004	0	0	0
2005	1	0	1
2006	0	0	0
2007	1	0	1
2008	0	0	0
2009	1	0	1
2010	0	0	0
2011	2	0	2
2012	3	0	3
	===========	===========	===========
	8	**0**	**8**

Benefits for occupants of LTVs

Table 2-28 is a summary of the benefits of safety technologies for LTV occupants. Actual fatalities in LTVs have rather steadily increased from 3,494 in 1960 to a peak of 13,096 in 2005, reflecting the growing market share of LTVs. But without the safety improvements they would have increased much more, from 3,516 in 1960 to 26,660 in 2005. Actual fatalities fell from 13,096 in 2005 to 9,595 by 2011 before rebounding slightly to 9,747 in 2012, reflecting the nationwide downturn in VMT and driving exposure. Without the safety improvements, they would only have fallen from 26,660 to 22,321 and rebounded to 23,247. Safety technologies saved 225,158 LTV occupants from 1960 through 2012, including 13,500 in 2012. Most of the lives saved (205,233) are by safety technologies directly associated with FMVSS in effect at that time. Voluntary improvements such as better instrument panels and compliance with FMVSS before their effective date have been saving from 400 to 1,000 lives a year since the mid-1990s.

The proportion of potential fatalities saved has grown from 0.63 percent in 1960, when 22 LTV occupants were saved by lap belts, to 58.07 percent in 2012. The latter is even higher than the corresponding proportion saved in cars (53.98% according to Table 2-10). That is primarily because seat belts are even more effective in LTVs than in cars – because fatal crashes of LTVs are more likely to involve rollover and/or ejection, and belts are especially effective in those situations. ESC is another technology that is even more effective in LTVs than in cars.

Indeed, the largest boosts in the percentage saved came from 1984 to 1988 (from 11.02% to 22.42%), when buckle-up laws took effect in most of the States, and from 1995 to 2002 (33.73% to 46.23%) when belt use, historically lower in LTVs, especially in pickup trucks, rapidly caught up to the use rate in cars; frontal air bags also contributed. The steady gains after 2002 (from 46.23% to 58.07% in 2012) reflect the growing availability of ESC and curtain air bags plus more belt use.

VMT data is available for LTVs from 1975 to 2012.[616] Occupant fatality rates per 100,000,000 VMT are shown in Table 2-29 and Figure 2-7. The trends are somewhat different from cars, because LTVs are a less homogeneous group of vehicles. Originally, the majority of LTVs were pickup trucks. The introduction of minivans in the mid-1980s, a new type of vehicle with exceptionally low fatality rates, helped to lower the average potential fatality rate for all LTVs from 2.33 in 1987 to 1.82 in 1992; the actual fatality rate fell even more sharply, from 1.86 to 1.29. After 1992, the market share for SUVs increased steadily relative to minivans and pickup trucks. Without the safety technologies, the potential fatality rate would have increased from 1.82 to 2.33 in 2003, back to the 1987 level. But thanks to increased belt use and other safety improvements, the actual fatality rate continued dropping from 1.29 to 1.21. Increased belt use and frontal air bags made it possible to accommodate the shift to SUVs without an increase of actual fatality rates per 100,000,000 VMT. The potential fatality rate leveled from 2003 (2.33) to 2007 (2.34) and had dropped to 2.00 by 2012 (still higher than the 1.82 in 1992). During that time, the actual rate fell from 1.21 in 2003 to 1.11 in 2007 to 0.84 in 2012, thanks to the additional contributions of ESC, curtain air bags, and other new technologies.

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[616] *Traffic safety facts 2011*, p. 26 specifies VMT for LTVs in 1975 to 2011; the estimate of total VMT in *Traffic safety facts research note – 2012 motor vehicle crashes* has been allocated to cars, LTVs, and other vehicles based on the 2010-to-2011 trends.

Table 2-28: LTV Summary – Actual Occupant Fatalities, Potential Fatalities Without the Safety Technologies, and Lives Saved

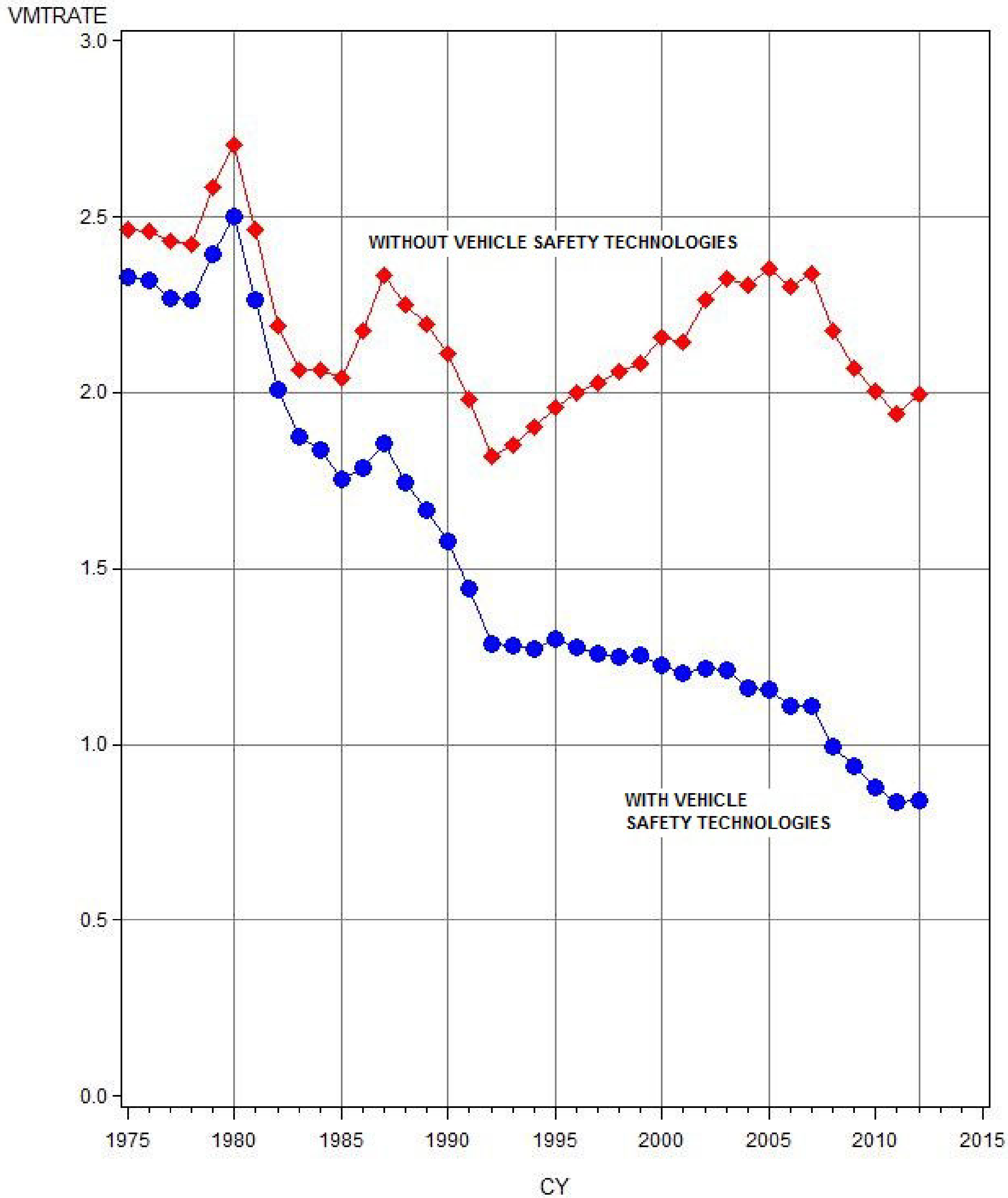
	LTV OCCUPANT FATALITIES		LIVES SAVED			
CY	ACTUAL	W/O SAFETY TECHS.	BY VOLUNTARY IMPROVEMENTS	BY FMVSS IN EFFECT	TOTAL	PERCENT SAVED
1960	3,494	3,516	22	0	22	0.63
1961	3,482	3,504	22	0	22	0.63
1962	3,787	3,812	25	0	25	0.65
1963	4,050	4,078	28	0	28	0.70
1964	4,414	4,448	34	0	34	0.76
1965	4,527	4,565	38	0	38	0.83
1966	4,785	4,831	46	0	46	0.95
1967	4,785	4,839	55	0	55	1.13
1968	5,299	5,379	80	0	80	1.49
1969	5,711	5,824	114	0	114	1.95
1970	5,505	5,641	136	0	136	2.41
1971	5,453	5,614	159	2	161	2.87
1972	5,659	5,853	173	21	194	3.31
1973	5,865	6,103	184	54	238	3.90
1974	5,042	5,286	172	72	244	4.61
1975	4,759	5,031	173	98	272	5.40
1976	5,419	5,742	199	125	324	5.64
1977	5,836	6,245	248	161	409	6.55
1978	6,550	7,012	279	183	462	6.59
1979	7,039	7,600	311	249	561	7.38
1980	7,389	7,997	350	258	608	7.60
1981	6,966	7,581	351	263	614	8.10
1982	6,465	7,051	335	251	585	8.30
1983	6,277	6,918	317	324	641	9.27
1984	6,581	7,396	309	506	815	11.02
1985	6,826	7,944	371	747	1,118	14.07
1986	7,437	9,064	366	1,261	1,626	17.94
1987	8,244	10,371	381	1,747	2,128	20.52
1988	8,528	10,992	403	2,061	2,464	22.42
1989	8,712	11,457	408	2,338	2,746	23.96
1990	8,757	11,721	404	2,559	2,963	25.28
1991	8,607	11,798	393	2,798	3,191	27.05
1992	8,261	11,696	395	3,040	3,435	29.37
1993	8,656	12,492	406	3,430	3,836	30.71
1994	9,052	13,532	446	4,034	4,479	33.10
1995	9,728	14,680	441	4,511	4,952	33.73
1996	10,046	15,731	475	5,210	5,685	36.14
1997	10,373	16,731	477	5,881	6,359	38.00
1998	10,745	17,753	480	6,527	7,007	39.47
1999	11,268	18,772	494	7,009	7,503	39.97
2000	11,530	20,264	489	8,245	8,733	43.10
2001	11,701	20,876	477	8,698	9,174	43.95
2002	12,308	22,889	514	10,067	10,581	46.23
2003	12,615	24,247	548	11,084	11,632	47.97
2004	12,737	25,322	620	11,965	12,585	49.70
2005	13,096	26,660	639	12,925	13,564	50.88
2006	12,843	26,614	721	13,051	13,771	51.74
2007	12,602	26,552	832	13,117	13,950	52.54
2008	10,976	24,089	925	12,188	13,113	54.43
2009	10,520	23,258	911	11,827	12,738	54.77
2010	10,000	22,871	871	12,000	12,871	56.28
2011	9,595	22,321	864	11,862	12,726	57.01
2012	9,747	23,247	1,017	12,483	13,500	58.07
	===========	===========	===========	===========	===========	
	420,649	**645,807**	**19,925**	**205,233**	**225,158**	

Table 2-29

LTVs: Actual and Potential Occupant Fatalities per 100,000,000 Miles VMT

CY	VMT (10^8 MILES)	ACTUAL FATALITIES N	ACTUAL FATALITIES RATE	POTENTIAL FATALITIES W/O SAFETY TECHNOLOGIES N	POTENTIAL FATALITIES W/O SAFETY TECHNOLOGIES RATE
1975	2,043	4,759	2.33	5,031	2.46
1976	2,334	5,419	2.32	5,742	2.46
1977	2,571	5,836	2.27	6,245	2.43
1978	2,895	6,550	2.26	7,012	2.42
1979	2,938	7,039	2.40	7,600	2.59
1980	2,955	7,389	2.50	7,997	2.71
1981	3,076	6,966	2.26	7,581	2.46
1982	3,220	6,465	2.01	7,051	2.19
1983	3,349	6,277	1.87	6,918	2.07
1984	3,586	6,581	1.84	7,396	2.06
1985	3,888	6,826	1.76	7,944	2.04
1986	4,165	7,437	1.79	9,064	2.18
1987	4,444	8,244	1.86	10,371	2.33
1988	4,884	8,528	1.75	10,992	2.25
1989	5,225	8,712	1.67	11,457	2.19
1990	5,557	8,757	1.58	11,721	2.11
1991	5,959	8,607	1.44	11,798	1.98
1992	6,424	8,261	1.29	11,696	1.82
1993	6,754	8,656	1.28	12,492	1.85
1994	7,115	9,052	1.27	13,532	1.90
1995	7,500	9,728	1.30	14,680	1.96
1996	7,873	10,046	1.28	15,731	2.00
1997	8,249	10,373	1.26	16,731	2.03
1998	8,620	10,745	1.25	17,753	2.06
1999	9,007	11,268	1.25	18,772	2.08
2000	9,402	11,530	1.23	20,264	2.16
2001	9,734	11,701	1.20	20,876	2.14
2002	10,108	12,308	1.22	22,889	2.26
2003	10,424	12,615	1.21	24,247	2.33
2004	10,971	12,737	1.16	25,322	2.31
2005	11,326	13,096	1.16	26,660	2.35
2006	11,567	12,843	1.11	26,614	2.30
2007	11,364	12,602	1.11	26,552	2.34
2008	11,059	10,976	.99	24,089	2.18
2009	11,229	10,520	.94	23,258	2.07
2010	11,407	10,000	.88	22,871	2.00
2011	11,513	9,595	.83	22,321	1.94
2012	11,630	9,747	.84	23,247	2.00

FIGURE 2-7: LTV OCCUPANT FATALITIES PER 100 MILLION MILES
WITH AND WITHOUT THE VEHICLE SAFETY TECHNOLOGIES, 1975 TO 2012



Lives saved by 27 individual safety technologies for LTVs will now be discussed in chronological order as listed in Table 2-2, based on the "median installation year." Table 2-30 covers the two earliest technologies, 208A – lap belts for outboard front seat occupants (5 and older), and 208B – lap belt use (at any seating position) by children 1 to 4 years old. By MY 1964, over half of new LTVs were equipped with lap belts; FMVSS No. 208 required them in LTVs as of July 1, 1971. Lap belts are more effective in LTVs than in cars, reducing fatality risk by 48 percent (versus 27% in cars). Although some LTV make-models received 3-point belts in the early 1970s, most kept lap belts through MY 1975 and some even until 1980. Some of those LTVs were still on the road in 2012. Thus, the number of lives saved by lap belts reached a peak of 110 in 1986, after buckle-up laws increased use, and it did not decline that much in the 1990s. In all, lap belts have saved an estimated 2,792 outboard front seat occupants age 5 or older.

Seat belts, without a safety seat, reduce the fatality risk of 1-to-4 year old children by an average of 48 percent in LTVs, and are assumed to have little or no value for infants less than a year old. Belts have saved an estimated 408 children 1 to 4 years old, at all seating positions, in LTVs.

Table 2-31 tallies the benefits of dual master cylinders (105A) and improved door locks (206). Dual master cylinders were not required until FMVSS No. 105 was extended to LTVs, effective September 1, 1983. But they were introduced much earlier, presumably at about the same time as in cars, often a few years before 1968. They reduce the risk of a fatal crash involvement by an estimated 0.7 percent, saving a total of 4,099 LTV occupants in from 1960 to 2012, including 163 in 2012. The number of lives saved grew year by year until 2005 as the "base" of registered LTVs, their VMT, and potentially fatal crashes continued to grow.

FMVSS No. 206 took effect on January 1, 1972 in LTVs, four years later than in cars. The model assumes that door lock improvements in LTVs started at about the same time as in cars, MY 1962, but extended until MY 1972, the year the standard took effect in LTVs. In cars, NHTSA's evaluation estimated a 15-percent reduction of fatalities in rollovers. However, NCSS data show that the proportion of ejections that are through the door portal is smaller in LTVs than in cars. The effectiveness in LTVs is estimated to be 10 percent. Despite that lower effectiveness, the benefits of improved door locks in LTVs are estimated to be substantial, because so many potentially fatal LTV crashes involve rollover and ejection: 16,758 lives saved from 1960 through 2012, including 641 in 2012.

Table 2-32 looks at the benefits of lap belts for occupants 5 and older at the outboard rear seating position (208C) and the center front seating position (208D). Lap belts were required at all designated seating positions in LTVs on July 1, 1971. FMVSS No. 208 upgraded to 3-point belts at the outboard rear seats in LTVs starting September 1, 1991. Even lap belts alone are quite effective in the rear seats of LTVs, reducing fatality risk by an average of 63 percent. They achieved their largest benefit, 80 lives saved, in 1993, just after the shift to 3-point belts, and saved an estimated 1,163 lives from 1960 to 2012, with dwindling numbers in recent years as LTVs with lap belts only were retired.

The center front seat is more frequently occupied in pickup trucks, especially those that have a wide bench seat in the front and no rear seats at all, than in cars. As a consequence, here is a technology that has saved more lives in LTVs (279) than in cars (94) during 1960 to 2012.

Table 2-30: LTV Occupant Lives Saved by Outboard-Front-Seat Lap Belts And Lap Belts For Children 1 to 4 Years Old, 1960-2012

	208A: LAP BELTS FOR OUTBOARD FRONT OCCS (MEDIAN INSTALL YR 1964, FMVSS 7/1/71)			208B: LAP BELT USE BY CHILDREN AGE 1-4 (MEDIAN INSTALL YR 1966, FMVSS 7/1/71)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	22	0	22	0	0	0
1961	22	0	22	0	0	0
1962	24	0	24	0	0	0
1963	26	0	26	0	0	0
1964	28	0	28	0	0	0
1965	29	0	29	0	0	0
1966	30	0	30	0	0	0
1967	31	0	31	0	0	0
1968	42	0	42	0	0	0
1969	59	0	59	0	0	0
1970	68	0	68	0	0	0
1971	73	2	76	0	0	0
1972	71	15	86	0	0	0
1973	62	35	97	0	0	0
1974	46	43	89	0	0	0
1975	35	55	89	0	0	0
1976	26	58	84	0	0	1
1977	23	58	80	0	0	0
1978	20	53	73	0	0	0
1979	12	67	79	0	0	0
1980	8	42	50	0	1	1
1981	8	40	47	0	1	1
1982	12	38	50	0	0	0
1983	6	25	32	0	0	0
1984	14	40	54	0	4	4
1985	21	60	81	0	3	3
1986	22	88	110	0	9	9
1987	18	74	92	0	10	10
1988	26	84	109	1	10	11
1989	14	56	70	0	12	12
1990	22	50	72	0	9	9
1991	25	64	89	0	12	12
1992	17	56	73	1	11	12
1993	22	61	83	1	13	14
1994	19	47	67	0	21	21
1995	22	61	83	1	23	23
1996	20	45	65	0	25	25
1997	13	32	46	0	23	23
1998	14	31	45	0	27	27
1999	15	36	51	0	16	16
2000	13	26	39	0	26	26
2001	12	19	30	0	19	19
2002	7	30	37	0	13	13
2003	10	22	32	0	14	14
2004	3	24	27	0	18	18
2005	5	22	28	0	17	17
2006	7	16	22	0	11	11
2007	8	8	16	0	9	9
2008	2	6	8	0	11	11
2009	6	7	13	0	12	12
2010	5	9	14	0	10	10
2011	4	7	10	0	5	5
2012	7	4	11	0	6	6
	===========	===========	===========	===========	===========	===========
	1,174	**1,617**	**2,792**	**7**	**402**	**408**

Table 2-31: LTV Occupant Lives Saved by Dual Master Cylinders
And Improved Door Locks, 1960-2012

	105A: DUAL MASTER CYLINDERS (MEDIAN INSTALL YR LATE 66, FMVSS 9/1/83)			206: IMPROVED DOOR LOCKS (MEDIAN INSTALL YR 1967, FMVSS 1/1/72)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	1	0	1
1963	1	0	1	2	0	2
1964	1	0	1	5	0	5
1965	1	0	1	8	0	8
1966	3	0	3	13	0	13
1967	7	0	7	17	0	17
1968	12	0	12	25	0	25
1969	17	0	17	34	0	34
1970	20	0	20	39	0	39
1971	23	0	23	46	0	46
1972	26	0	26	51	5	56
1973	30	0	30	48	18	66
1974	28	0	28	35	27	63
1975	28	0	28	22	41	63
1976	33	0	33	23	55	78
1977	38	0	38	23	82	105
1978	43	0	43	25	90	115
1979	48	0	48	27	137	164
1980	52	0	52	25	163	188
1981	49	0	49	24	152	176
1982	46	0	46	20	142	162
1983	46	0	46	19	152	171
1984	43	6	49	18	163	181
1985	40	13	53	14	181	195
1986	39	22	61	13	232	244
1987	38	33	70	15	277	291
1988	35	40	75	12	308	320
1989	31	48	78	11	317	328
1990	28	53	81	8	328	336
1991	26	55	81	10	335	345
1992	23	58	81	7	346	353
1993	22	64	86	6	355	361
1994	20	74	93	7	398	405
1995	18	83	102	6	423	429
1996	16	93	109	5	462	467
1997	14	102	116	5	501	506
1998	12	111	123	4	535	539
1999	11	119	131	3	568	571
2000	9	132	141	3	619	621
2001	7	138	146	2	625	627
2002	7	153	160	2	700	702
2003	6	164	169	2	724	726
2004	4	173	177	1	792	793
2005	3	183	186	1	850	851
2006	3	183	186	1	833	834
2007	2	183	186	1	797	798
2008	2	167	168	1	724	725
2009	2	161	163	1	669	670
2010	1	158	160	0	663	663
2011	1	155	156	0	639	639
2012	1	161	163	0	641	641
	===========	===========	===========	===========	===========	===========
	1,015	**3,084**	**4,099**	**689**	**16,069**	**16,758**

Table 2-32: LTV Occupant Lives Saved by Lap Belts for Outboard Rear Seat Occupants And Lap Belts for Center Front Seat Passengers, 1960-2012

	208C: LAP BELTS FOR OUTBOARD REAR SEAT OCCS (MEDIAN INSTALL YR LATE 67, FMVSS 7/1/71)			208D: LAP BELTS FOR CENTER FRONT SEAT OCCS (MEDIAN INSTALL YR 1968, FMVSS 7/1/71)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	1	0	1	0	0	0
1971	1	0	1	0	0	0
1972	1	0	1	0	0	0
1973	1	1	1	0	0	1
1974	1	1	1	0	0	1
1975	2	1	3	1	1	2
1976	0	10	10	0	1	1
1977	0	3	3	1	0	1
1978	0	4	4	0	1	1
1979	0	6	6	0	1	1
1980	0	1	1	0	0	0
1981	0	2	2	0	1	1
1982	0	2	2	0	0	0
1983	0	1	1	0	0	0
1984	0	9	10	0	0	0
1985	0	13	13	0	5	5
1986	0	25	25	0	1	1
1987	0	46	46	0	10	10
1988	0	52	52	0	8	8
1989	0	45	46	0	11	11
1990	1	58	59	0	5	5
1991	0	67	67	0	5	5
1992	0	63	63	0	10	10
1993	0	80	80	0	8	8
1994	0	63	63	1	12	12
1995	0	48	48	1	12	13
1996	0	43	43	0	11	11
1997	0	76	76	0	14	14
1998	0	59	59	0	10	10
1999	0	50	50	0	7	7
2000	0	64	64	0	9	9
2001	0	45	45	0	13	13
2002	0	31	31	0	14	14
2003	4	27	31	0	12	12
2004	0	34	34	0	16	16
2005	0	18	18	0	12	12
2006	0	26	26	0	13	13
2007	0	16	16	0	11	11
2008	0	20	20	0	7	8
2009	0	13	13	0	9	9
2010	0	15	15	0	5	5
2011	0	12	12	0	6	6
2012	0	0	0	0	10	10
	===========	===========	===========	===========	===========	===========
	13	**1,150**	**1,163**	**6**	**273**	**279**

Table 2-33 considers lap belts for center rear seat passengers (208E) and front disc brakes (105B). Center-rear seats are occupied fairly often in vans and large SUVs and lap belts are quite effective, reducing fatality risk by an estimated 63 percent. The belts saved 736 lives from 1960 to 2012, reaching a peak of 65 lives saved in 2000 and then gradually dwindling as more and more LTVs were equipped with 3-point belts at the center rear seats.

The model assumes front disc brakes were introduced in LTVs at about the same time as in cars – i.e., during MY 1965 to 1977 – even though FMVSS No. 105 did not apply to LTVs until September 1, 1983.[617] Front disc brakes reduce the risk of a fatal crash involvement by an estimated 0.17 percent. They saved an estimated 902 LTV occupants in 1960 to 2012.

Table 2-34 analyzes voluntary modifications to middle and lower instrument panels (201A) and energy-absorbing steering assemblies (203), two basic “built-in” protections in frontal crashes. Instrument panels of LTVs were redesigned over several years, from about MY 1969 to 1976. That resulted in a 15.9-percent fatality reduction for unrestrained RF passengers in frontal impacts. It saved an estimated 7,564 lives through CY 2012, averaging about 300 per year after 2000.

FMVSS Nos. 203 and 204 were not extended to LTVs until September 1, 1981. However, energy-absorbing columns were introduced in some LTVs as early as 1970, and in the majority by MY 1975 or 1976, but in some not until MY 1982. Energy-absorbing steering assemblies have saved 22,877 lives through CY 2012, including 1,084 in 2012. They rank first in cumulative benefits among the non-belt technologies for LTVs, as well as for passenger cars.

Table 2-35 estimates the benefits of 3-point belts for outboard front seat occupants (208F) and adhesive windshield bonding (212). FMVSS No. 208 required 3-point belts at the outboard front seats of most LTVs on January 1, 1976, but on some not until September 1, 1981. However, some make-models received 3-point belts well before January 1, 1976. Seat belt use is critically important in LTVs, because a high proportion of potentially fatal crashes involve rollover and/or ejection, and because belts are also highly effective in the other crash modes. Three-point belts reduce fatality risk by an average of 60 percent in LTVs, when they are used. Fortunately, belt use is as high in SUVs and vans as in cars.[618] Three-point belts saved an estimated 128,376 drivers and RF passengers from 1960 through 2012, including 7,675 in 2012. Both of these numbers are more than half the overall benefits of all the LTV safety technologies in the same time period, and so are the estimates for each individual year from 1988 to 2012.

Adhesive windshield bonding gradually superseded the older installation method using rubber gaskets during approximately 1978 to 1985 in LTVs. The model assumes that adhesive bonding has the same effect on ejection fatalities in LTVs as in cars: NCSS data show that the proportion of ejections that are via the windshield portal was about the same in LTVs with rubber gaskets as in cars with rubber gaskets. Adhesive bonding has saved an estimated 2,585 lives through CY 2012, including 95 in 2012.

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[617] *Ward's Automotive Yearbooks* show nearly identical percentages of U.S. cars, U.S. LTVs and imported cars with front disc brakes in MY 1975 to 1977 and have no information for U.S. LTVs and imported cars before MY 1975.
[618] Glassbrenner (2003, September).

Table 2-33: LTV Occupant Lives Saved by Lap Belts for Center Rear Seat Passengers And by Front Disc Brakes, 1960-2012

	208E: LAP BELTS FOR CENTER REAR SEAT OCCS (MEDIAN INSTALL YR 1968, FMVSS 7/1/71)			105B: FRONT DISC BRAKES (MEDIAN INSTALL YEAR 1971, FMVSS 9/1/83)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	1	0	1
1970	0	0	0	1	0	1
1971	0	0	0	2	0	2
1972	0	0	0	2	0	2
1973	0	0	1	3	0	3
1974	0	0	1	4	0	4
1975	0	0	0	4	0	4
1976	1	0	1	5	0	5
1977	0	4	4	7	0	7
1978	0	7	7	8	0	8
1979	0	2	2	9	0	9
1980	0	0	0	10	0	10
1981	0	0	0	10	0	10
1982	0	0	0	9	0	9
1983	0	0	0	9	0	9
1984	0	0	0	9	1	10
1985	0	2	2	8	3	11
1986	0	3	3	8	5	13
1987	0	6	6	8	8	16
1988	4	10	14	7	9	17
1989	0	11	11	7	11	18
1990	0	10	10	6	12	18
1991	0	18	18	5	13	18
1992	0	14	14	5	13	18
1993	0	13	13	5	15	20
1994	0	16	16	4	17	21
1995	0	18	18	4	19	23
1996	0	19	19	4	22	25
1997	0	39	39	3	24	27
1998	0	36	36	3	26	28
1999	0	31	31	2	28	30
2000	0	65	65	2	31	33
2001	0	30	30	2	32	34
2002	0	44	44	1	36	37
2003	0	34	34	1	38	39
2004	1	55	56	1	40	41
2005	0	41	41	1	43	43
2006	0	44	44	1	43	43
2007	0	39	39	1	43	43
2008	0	27	27	0	39	39
2009	0	24	24	0	38	38
2010	0	27	27	0	37	37
2011	0	15	15	0	36	36
2012	0	22	22	0	38	38
	===========	===========	===========	===========	===========	===========
	8	**728**	**736**	**184**	**718**	**902**

Table 2-34: LTV Occupant Lives Saved by Voluntary Instrument Panel Improvements And Energy-Absorbing Steering Assemblies, 1960-2012

	201A: VOLUNTARY INSTRUMENT PANEL IMPROVEMENTS (MEDIAN INSTALL YR 1972, FMVSS 9/1/81)	203: ENERGY-ABSORBING STEERING ASSEMBLIES (MEDIAN INSTALL YEAR 1975, FMVSS 9/1/81)		
CY	**TOTAL (VOLUNTARY)**	**VOLUNTARY**	**POST-FMVSS**	**TOTAL**
1960	0	0	0	0
1961	0	0	0	0
1962	0	0	0	0
1963	0	0	0	0
1964	0	0	0	0
1965	0	0	0	0
1966	0	0	0	0
1967	0	0	0	0
1968	0	0	0	0
1969	1	0	0	0
1970	4	1	0	1
1971	7	2	0	2
1972	13	2	0	2
1973	20	13	0	13
1974	23	25	0	25
1975	27	30	0	30
1976	37	45	0	45
1977	47	71	0	71
1978	66	91	0	91
1979	73	112	0	112
1980	90	133	0	133
1981	92	141	1	142
1982	84	136	22	158
1983	83	114	48	162
1984	96	97	93	191
1985	103	108	137	245
1986	122	96	181	277
1987	140	89	233	323
1988	147	86	282	368
1989	167	84	328	412
1990	180	72	365	438
1991	177	65	380	445
1992	171	61	384	445
1993	180	63	432	495
1994	188	57	489	546
1995	206	51	577	628
1996	239	47	603	650
1997	239	43	661	704
1998	256	33	723	756
1999	246	32	754	786
2000	284	25	839	864
2001	277	21	919	941
2002	305	22	992	1,015
2003	318	17	1,069	1,086
2004	337	13	1,108	1,120
2005	330	11	1,181	1,193
2006	328	6	1,218	1,224
2007	346	8	1,252	1,260
2008	322	6	1,167	1,173
2009	315	7	1,156	1,163
2010	287	3	1,041	1,044
2011	285	2	1,016	1,018
2012	304	3	1,081	1,084
	===========	===========	===========	===========
	7,564	**2,143**	**20,733**	**22,877**

Table 2-35: LTV Occupant Lives Saved by 3-Point Belts for Outboard Front Seat Occupants And by Adhesive Windshield Bonding, 1960-2012

	208F: 3-POINT BELTS FOR OUTBOARD FRONT OCCS (MEDIAN INSTALL YR 1977, FMVSS 1/1/76)			212: ADHESIVE WINDSHIELD BONDING (MEDIAN INSTALL YR 1980, FMVSS 9/1/78)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	1	0	1	0	0	0
1970	2	0	2	0	0	0
1971	3	0	3	0	0	0
1972	4	0	4	0	0	0
1973	5	0	5	0	0	0
1974	9	0	9	0	0	0
1975	23	0	23	0	0	0
1976	26	0	26	0	0	0
1977	37	13	50	0	0	0
1978	23	28	51	1	0	1
1979	28	34	61	2	3	5
1980	27	43	70	2	7	9
1981	25	56	82	1	9	11
1982	20	33	53	1	12	13
1983	35	81	116	1	15	16
1984	27	157	184	1	21	22
1985	67	289	356	1	29	30
1986	63	642	705	1	38	39
1987	64	973	1,037	1	50	51
1988	72	1,169	1,241	1	58	59
1989	83	1,413	1,496	1	61	61
1990	76	1,576	1,652	1	66	67
1991	45	1,747	1,792	1	67	67
1992	62	1,954	2,016	1	62	62
1993	50	2,232	2,283	1	68	69
1994	80	2,645	2,726	0	76	76
1995	49	2,930	2,978	0	83	84
1996	63	3,472	3,535	0	85	86
1997	55	3,790	3,846	0	90	90
1998	41	4,222	4,262	0	99	99
1999	55	4,394	4,449	0	105	105
2000	48	5,289	5,336	0	108	108
2001	35	5,506	5,541	0	113	113
2002	38	6,250	6,289	0	119	119
2003	16	7,041	7,057	0	117	117
2004	13	7,477	7,490	0	118	118
2005	15	8,052	8,067	0	124	124
2006	9	8,069	8,077	0	129	129
2007	23	8,026	8,049	0	127	128
2008	13	7,565	7,578	0	112	112
2009	9	7,196	7,205	0	105	105
2010	8	7,499	7,507	0	98	98
2011	7	7,383	7,390	0	93	93
2012	2	7,673	7,675	0	95	95
	===========	===========	===========	===========	===========	===========
	1,456	**126,920**	**128,376**	**21**	**2,564**	**2,585**

Table 2-36 considers child safety seats, including booster seats (213) and 3-point belts for outboard rear seat occupants (208G). NHTSA's evaluation estimates that safety seats reduce fatality risk in LTVs by 58 percent for infants and by 59 percent for toddlers. The latter effect will also be assumed for booster seats until NHTSA is able to evaluate them in more detail. Safety seats saved an estimated 2,634 lives in 1960 to 2012, of which 2,285 were children obligated by a State law to be in a safety seat, while 350 were voluntary saves before State laws or involving children older than the age up to which the law in effect at that time required a safety seat.

FMVSS No. 208 has required lap/shoulder belts at outboard rear seats of LTVs since September 1, 1991, but most LTVs were voluntarily equipped with 3-point belts a few years before that date. Three-point belts are highly effective for rear seat occupants, reducing fatality risk by an average of 73 percent. Belt use, occupancy of the rear seat and the proportion of LTVs on the road equipped with 3-point belts have increased rapidly, pushing benefits to a peak of 621 lives saved in 2007 and a total of 7,821 cumulative through 2012.

Table 2-37 estimates lives saved by side door beams (214A). The side door strength test of FMVSS No. 214 was extended to LTVs effective September 1, 1993. Most LTVs were first equipped with side door beams in MY 1994, but on a few models they were voluntarily introduced in 1991 to 1993. Side door beams reduce fatality risk in single-vehicle side impacts by 19 percent. They saved an estimated 2,940 lives in 1991 to 2012, including 242 in 2012; annual benefits rose until 2010 as LTVs with side door beams replaced the pre-standard fleet.

Table 2-38 estimates **net** lives saved by frontal air bags (208I), including separate estimates for the three major types or "generations" of air bags: barrier-certified (until the late 1990s), sled-certified (late 1990s to mid-2000s), and certified-advanced (since the mid-2000s). Frontal air bags have approximately the same effects in cars and LTVs. They significantly reduce the fatality risk of adults and adolescents (13 and older) in frontal and partially frontal crashes. Benefits of barrier-certified and sled-certified air bags are to a numerically small extent offset by increased risk to certain subgroups of child passengers (12 and younger). Especially before advanced air bags, many pickup trucks and some cargo vans and sporty SUVs had manual on-off switches for passenger air bags. Turning the switch "off" can prevent harm to a child passenger, but takes away the benefit of air bags from an adult passenger. At the end of this chapter, Tables 2-49 through 2-54 furnish more detailed analyses effects separately by type of air bag, occupant age group, and seating position; they also explore the effects of the manual switches.

The FMVSS No. 208 phase-in period for automatic protection in LTVs extended from September 1, 1994, to August 30, 1997. LTVs equipped with driver or dual air bags before September 1, 1994, account for the voluntary saves on Table 2-38 – e.g., Chrysler equipped some MY 1991 and all 1992 minivans with driver air bags. All other air bags, supplied either during or after the phase-in period, have their benefits listed in the "Post-FMVSS" column. Frontal air bags had saved a net estimated 15,091 lives in LTVs from 1991 through 2012, including 1,193 in 2012. The number of lives saved by air bags grew rapidly at first, commensurate with the proportion of LTVs on the road equipped with air bags, peaking at 1,320 in 2007.

Table 2-36: LTV Occupant Lives Saved by Child Safety Seats (Including Booster Seats) And 3-Point Belts for Outboard Rear Seat Occupants, 1960-2012

	213: CHILD SAFETY SEATS (USE > 50% 1985, FMVSS 4/1/71, STATE LAWS 1978-85)			208G: 3-POINT BELTS FOR OUTBOARD REAR SEAT OCCS (MEDIAN INSTALL YR 1992, FMVSS 9/1/91)		
CY	VOLUNTARY	OBLIGATORY	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	1	0	1	0	0	0
1973	1	0	1	0	0	0
1974	1	0	1	0	0	0
1975	2	0	2	0	0	0
1976	3	0	3	0	0	0
1977	2	0	2	0	0	0
1978	2	0	2	0	0	0
1979	1	0	1	0	0	0
1980	3	0	3	0	0	0
1981	1	0	1	0	0	0
1982	6	0	6	0	0	0
1983	4	1	5	0	0	0
1984	4	9	13	0	0	0
1985	7	13	20	0	0	0
1986	2	16	17	0	0	0
1987	7	27	34	0	0	0
1988	5	32	37	8	0	8
1989	4	26	30	6	0	6
1990	5	27	32	6	0	6
1991	8	35	44	28	0	28
1992	10	28	38	26	43	69
1993	5	31	36	23	57	80
1994	6	54	61	22	105	127
1995	10	61	71	16	88	105
1996	13	66	78	12	96	108
1997	24	60	84	16	208	224
1998	9	69	77	31	202	233
1999	20	82	101	35	288	322
2000	15	79	93	9	304	314
2001	16	77	93	14	334	349
2002	19	96	115	10	526	536
2003	15	92	107	16	443	459
2004	15	162	177	11	562	574
2005	11	129	139	10	663	672
2006	16	186	202	2	577	579
2007	24	164	188	0	621	621
2008	14	122	136	2	497	499
2009	11	140	151	2	533	536
2010	3	134	137	0	443	443
2011	18	132	151	5	454	459
2012	8	137	145	2	465	468
	===========	===========	===========	===========	===========	===========
	350	**2,285**	**2,634**	**314**	**7,507**	**7,821**

Table 2-37: LTV Occupant Lives Saved by Side Door Beams, 1960-2012

214A: SIDE DOOR BEAMS
(MEDIAN INSTALL YEAR 1994, FMVSS 9/1/93)

CY	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0
1961	0	0	0
1962	0	0	0
1963	0	0	0
1964	0	0	0
1965	0	0	0
1966	0	0	0
1967	0	0	0
1968	0	0	0
1969	0	0	0
1970	0	0	0
1971	0	0	0
1972	0	0	0
1973	0	0	0
1974	0	0	0
1975	0	0	0
1976	0	0	0
1977	0	0	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	0	0	0
1984	0	0	0
1985	0	0	0
1986	0	0	0
1987	0	0	0
1988	0	0	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	1	0	1
1993	3	1	3
1994	4	12	16
1995	4	29	33
1996	2	46	47
1997	1	46	47
1998	3	70	73
1999	4	97	100
2000	3	108	111
2001	3	122	125
2002	4	144	148
2003	4	163	166
2004	4	215	219
2005	1	211	212
2006	1	221	222
2007	2	237	239
2008	3	217	220
2009	1	219	221
2010	1	259	261
2011	2	232	233
2012	2	240	242
	===========	===========	===========
	52	**2,888**	**2,940**

Table 2-38: LTV Occupant Lives Saved by Frontal Air Bags (208I), 1960-2012
(Median Installation Year 1995, Phase-In Began September 1, 1994)

CY	VOLUNTARY	POST-FMVSS	TOTAL	BARRIER-CERTIFIED	SLED-CERTIFIED	ADVANCED
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	0	0	0	0
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	0
1983	0	0	0	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	0	0	0	0	0	0
1987	0	0	0	0	0	0
1988	0	0	0	0	0	0
1989	0	0	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	0	0
1992	4	0	4	4	0	0
1993	12	0	12	12	0	0
1994	24	1	25	25	0	0
1995	37	46	83	83	0	0
1996	41	110	152	152	0	0
1997	44	191	235	233	2	0
1998	54	276	330	278	52	0
1999	47	386	433	302	131	0
2000	50	489	539	291	248	0
2001	53	630	684	321	363	0
2002	63	789	852	338	513	1
2003	53	954	1,008	347	645	15
2004	49	975	1,024	304	674	46
2005	42	1,130	1,171	322	744	105
2006	36	1,194	1,230	279	758	193
2007	38	1,283	1,320	287	746	288
2008	31	1,200	1,232	224	660	348
2009	21	1,188	1,209	190	636	383
2010	18	1,150	1,168	172	605	391
2011	18	1,169	1,187	170	578	439
2012	16	1,177	1,193	160	552	480
	===========	===========	===========	===========	===========	===========
	751	**14,340**	**15,091**	**4,496**	**7,907**	**2,688**

Initially, all air bags were barrier-certified. In late CY 1997 (i.e., early MY 1998), sled-certified air bags began to appear and, after 2005, lives saved by barrier-certified air bags dwindled as LTVs with those early systems were retired. The first advanced air bags were introduced in late CY 2002 (i.e., early MY 2003), when GM and Honda certified to advanced air bags in selected models, one year before the phase-in. Eventually, advanced air bags will supersede barrier-certified and sled-certified in the on-road fleet, and all the benefits will gradually shift to advanced air bags.

Table 2-39 analyzes conspicuity tape for heavy trailers (108) and the head-impact upgrade of FMVSS No. 201 (208B). When heavy trailers are equipped with the red-and-white tape, they are easier to see in the dark, and LTVs are 29 percent less likely to hit them. The tape has saved a total of 1,136 LTV occupants through 2012, including 70 in 2012.

The head-impact upgrade of FMVSS No. 201 phased in from MY 1999 to 2003. Effectiveness in LTVs is approximately the same as in cars, amounting to a 4.28-percent overall reduction of fatality risk, across all types of crashes, for all occupants seated within the occupant compartment. Table 2-39 shows that padding installed to meet the upgrade saved 2,134 LTV occupants from 1999 through 2012, including a peak of 269 in 2012. Benefits may increase after 2012, because only 61 percent of the LTVs on the road that year were certified to the upgrade. Because no vehicle was certified in advance of the phase-in period, all the lives saved in Table 2-39 are tallied in the "post-FMVSS" column.

Table 2-40 analyzes the two most recent seat-belt technologies evaluated by NHTSA: belt pretensioners and load limiters (208K) and 3-point belts for center rear seat passengers (208J). Pretensioners and load limiters are technologies designed to make seat belts more effective. By MY 2002, the majority of new LTVs and by MY 2008, all new LTVs sold in the United States were voluntarily equipped with pretensioners and load limiters at the driver's and RF passenger's seats. NHTSA's evaluation suggests that the effect in CUVs and minivans is about the same as in cars, namely, a 12.8-percent fatality reduction that our model will apply for belted drivers and RF passengers, but only in frontal impacts. The model will not tally any benefits for pickup trucks, full-size vans, or pickup-truck-based SUVs, because the evaluation did not find a statistically significant effect. Pretensioners and load limiters have saved 531 lives in CUVs and minivans through 2012, including a peak of 80 in 2012.

NHTSA upgraded FMVSS No. 208 to phase in 3-point belts at center rear seats between September 1, 2005 and August 31, 2007.[619] However, manufacturers had already furnished this technology voluntarily on selected LTVs as early as MY 1998. Three-point belts reduce fatality risk in the rear seat of LTVs, on the average, by 73 percent. It is estimated that they had saved 168 lives by the end of 2012.

[619] In a typical minivan, the two seats in the second row are considered "outboard" seats and have been equipped with 3-point belts since MY 1992 or earlier. Only the middle seat in the third row is considered a "center" seat.

Table 2-39: LTV Occupant Lives Saved By Conspicuity Tape on Heavy Trailers And by the Head Impact Upgrade of FMVSS No. 201, 1960-2012

	108: CONSPICUITY TAPE ON HEAVY TRAILERS (ON-ROAD FLEET EXCEEDED 50% IN 1996, FMVSS 12/1/93, FMCSA RETROFIT 6/1/2001)			201B: HEAD-IMPACT UPGRADE (PADDING) (MEDIAN INSTALL YR EARLY 2002, FMVSS PHASE-IN BEGAN MY 1999)		
CY	VOLUNTARY	POST-STANDARD	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	0	0	0	0
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	0
1983	0	0	0	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	0	0	0	0	0	0
1987	0	0	0	0	0	0
1988	0	0	0	0	0	0
1989	0	0	0	0	0	0
1990	0	0	0	0	0	0
1991	3	0	3	0	0	0
1992	7	0	7	0	0	0
1993	11	0	11	0	0	0
1994	13	4	17	0	0	0
1995	14	10	24	0	0	0
1996	13	13	27	0	0	0
1997	19	25	44	0	0	0
1998	19	32	52	0	0	0
1999	22	43	65	0	5	5
2000	19	44	62	0	13	13
2001	6	43	49	0	32	32
2002	0	70	70	0	60	60
2003	0	74	74	0	97	97
2004	0	69	69	0	128	128
2005	0	82	82	0	168	168
2006	0	85	85	0	198	198
2007	0	71	71	0	225	225
2008	0	68	68	0	227	227
2009	0	67	67	0	236	236
2010	0	67	67	0	237	237
2011	0	51	51	0	240	240
2012	0	70	70	0	269	269
	===========	===========	===========	===========	===========	===========
	146	**990**	**1,136**	**0**	**2,134**	**2,134**

Table 2-40: LTV Occupant Lives Saved by Belt Pretensioners and Load Limiters And by 3-Point Belts for Center Rear Seat Passengers, 1960-2012

	208K: PRETENSIONERS & LOAD LIMITERS (MEDIAN INSTALLATION YEAR 2002)	208J: 3-POINT BELTS FOR CENTER REAR SEAT OCCS (MEDIAN INSTALL YR 2003, PHASE-IN BEGAN MY 2006)		
CY	TOTAL (VOLUNTARY)	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0
1961	0	0	0	0
1962	0	0	0	0
1963	0	0	0	0
1964	0	0	0	0
1965	0	0	0	0
1966	0	0	0	0
1967	0	0	0	0
1968	0	0	0	0
1969	0	0	0	0
1970	0	0	0	0
1971	0	0	0	0
1972	0	0	0	0
1973	0	0	0	0
1974	0	0	0	0
1975	0	0	0	0
1976	0	0	0	0
1977	0	0	0	0
1978	0	0	0	0
1979	0	0	0	0
1980	0	0	0	0
1981	0	0	0	0
1982	0	0	0	0
1983	0	0	0	0
1984	0	0	0	0
1985	0	0	0	0
1986	0	0	0	0
1987	0	0	0	0
1988	0	0	0	0
1989	0	0	0	0
1990	0	0	0	0
1991	0	0	0	0
1992	0	0	0	0
1993	0	0	0	0
1994	0	0	0	0
1995	0	0	0	0
1996	0	0	0	0
1997	0	0	0	0
1998	0	0	0	0
1999	1	0	0	0
2000	1	0	0	0
2001	4	0	0	0
2002	11	3	0	3
2003	17	13	0	13
2004	26	9	0	9
2005	35	9	0	9
2006	45	16	4	20
2007	49	5	2	7
2008	57	5	1	6
2009	68	4	9	12
2010	66	12	15	27
2011	70	3	14	17
2012	80	30	14	44
	===========	===========	===========	===========
	531	**108**	**59**	**168**

Table 2-41 addresses the benefits of the rear impact upgrade of FMVSS No. 301, "Fuel system integrity" and the lives saved by ESC. The 50 mph offset-rear impact test phased into FMVSS No. 301 in MY 2007 to 2009; however, there was an option of already certifying in MY 2006 (benefits counted in the "voluntary" column). NHTSA's evaluation finds similar effects for cars and LTVs (35% fatality reduction in rear impacts with post-crash fires). The upgrade saved an estimated 13 lives through 2012, including 4 in that year. Benefits are likely to increase, because only 21 percent of the LTVs on the road in 2012 were certified to the upgraded standard.

ESC first appeared on selected LTV models in MY 1999 and 2000. Its extraordinary success in these early installations encouraged manufacturers to extend ESC to other LTV models even sooner than to cars. By MY 2008, well over half of new LTVs had ESC. FMVSS No. 126 phased in from MY 2009 to 2012. NHTSA's evaluation finds ESC even more effective for preventing single-vehicle crashes of LTVs than for cars: it reduces first-event rollovers by 74 percent, other single-vehicle crashes (not involving pedestrians or bicyclists) by 45 percent; it also reduces culpable involvements in multivehicle crashes by 16 percent. This is good news, because, historically, rollovers and run-off-road crashes have been more of an issue in LTVs than in cars. Table 2-41 estimates that ESC saved 3,604 lives from 1999 through 2012, including 824 in 2012. (Benefits up to MY 2008, before the phase-in of FMVSS No. 126 are counted in the "voluntary" column; benefits in MY 2009 and later LTVs are "post-FMVSS".) Because only 22 percent of the LTVs on the road as of 2012 were equipped with ESC, benefits should increase in subsequent years.

Table 2-42 enumerates the lives saved by the four major types of curtain and side air bags for LTV drivers and RF passengers in near-side impacts. Torso bags were the first type offered on LTVs, beginning with GM minivans and Mercedes SUVs in MY 1998. By MY 2008, the majority of new LTVs had some type of curtain and/or side air bags, by MY 2011, 95 percent. By far the greatest number of these was equipped with curtains plus torso bags. The oblique pole-test upgrade of FMVSS No. 214 phases in from MY 2011 to 2015.

NHTSA's evaluation indicates that all four types of curtain and side air bags are effective in near-side impacts and that the effectiveness is about the same in LTVs as in cars. Table 2-42 estimates that curtain and side air bags saved 377 lives from 1998 through 2012, including 73 in 2012. That includes 170 by curtain plus torso bags, 105 by combination bags, 49 by curtain bags only, and 53 by torso bags only. Although effectiveness is about the same in LTVs as in cars, the absolute number of lives saved in much lower in LTVs (377 versus 1,697) because: (1) LTVs are considerably less vulnerable than cars in near-side impacts and (2) installation in LTVs lagged somewhat behind cars. Benefits are likely to increase in the future, because, as of CY 2012, only 28 percent of the LTVs on the road were equipped with some type of curtain or side air bags.

Table 2-41: LTV Occupant Lives Saved by Fuel System Integrity/ Rear Impact Upgrade and by ESC, 1960-2012

	301: FUEL SYSTEM INTEGRITY/REAR IMPACT UPGRADE (MED INSTALL YR 2007, PHASE-IN BEGAN MY 2007)			126: ESC (MED INSTALL YR EARLY 2008, FMVSS PHASE-IN BEGAN 2009)		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	0	0	0	0
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	0
1983	0	0	0	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	0	0	0	0	0	0
1987	0	0	0	0	0	0
1988	0	0	0	0	0	0
1989	0	0	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	0	0
1992	0	0	0	0	0	0
1993	0	0	0	0	0	0
1994	0	0	0	0	0	0
1995	0	0	0	0	0	0
1996	0	0	0	0	0	0
1997	0	0	0	0	0	0
1998	0	0	0	0	0	0
1999	0	0	0	0	0	0
2000	0	0	0	7	0	7
2001	0	0	0	21	0	21
2002	0	0	0	15	0	15
2003	0	0	0	45	0	45
2004	0	0	0	109	0	109
2005	0	0	0	138	0	138
2006	0	0	0	214	0	214
2007	1	2	2	284	0	284
2008	0	2	2	413	8	421
2009	0	0	0	399	46	445
2010	2	2	4	384	128	512
2011	0	1	1	373	196	569
2012	0	4	4	468	357	824
	===========	===========	===========	===========	===========	===========
	2	**10**	**13**	**2,869**	**735**	**3,604**

Table 2-42: LTV Occupant Lives Saved by Curtain and Side Air Bags in Near-Side Impacts (214C), 1960-2012 (Median Installation Year 2008, Phase-In of Pole Test in FMVSS No. 214 Began MY 2011)

CY	VOLUNTARY	POST-FMVSS	TOTAL	TORSO BAG ONLY	COMBINATION BAG	CURTAIN ONLY	CURTAIN + TORSO
1960	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0
1999	1	0	1	0	1	0	0
2000	1	0	1	1	1	0	0
2001	3	0	3	2	1	0	0
2002	7	0	7	2	4	0	0
2003	9	0	9	3	5	0	0
2004	18	0	18	5	10	1	2
2005	20	0	20	5	8	3	4
2006	26	0	26	5	10	3	8
2007	29	0	29	5	9	4	12
2008	31	0	31	4	8	5	13
2009	44	0	44	4	12	7	20
2010	57	1	58	6	12	8	33
2011	51	6	56	5	12	7	32
2012	54	19	73	5	13	9	46
	===========	===========	===========	===========	===========	===========	===========
	351	**26**	**377**	**53**	**105**	**49**	**170**

Curtains that deploy in rollovers are the latest technology evaluated by NHTSA. Ford began to offer rollover curtains on the Explorer and Mountaineer in MY 2002. Subsequently, the manufacturers furnished numerous LTV models with rollover curtains, either by adding rollover sensors to existing curtains or including the sensors immediately when they added curtains. By MY 2009, the majority of new LTVs had rollover curtains and by MY 2011, 83 percent (much higher percentages than in cars, where, historically, rollovers have been less of an issue). However, given the longevity of LTVs and the slow turnover of the fleet, only 15 percent of the LTVs on the road in CY 2012 had rollover curtains. FMVSS No. 226, "Ejection mitigation" phases in from MY 2014 to 2017. NHTSA's evaluation estimates that rollover curtains reduce occupants' fatality risk by 41 percent in first-event rollovers. Table 2-43 shows that rollover curtains had saved 171 lives from 2002 through 2012, including 41 in 2012. All of the saves are in the "voluntary" column because the phase-in of FMVSS No. 226 did not begin until MY 2014.

Benefits for pedestrians, bicyclists, and other non-occupants

Table 2-44 is a summary of the non-occupant lives saved by car/LTV safety technologies, specifically braking improvements. The computation is straightforward: dual master cylinders reduce fatal crash involvements, including collisions with non-occupants by 0.70 percent, front disc brakes by 0.17 percent. Thus, when all cars and LTVs on the road are equipped with dual master cylinders and front disc brakes, 0.87 percent of potential non-occupant fatalities will be avoided. Indeed, the right column of Table 2-44 shows that the proportion of potential fatalities saved had reached 0.85 percent by 1987 and was converging on 0.87 percent by 2000. For example, in 2012, there were 5,156 actual pedestrian, bicyclist and other non-occupant fatalities in collisions with cars or LTVs. Without the braking improvements there would have been 5,202; the brakes prevented 45 fatalities, 0.87 percent of 5,202.

Non-occupant fatalities in collisions with cars/LTVs peaked at 9,277 in 1972 and greatly declined until 2009, reaching a low of 4,417, before rebounding somewhat to 5,156 by 2012. Braking improvements in cars and LTVs have played a relatively small role in the decline. They have prevented an estimated 2,211 of 353,436 potential fatalities. Furthermore, the absolute number of lives saved has decreased from a peak of 65 in 1980 to 45 in 2012 because the "base" of non-occupant exposure to potentially fatal crash situations has shrunk. Table 2-45 apportions the non-occupant lives saved between the two brake technologies: dual master cylinders saved an estimated 1,841 lives from 1960 through 2012; front disc brakes, 370.

Table 2-43: LTV Occupant Lives Saved by Curtain That Deploy in Rollovers, 1960-2012

226: ROLLOVER CURTAINS
(MEDIAN INSTALLATION YEAR 2009, FMVSS PHASE-IN BEGAN MY 2014)

CY	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0
1961	0	0	0
1962	0	0	0
1963	0	0	0
1964	0	0	0
1965	0	0	0
1966	0	0	0
1967	0	0	0
1968	0	0	0
1969	0	0	0
1970	0	0	0
1971	0	0	0
1972	0	0	0
1973	0	0	0
1974	0	0	0
1975	0	0	0
1976	0	0	0
1977	0	0	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	0	0	0
1984	0	0	0
1985	0	0	0
1986	0	0	0
1987	0	0	0
1988	0	0	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	0	0	0
1993	0	0	0
1994	0	0	0
1995	0	0	0
1996	0	0	0
1997	0	0	0
1998	0	0	0
1999	0	0	0
2000	0	0	0
2001	0	0	0
2002	0	0	0
2003	2	0	2
2004	4	0	4
2005	6	0	6
2006	11	0	11
2007	13	0	13
2008	22	0	22
2009	21	0	21
2010	23	0	23
2011	26	0	26
2012	41	0	41
	===========	===========	===========
	171	**0**	**171**

Table 2-44: Pedestrian/Bicyclist Summary – Actual Non-Occupant Fatalities in Collisions With Cars/LTVs, Potential Fatalities Without Car/LTV Braking Improvements, And Lives Saved by Car/LTV Braking Improvements

	NON-OCCUPANT FATALITIES		LIVES SAVED			
CY	ACTUAL	W/O CAR/LTV BRAKE TECHS.	BY VOLUNTARY IMPROVEMENTS	BY FMVSS IN EFFECT	TOTAL	PERCENT SAVED
1960	6,447	6,447	0	0	0	0.00
1961	6,407	6,407	0	0	0	0.00
1962	6,604	6,604	0	0	0	0.00
1963	6,918	6,919	1	0	1	0.01
1964	7,587	7,588	1	0	1	0.02
1965	7,469	7,470	2	0	2	0.02
1966	7,901	7,905	4	0	4	0.05
1967	7,941	7,949	9	0	9	0.11
1968	8,334	8,349	13	2	15	0.18
1969	8,334	8,355	15	6	21	0.25
1970	8,805	8,834	17	11	28	0.32
1971	9,002	9,037	18	17	35	0.39
1972	9,277	9,319	21	22	42	0.46
1973	9,159	9,207	23	26	48	0.52
1974	7,626	7,671	20	25	45	0.59
1975	7,882	7,935	22	31	53	0.67
1976	7,599	7,653	21	33	54	0.70
1977	7,828	7,886	22	36	58	0.73
1978	7,776	7,836	22	38	60	0.77
1979	8,088	8,152	22	42	64	0.78
1980	8,077	8,142	22	43	65	0.80
1981	7,879	7,943	20	45	64	0.81
1982	7,472	7,533	20	42	62	0.82
1983	6,835	6,891	18	39	57	0.82
1984	7,116	7,176	17	43	60	0.83
1985	6,911	6,969	16	43	59	0.84
1986	6,989	7,048	13	47	60	0.84
1987	6,997	7,057	12	48	60	0.85
1988	7,128	7,189	10	51	61	0.85
1989	6,714	6,772	9	49	58	0.85
1990	6,708	6,766	8	49	58	0.86
1991	6,097	6,150	7	46	53	0.86
1992	5,759	5,809	5	45	50	0.86
1993	5,980	6,032	5	47	52	0.86
1994	5,739	5,789	5	45	50	0.86
1995	5,912	5,964	4	47	51	0.86
1996	5,689	5,739	3	46	50	0.86
1997	5,636	5,685	3	46	49	0.86
1998	5,484	5,532	2	45	48	0.87
1999	5,187	5,232	2	43	45	0.86
2000	4,970	5,014	2	42	43	0.87
2001	5,123	5,168	1	44	45	0.87
2002	5,060	5,104	1	43	44	0.87
2003	4,943	4,986	1	42	43	0.87
2004	4,916	4,959	1	42	43	0.87
2005	5,209	5,255	1	45	46	0.87
2006	5,117	5,162	0	44	45	0.87
2007	4,944	4,987	0	43	43	0.87
2008	4,719	4,760	0	41	41	0.87
2009	4,417	4,456	0	39	39	0.87
2010	4,588	4,628	0	40	40	0.87
2011	4,768	4,810	0	42	42	0.87
2012	5,156	5,202	0	45	45	0.87
	===========	===========	===========	===========	===========	
	351,225	**353,436**	**460**	**1,751**	**2,211**	

Table 2-45: Non-Occupant Lives Saved by
Car/LTV Dual Master Cylinders and Front Disc Brakes, 1960-2012

	105A: DUAL MASTER CYLINDERS (MEDIAN INSTALLATION YEAR LATE 1966, FMVSS 1/1/68 [CARS], 9/1/83 [LTVs])			105B: FRONT DISC BRAKES (MEDIAN INSTALLATION YEAR 1971, FMVSS 1/1/76 [CARS], 9/1/83 [LTVs])		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	1	0	1	0	0	0
1964	1	0	1	0	0	0
1965	2	0	2	0	0	0
1966	4	0	4	0	0	0
1967	9	0	9	0	0	0
1968	13	2	15	0	0	0
1969	15	6	21	1	0	1
1970	16	11	27	1	0	1
1971	16	17	33	2	0	2
1972	17	22	39	3	0	3
1973	18	26	44	4	0	4
1974	16	25	40	5	0	5
1975	16	31	47	6	0	6
1976	14	33	47	6	0	7
1977	15	35	50	7	1	8
1978	15	36	51	7	2	9
1979	16	38	54	7	3	10
1980	15	39	54	7	4	11
1981	14	40	54	6	5	11
1982	14	37	51	6	5	11
1983	13	34	47	5	5	10
1984	12	37	49	5	6	11
1985	12	36	48	4	7	11
1986	9	39	49	3	8	11
1987	9	40	49	3	8	11
1988	8	42	50	3	9	11
1989	7	40	47	2	9	11
1990	7	40	47	2	9	11
1991	5	37	43	1	9	10
1992	4	36	40	1	8	10
1993	4	38	42	1	9	10
1994	4	37	40	1	9	10
1995	3	38	42	1	9	10
1996	3	37	40	1	9	10
1997	2	37	40	1	9	9
1998	2	37	39	0	9	9
1999	2	35	36	0	8	9
2000	1	34	35	0	8	8
2001	1	35	36	0	8	9
2002	1	35	36	0	8	9
2003	1	34	35	0	8	8
2004	1	34	35	0	8	8
2005	0	36	37	0	9	9
2006	0	36	36	0	9	9
2007	0	35	35	0	8	8
2008	0	33	33	0	8	8
2009	0	31	31	0	7	8
2010	0	32	32	0	8	8
2011	0	33	34	0	8	8
2012	0	36	36	0	9	9
	===========	===========	===========	===========	===========	===========
	356	**1,485**	**1,841**	**104**	**266**	**370**

Benefits for motorcyclists

Table 2-46 summarizes motorcyclist lives saved by car/LTV braking improvements. Until 1997, the computation is similar to Table 2-44: when all cars and LTVs on the road are equipped with dual master cylinders and front disc brakes, 0.87 percent of potential motorcyclist fatalities in collisions between cars/LTVs and motorcycles will be avoided. In 1997, for example, 1,004 motorcyclists were actually killed in collisions with cars or LTVs. Without the braking improvements in the cars/LTVs there would have been 1,013; the brakes saved 9 lives, 0.87 percent of 1,013. However, starting 1998, ESC in cars and LTVs adds benefits for motorcyclists. NHTSA's evaluation of ESC for cars and LTVs shows a 16-percent reduction of culpable involvements by cars and LTVs in collisions with other vehicles (which include motorcycles), but no significant effect on collisions of cars and LTVs with pedestrians or bicyclists. By 2012, the combination of braking improvements and the ESC in cars and LTVs on the road in that year saved 58 lives, 2.54 percent of the 2,260 potential fatalities.

As the popularity of motorcycles has risen and fallen over the years, so have motorcyclist fatalities in collisions with cars/LTVs: rising from 388 in 1960 to 2,327 in 1980, falling to 1,003 in 1996, returning to 2,328 by 2008 as many baby-boomers took up motorcycling again, and declining slightly after 2008. Motorcycle helmets (a safety technology outside the scope of this report) also have a major impact on fatalities. Braking improvements and ESC in cars and LTVs have played a relatively small role. They have prevented an estimated 725 of 79,219 potential fatalities. Table 2-47 shows that dual master cylinders in cars/LTVs saved an estimated 478 motorcyclists in 1960 to 2012; front disc brakes, 101. Table 2-48 shows ESC in cars and LTVs has saved 146 motorcyclists from 1998 through 2012.

Effect of frontal air bags by seating position, occupant age, and type of air bag

The analysis model developed for this report permits more detailed estimates of the **net** effect of frontal air bags on various population subgroups. Tables 2-7, 2-21 and 2-32 show that frontal air bags had saved a net total of 42,856 lives by the end of CY 2012, including 27,765 in passenger cars and 15,091 in LTVs. Table 2-49 shows that 35,849 of the lives saved were drivers. The computation of benefits is simpler for drivers than for RF passengers. Even though SCI shows individual cases where air bags have harmed drivers, the statistical analysis of FARS data shows a net fatality reduction for every age/gender group and vehicle type. The model applies the effectiveness estimates – ranging from 33 percent for unbelted drivers in directly frontal impacts (12 o'clock) down to 5 percent for belted drivers in side impacts partially frontal force (10 o'clock or 2 o'clock) to zero in entirely non-frontal impacts – to the actual FARS cases of driver fatalities in vehicles equipped with air bags, inflating these cases to determine how many additional fatalities there would have been without air bags. Moreover, effectiveness for drivers is approximately the same in cars and LTVs and for barrier-certified, sled-certified, and advanced air bags. Table 2-49 estimates that frontal air bags saved 22,844 car drivers and 13,005 LTV drivers. The number of lives saved grew year by year until 2007, as vehicles with driver or dual air bags replaced older vehicles without air bags, declined slightly in 2008 to 2010, and then leveled off.

Table 2-46: Motorcyclist Summary – Actual Motorcyclist Fatalities in Collisions With Cars/LTVs, Potential Fatalities Without Car/LTV Braking Improvements and ESC, And Lives Saved by Car/LTV Braking Improvements and ESC

	MOTORCYCLIST FATALITIES		LIVES SAVED			
CY	ACTUAL	W/O CAR/LTV TECHNOLOGIES	BY VOLUNTARY IMPROVEMENTS	BY FMVSS IN EFFECT	TOTAL	PERCENT SAVED
1960	388	388	0	0	0	0.00
1961	362	362	0	0	0	0.00
1962	414	414	0	0	0	0.00
1963	465	465	0	0	0	0.01
1964	569	569	0	0	0	0.02
1965	827	827	0	0	0	0.02
1966	1,111	1,112	1	0	1	0.05
1967	1,034	1,035	1	0	1	0.11
1968	982	984	2	0	2	0.18
1969	1,008	1,011	2	1	2	0.24
1970	1,189	1,193	2	1	4	0.31
1971	1,137	1,142	2	2	4	0.37
1972	1,396	1,402	3	3	6	0.44
1973	1,603	1,611	4	4	8	0.51
1974	1,654	1,664	5	5	9	0.57
1975	1,568	1,578	5	6	10	0.65
1976	1,599	1,610	5	6	11	0.69
1977	1,959	1,973	6	8	14	0.72
1978	2,136	2,152	7	9	16	0.75
1979	2,282	2,300	7	11	18	0.78
1980	2,327	2,346	7	11	18	0.79
1981	2,230	2,248	7	11	18	0.80
1982	2,019	2,036	6	10	16	0.81
1983	1,864	1,879	6	10	15	0.81
1984	2,040	2,057	6	11	17	0.83
1985	2,003	2,020	5	12	17	0.84
1986	2,021	2,038	4	13	17	0.83
1987	1,808	1,823	3	12	15	0.84
1988	1,688	1,702	3	11	14	0.85
1989	1,386	1,397	2	9	12	0.85
1990	1,448	1,460	2	10	12	0.86
1991	1,222	1,232	2	9	11	0.85
1992	1,044	1,053	1	8	9	0.86
1993	1,128	1,138	1	8	10	0.86
1994	1,034	1,043	1	8	9	0.86
1995	1,042	1,051	1	8	9	0.87
1996	1,003	1,012	1	8	9	0.86
1997	1,004	1,013	1	8	9	0.87
1998	1,006	1,015	1	8	9	0.87
1999	1,068	1,078	0	9	9	0.87
2000	1,275	1,287	1	11	12	0.90
2001	1,410	1,423	1	12	13	0.93
2002	1,384	1,398	1	12	13	0.94
2003	1,644	1,661	2	14	16	0.98
2004	1,721	1,738	2	15	17	0.98
2005	2,096	2,118	4	18	22	1.03
2006	2,211	2,238	7	19	26	1.17
2007	2,261	2,294	13	20	33	1.42
2008	2,328	2,363	14	21	35	1.48
2009	1,965	1,998	14	20	33	1.67
2010	1,947	1,985	15	23	38	1.90
2011	1,980	2,025	15	30	45	2.23
2012	2,203	2,260	18	40	58	2.54
	===========	===========	===========	===========	===========	
	78,494	**79,219**	**221**	**504**	**725**	

Table 2-47: Motorcyclist Lives Saved by Car/LTV Dual Master Cylinders and Front Disc Brakes, 1960-2012

	105A: DUAL MASTER CYLINDERS (MEDIAN INSTALLATION YEAR LATE 1966, FMVSS 1/1/68 [CARS], 9/1/83 [LTVs])			105B: FRONT DISC BRAKES (MEDIAN INSTALLATION YEAR 1971, FMVSS 1/1/76 [CARS], 9/1/83 [LTVs])		
CY	VOLUNTARY	POST-FMVSS	TOTAL	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0	0	0	0
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	1	0	1	0	0	0
1967	1	0	1	0	0	0
1968	2	0	2	0	0	0
1969	2	1	2	0	0	0
1970	2	1	4	0	0	0
1971	2	2	4	0	0	0
1972	3	3	6	0	0	0
1973	3	4	7	1	0	1
1974	4	5	9	1	0	1
1975	4	6	9	1	0	1
1976	4	6	10	1	0	1
1977	4	8	12	2	0	2
1978	5	9	14	2	1	2
1979	5	10	15	2	1	3
1980	5	10	15	2	1	3
1981	5	10	15	2	1	3
1982	5	9	14	2	1	3
1983	4	8	13	2	1	3
1984	4	10	14	2	1	3
1985	4	10	14	1	2	3
1986	3	11	14	1	2	3
1987	2	10	13	1	2	3
1988	2	9	12	1	2	3
1989	2	8	10	1	2	2
1990	2	8	10	0	2	2
1991	1	7	9	0	2	2
1992	1	6	7	0	1	2
1993	1	7	8	0	2	2
1994	1	7	7	0	2	2
1995	1	7	7	0	2	2
1996	1	6	7	0	2	2
1997	1	7	7	0	2	2
1998	0	7	7	0	2	2
1999	0	7	8	0	2	2
2000	0	9	9	0	2	2
2001	0	10	10	0	2	2
2002	0	9	10	0	2	2
2003	0	11	12	0	3	3
2004	0	12	12	0	3	3
2005	0	15	15	0	4	4
2006	0	15	16	0	4	4
2007	0	16	16	0	4	4
2008	0	16	17	0	4	4
2009	0	14	14	0	3	3
2010	0	14	14	0	3	3
2011	0	14	14	0	3	3
2012	0	16	16	0	4	4
	===========	===========	===========	===========	===========	===========
	90	**388**	**478**	**27**	**74**	**101**

Table 2-48: Motorcyclist Lives Saved by ESC in Cars and LTVs, 1960-2012

126: ELECTRONIC STABILITY CONTROL
(MEDIAN INSTALLATION YEAR 2010 [CARS], EARLY 2008 [LTVs]; FMVSS PHASE-IN BEGAN MY 2009)

CY	VOLUNTARY	POST-FMVSS	TOTAL
1960	0	0	0
1961	0	0	0
1962	0	0	0
1963	0	0	0
1964	0	0	0
1965	0	0	0
1966	0	0	0
1967	0	0	0
1968	0	0	0
1969	0	0	0
1970	0	0	0
1971	0	0	0
1972	0	0	0
1973	0	0	0
1974	0	0	0
1975	0	0	0
1976	0	0	0
1977	0	0	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	0	0	0
1984	0	0	0
1985	0	0	0
1986	0	0	0
1987	0	0	0
1988	0	0	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	0	0	0
1993	0	0	0
1994	0	0	0
1995	0	0	0
1996	0	0	0
1997	0	0	0
1998	0	0	0
1999	0	0	0
2000	0	0	0
2001	1	0	1
2002	1	0	1
2003	2	0	2
2004	2	0	2
2005	4	0	4
2006	7	0	7
2007	13	0	13
2008	14	0	15
2009	14	2	16
2010	15	6	21
2011	15	13	28
2012	18	20	38
	===========	===========	===========
	104	**41**	**146**

Table 2-49: Lives Saved By Driver Air Bags in Cars and LTVs, 1984-2012

LIVES SAVED BY DRIVER AIR BAGS

CY	TOTAL	IN CARS	IN LTVs
1984	0	0	0
1985	0	0	0
1986	1	1	0
1987	2	2	0
1988	3	3	0
1989	8	8	0
1990	44	44	0
1991	74	74	0
1992	102	99	4
1993	202	190	12
1994	293	268	25
1995	481	401	81
1996	693	545	149
1997	851	631	220
1998	1,049	749	300
1999	1,267	882	385
2000	1,505	1,031	474
2001	1,773	1,167	606
2002	2,088	1,354	734
2003	2,295	1,430	864
2004	2,431	1,562	869
2005	2,631	1,628	1,003
2006	2,774	1,714	1,061
2007	2,821	1,696	1,125
2008	2,647	1,605	1,042
2009	2,552	1,525	1,027
2010	2,385	1,396	989
2011	2,440	1,422	1,018
2012	2,434	1,418	1,016
	===========	===========	===========
	35,849	**22,844**	**13,005**

Drivers account for a large proportion (35,849 of 42,856) of the lives saved by air bags because:

- The RF seat is occupied in only 1 of every 3 vehicles, but the driver’s seat is always occupied.
- There are many vehicles with driver air bags only and they have been in service longer than the more recent vehicles with dual air bags.

Table 2-50 estimates the effects for adults and adolescents 13 or older of passenger air bags in vehicles without manual on-off switches for those air bags. Such vehicles include most cars, SUVs, minivans, full-size vans; most pickup trucks with full crew cabs; and almost all the more recent vehicles with advanced air bags that automatically suppress deployment for small child passengers. For adults and adolescents, air bags are beneficial; in fact, they are slightly more effective than for drivers. The computation is similar to the analysis of drivers in Table 2-49. Passenger air bags saved an estimated 6,775 adults and adolescents in vehicles without manual on-off switches from 1987 through 2012.

Table 2-50: Estimated Effect of Passenger Air Bags on Adults and Adolescents (13 and Older) in Cars and LTVs **Without** Manual On-Off Switches, 1987-2012

ADULTS (AGE 13+) SAVED BY PASSENGER AIR BAGS

CY	TOTAL	IN CARS	IN LTVs W/O SWITCHES
1987	0	0	0
1988	0	0	0
1989	0	0	0
1990	0	0	0
1991	3	3	0
1992	2	2	0
1993	9	9	0
1994	22	21	1
1995	68	65	2
1996	92	84	8
1997	144	130	14
1998	192	167	26
1999	221	187	34
2000	281	236	44
2001	306	256	49
2002	420	330	90
2003	452	343	110
2004	497	379	118
2005	515	382	133
2006	541	405	136
2007	564	408	156
2008	523	362	161
2009	490	335	155
2010	500	343	157
2011	457	310	148
2012	477	321	156
	===========	===========	===========
	6,775	**5,077**	**1,698**

Table 2-51 statistically estimates the effects of barrier-certified and sled-certified air bags in vehicles without manual on-off switches on child passengers up to 12 years old. The model does not assume any net effect for advanced air bags for children up to 12 years old. A negative number in Table 2-51 indicates a fatality increase. The computations in Table 2-51 are:

- Strictly based on the same type of statistical model used to compute the benefits of air bags for people age 13 or older. In other words,
    - The [often negative] effect of air bags was estimated by double-pair comparison analysis of FARS data and it depends on the type of air bag, the age of the child, the child's restraint use, and vehicle impact location.
    - Only statistically significant effects are included in the model; there were significant fatality increases for several younger age/restraint groups but no offsetting significant fatality reductions for the somewhat older groups of children.
    - The negative effectiveness estimates are applied to the actual FARS cases of child passenger fatalities in vehicles equipped with dual air bags, deflating these cases to determine how many fewer fatalities there would have been without air bags.
- Information from NHTSA's Special Crash Investigations was not directly used in generating these statistical estimates (except, of course, many of the SCI cases are also FARS cases and, as such, part of the statistical analysis).

- As discussed in the chapter for FMVSS No. 208 in Part 1 of this report, the negative effects of sled-certified air bags are, on the average, 83 percent smaller than the negative effects of barrier-certified air bags. As stated above, the model does not assume any negative net effect for advanced air bags.

Table 2-51: Estimated Effect of Barrier-Certified and Sled-Certified Passenger Air Bags on Children (12 or Younger) in Cars and LTVs **Without** Manual On-Off Switches, 1987-2012

NET EFFECT ON CHILD PASSENGERS (AGE < 13)
(Negative numbers indicate a net increase in fatalities)

CY	BARRIER-CERTIFIED	SLED-CERTIFIED
1987	0	0
1988	0	0
1989	0	0
1990	0	0
1991	0	0
1992	0	0
1993	-1	0
1994	-4	0
1995	-7	0
1996	-21	0
1997	-13	0
1998	-17	-1
1999	-15	-1
2000	-13	-2
2001	-16	-2
2002	-14	-1
2003	-12	-3
2004	-12	-4
2005	-12	-3
2006	-9	-3
2007	-3	-2
2008	-2	-2
2009	-4	-3
2010	-1	-1
2011	-4	-1
2012	-2	-1
	===========	===========
	-183	**-29**

Based on this statistical approach, the model estimates that barrier-certified passenger air bags are associated with a net increase of 183 child passenger fatalities through 2012, in vehicles without manual on-off switches. Sled-certified air bags are attributed a net increase of 29 fatalities. The statistical estimates in Table 2-51 agree closely with the case counts in SCI. Through CY 2008, Table 2-51 estimates 172 additional fatalities with barrier-certified air bags and 23 with sled-certified. As of January 1, 2009 (the latest SCI report), SCI had identified 165 actual cases where barrier-certified air bags resulted in fatal injuries to children in relatively low-speed crashes of vehicles without on-off switches and 20 in sled-certified vehicles without switches. There are no SCI cases of children fatally injured by frontal air bags in vehicles with advanced air bags.

Tables 2-50 and 2-51 allow a year-by-year comparison of the estimated fatality reduction for adults and adolescents 13 and older with the fatality increase for children 12 and younger. In

1996, passenger air bags saved 92 adults and adolescents, but child passenger fatalities increased by an estimated 21. That is a ratio of 4.4 adults saved per child passenger fatality. In 2002, a much larger number of vehicles with dual air bags on the road saved 420 adult lives, but child passenger fatalities attributable to barrier- or sled-certified air bags had decreased to 15. That is a ratio of 28 adults saved per child passenger fatality. In 2012, the 477 adults saved and 3 child fatalities are a ratio of 159 to 1. The enormous improvements in the ratio can be attributed two factors: (1) The shift from barrier-certified to sled-certified to advanced air bags; (2) The public, to a large extent, has moved child passengers to the rear seat; consequently, the exposure of small children to air bags has been greatly reduced.

Tables 2-52 and 2-53 estimate the effects of passenger air bags in pickup trucks and other vehicles with manual on-off switches and also the effect of the switches. Table 2-52 considers adult and adolescent passengers, Table 2-53, child passengers. The switches have generally been standard, factory-installed equipment in vehicles without a rear seat large enough to accommodate rear-facing child safety seats, including 2-door pickup trucks; crew-cab pickups with a limited rear seat; cars, SUVs, or cargo vans without any rear seat; and sporty cars with a small rear seat. Immediately or a few years after the shift to advanced air bags with automatic deployment suppression, the manufacturers phased out the manual switches; FMVSS No. 208 does not permit manual switches in MY 2012 or later vehicles.

Ideally, switches would always be “on” for passengers 13 and older, securing for them the benefits of air bags and “off” for child passengers up to 12, assuring that children would never be exposed to air bags. In reality, though, NHTSA’s survey in 2000 indicated that switches were turned off, for example, for 22 percent of 13-to-15 year olds, 15 percent of adults 20 to 59, and 56 percent of people 70 or older. Switches were turned on for 14 percent of infants, 26 percent of 1-to-6 year olds, and 70 percent of 11- and12-year-olds. The statistical model for this report factors in the probability that the switch was on and the effectiveness of air bags, given the occupant’s age, the vehicle’s impact location, and the type of air bag to estimate how the actual number of fatalities in FARS would have changed:

- If the vehicles had passenger air bags and no switches – or if they did have switches, but they were left on all the time (these are the same).
- If the vehicles did not have passenger air bags – or if they did have air bags and the switches were left off all the time (these are the same).

Table 2-52: Estimated Effect of Passenger Air Bags on Adults and Adolescents (13 and Older) in Vehicles **With** Manual On-Off Switches, 1995-2012

(Positive numbers indicate lives saved; negative numbers indicate net increases in fatalities. Block print indicates actual effects of air bags with switches 'on'; *Italics indicate hypothetical effects*)

CY	ACTUAL LIVES SAVED BY AIR BAGS WITH SWITCHES 'ON'	*LIVES SAVED IF ALL SWITCHES HAD BEEN 'ON'*	*POTENTIAL SAVINGS LOST BECAUSE SWITCHES WERE TURNED OFF*
1995	0	*0*	*0*
1996	0	*0*	*0*
1997	2	*3*	*-0*
1998	9	*11*	*-2*
1999	17	*21*	*-4*
2000	25	*32*	*-7*
2001	33	*42*	*-9*
2002	31	*38*	*-7*
2003	38	*47*	*-10*
2004	44	*55*	*-11*
2005	41	*51*	*-10*
2006	37	*45*	*-8*
2007	43	*54*	*-11*
2008	33	*41*	*-8*
2009	30	*37*	*-8*
2010	23	*29*	*-6*
2011	26	*33*	*-7*
2012	22	*29*	*-7*
	===========	===========	===========
	453	*567*	*-114*

Table 2-52 estimates that passenger air bags in vehicles with manual switches actually saved 453 people 13 or older. In other words, the switches were left on for these occupants; the air bags deployed and saved their lives. However, if in these same vehicles the switch had been correctly left on for every occupant 13 or older (or if vehicles had passenger air bags and no switches), the number of people (13 or older) saved by air bags would have been 567 rather than 453. In other words, 114 of the 567 potential saves were lost because an air bag was turned off for a person 13 or older. There are two ways of looking at these statistics. On the one hand, it could be said that inappropriate use of the switches cost 114 lives. More positively, it could be argued that, without some device such as the switches to protect child passengers, dual air bags simply could not have been mandated in pickup trucks or other vehicles without a full rear seat; in that sense, the switches saved 453 adults who, otherwise, would not have had the protection of frontal air bags.

In the first column of Table 2-53, the statistical method used by our model estimates that frontal air bags increased child passenger fatalities by 8 in vehicles with manual switches because the switches were incorrectly left on: 5 of them in vehicles with barrier-certified air bags, 3 sled-certified. Again, the statistical estimates are compatible with SCI, which had 6 actual cases as of January 1, 2009 of children with fatal injuries from air bags in pickup trucks where the switches were left on.

Table 2-53: Estimated Effect of Passenger Air Bags on Child Passengers (12 or Younger) in Vehicles **With** Manual On-Off Switches, 1995-2012

(Positive numbers indicate lives saved; negative numbers indicate net increases in fatalities. Block print indicates actual effects of air bags with switches "on"; *italics indicate hypothetical effects*; ***bold italics indicate children saved because switches were correctly turned "off"***)

CY	NET EFFECT ON CHILDREN BY AIR BAGS BECAUSE SWITCHES WERE 'ON'	*NET EFFECT IF ALL SWITCHES HAD BEEN 'ON'*	***CHILDREN SAVED BECAUSE SWITCHES WERE TURNED OFF***
	WITH BARRIER-CERTIFIED AIR BAGS		
1995	0	*0*	***0***
1996	0	*0*	***0***
1997	-0	*-1*	***0***
1998	-1	*-3*	***3***
1999	-1	*-2*	***1***
2000	-0	*-1*	***1***
2001	-1	*-3*	***2***
2002	-1	*-3*	***2***
2003	-0	*-0*	***0***
2004	-0	*-1*	***0***
2005	0	*0*	***0***
2006	-0	*-1*	***1***
2007	-0	*-0*	***0***
2008	-0	*-1*	***1***
2009	-0	*-2*	***1***
2010	0	*0*	***0***
2011	0	*0*	***0***
2012	0	*0*	***0***
	===========	===========	===========
	-5	*-17*	***12***
	WITH SLED-CERTIFIED AIR BAGS		
1995	0	*0*	***0***
1996	0	*0*	***0***
1997	0	*0*	***0***
1998	-0	*-0*	***0***
1999	-0	*-0*	***0***
2000	-0	*-1*	***0***
2001	-0	*-1*	***1***
2002	-0	*-2*	***2***
2003	-0	*-1*	***1***
2004	-0	*-2*	***1***
2005	-0	*-1*	***0***
2006	-0	*-1*	***1***
2007	-0	*-1*	***0***
2008	-0	*-0*	***0***
2009	-0	*-1*	***1***
2010	-0	*-1*	***0***
2011	-0	*-1*	***0***
2012	-0	*-0*	***0***
	===========	===========	===========
	-3	*-13*	***10***

The statistical model also considers the hypothetical situation that all switches had been left on (or that all the vehicles actually equipped with switches instead had air bags but no switches). The second column of Table 2-53 estimates that air bags would have increased child passenger fatalities by 30 (17 barrier-certified and 13 sled-certified) rather than 8. In other words, 22 potential fatalities to children were avoided because air bags were correctly turned off (third column). Essentially, the switch was turned off in three-quarters of the situations (22 of 30) where it needed to be off – i.e., especially for infants and toddlers.

The statistics for adults and children – Tables 2-52 and 2-53 – can be compared:

- As actually used by the public in 1995 to 2012, the combination of passenger air bags with manual on-off switches saved an estimated 453 adults at a cost of 8 child-passenger fatalities. That is a ratio of 56.6 adult lives saved per child passenger fatality: not too different from the ratios after 2000 in vehicles with full rear seats and no switches (where children can escape harm from air bags simply by riding in the rear seat, an option not available in pickup trucks without rear seats).
- Air bags without switches, hypothetically, would have saved an estimated 567 adults at a cost of 30 child passenger fatalities. That would have been a much worse ratio of 18.9 adult lives saved per child passenger fatality: comparable to some of the ratios before 1998 in vehicles without switches, before the public became well aware of the risks of air bags to small children.
- If these pickup trucks and other vehicles had not been equipped with passenger air bags at all, the statistics would have been, of course, zero adults saved and zero children harmed by frontal air bags.
- If the public had been fully aware of the correct way to use the switches, or if the manual switches had already been superseded by advanced systems that automatically trigger or suppress deployment depending on the size and location of the occupant, the statistics could have been 567 adults saved and zero children harmed.

The statistics in Table 2-50 and 2-51 for vehicles without switches can be combined with the estimates for vehicles with switches in Tables 2-52 and 2-53.

- In all vehicles, passenger air bags saved 6,775 + 453 = 7,228 people 13 or older from 1987 through 2012.
- Child passenger fatalities increased by an estimated 183 + 29 + 5 + 3 = 220.
- Net lives saved by passenger air bags were 7,228 – 220 = 7,008.

Finally, Table 2-54 quantifies three **tangible** benefits of sled-certified and advanced air bags for RF passengers through 2012 – by estimating hypothetical additional fatalities that would have occurred if the vehicles had instead been equipped with barrier-certified air bags. Of course, in additional to these benefits there is the intangible boon that the 1998-to-1999 redesign and the 2004-to-2007 shift to advanced air bags preserved public confidence that frontal air bags are a safe and effective technology.

Table 2-54: Hypothetical Additional Fatalities if Sled-Certified or Advanced Air Bags for RF Passengers Had Still Been Barrier-Certified Air Bags, 1995-2012

	ADDITIONAL FATALITIES IF		
CY	CHILDREN EXPOSED TO SLED-CERTIFIED AIR BAGS HAD BEEN EXPOSED TO BARRIER-CERTIFIED	CHILDREN EXPOSED TO ADVANCED AIR BAGS HAD BEEN EXPOSED TO BARRIER-CERTIFIED	ADULTS/ADOLESCENTS IN VEHICLES W/O FULL REAR SEATS WITH ADVANCED AIR BAGS & NO SWITCHES HAD BEEN EXPOSED TO SLED- OR BARRIER-CERTIFIED PLUS MANUAL SWITCHES
1995	0	0	0
1996	0	0	0
1997	0	0	0
1998	4	0	0
1999	4	0	0
2000	13	0	0
2001	13	0	0
2002	10	0	0
2003	17	0	0
2004	26	0	1
2005	22	1	1
2006	21	3	2
2007	11	6	2
2008	9	3	2
2009	22	1	2
2010	7	1	2
2011	5	4	2
2012	7	4	2
	===========	===========	===========
	189	24	16

The first column of Table 2-54 tallies the benefits for child passengers of the shift from barrier-certified to sled-certified air bags. Tables 2-51 and 2-53 showed that sled-certified air bags still present some risk to small children, resulting in an increase of 32 (29 plus 3) fatalities through 2012. But NHTSA's evaluations show the risk is, on the average, 83 percent lower with sled-certified than with barrier-certified air bags. If all those sled-certified air bags had performance equivalent to the earlier barrier-certified air bags, and everything else had stayed the same, there would have been yet another 189 fatalities.

The second column of Table 2-54 performs a similar computation for advanced air bags. Their suppression and low-risk deployment features have minimized the added risk for child passengers. If the advanced air bags in FARS cases through 2012 had instead been barrier-certified air bags and everything else stayed the same, there would have been 24 additional child-passenger fatalities.

Advanced air bags also have a benefit for adults and adolescents, estimated in the last column of Table 2-54. Make-models without a full rear seat, if equipped with passenger air bags that are not certified-advanced, also need manual on-off switches to make it feasible to transport children. These switches are incorrectly turned off for some adults and adolescents, depriving them of the protection of a frontal air bag. The automatic suppression feature of advanced air bags allowed phasing out the manual switches, which had occurred in all of those make-models immediately after the shift to advanced air bags, or a few years later, but in all cases by MY 2012. If the vehicles in those makes and models, now with advanced air bags and no switches, had instead been equipped with a sled- or barrier-certified air bag and a manual switch, there would have been an estimated 16 additional fatalities because the switch would have been turned off for some of the adult or adolescent passengers.

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31 (March 8, 1966): 4091, GSA proposes safety standards for Federally purchased vehicles.

31 (July 15, 1966): 9631, GSA final rule, safety standards for Federally purchased vehicles.

31 (December 3, 1966): 15212, NPRM for the initial FMVSS.

32 (February 3, 1967): 2414, final rule for the initial FMVSS, including among others FMVSS Nos. 103, 105, 108, 201, 203, 204, 205, 206, 207, 208, 209, 210 and 301.

32 (October 13, 1967): 14278, ANPRM to consider regulations to limit roof crush and intrusion.

32 (December 16, 1967): 18033, final rule extending FMVSS No. 108 to cars and LTVs.

32 (December 28, 1967): 20865, NPRM to establish FMVSS No. 202 for passenger cars.

33 (February 14, 1968): 2945, final rule establishing FMVSS No. 202 for passenger cars.

33 (August 16, 1968): 11652, final rule establishing FMVSS No. 212 for passenger cars.

33 (October 5, 1968): 14971, ANPRM announcing the intention to regulate side door strength.

33 (December 11, 1968): 18386, first NPRM proposing FMVSS No. 214.

34 (January 24, 1969): 1150, final rule extending FMVSS No. 206 to trucks, buses and multipurpose passenger vehicles.

34 (July 2, 1969): 11148, initial ANPRM to consider air bags or other automatic protection.

35 (January 21, 1970): 813, second NPRM proposing FMVSS No. 214.

35 (April 23, 1970): 6513, third NPRM proposing FMVSS No. 214.

35 (May 7, 1970): 7187, initial NPRM for automatic occupant protection, did not become a final rule.

35 (September 23, 1970): 14778, final rule establishing FMVSS No. 213.

35 (September 30, 1970): 15222, final rule extending the original FMVSS No. 208 to LTVs.

35 (September 25, 1970): 14936, NPRM proposing to add a knee impact test to FMVSS No. 201, never became a final rule.

35 (October 30, 1970): 16801, final rule establishing FMVSS No. 214 (side door strength, passenger cars).

35 (November 11, 1970): 17345, original NPRM to establish FMVSS No. 105a for passenger cars, effective October 1, 1972.

36 (January 6, 1971): 166, NPRM to establish FMVSS No. 216 for passenger cars.

36 (March 10, 1971): 4600, final rule amending FMVSS No. 208 to require shoulder belts and warning buzzers in all cars, and to permit automatic occupant protection.

36 (December 2, 1971): 22902, final rule extending FMVSS No. 207 to LTVs.

36 (December 8, 1971): 23299, final rule establishing FMVSS No. 216 for passenger cars.

37 (September 2, 1972): 17970, original final rule establishing FMVSS No. 105a in passenger cars and LTVs, effective September 1, 1974 (subsequently revised).

38 (May 18, 1973): 13017, delays FMVSS No. 105a to September 1, 1975 (subsequently revised).

38 (June 20, 1973): 16072, final rule amending FMVSS No. 208 to require integral 3-point belts and ignition interlocks in passenger cars.

39 (February 22, 1974): 6708, renames FMVSS No. 105a to FMVSS No. 105-75 and limits it to passenger cars (subsequently revised).

39 (March 19, 1974): 10268, NPRM proposing to upgrade FMVSS No. 202, including fixed head restraints for drivers, never became a final rule.

39 (March 21, 1974): 10588, final rule adding lateral and rear impact tests to FMVSS No. 301 and extending the standard to LTVs.

39 (October 31, 1974): 38380, final rule amending FMVSS No. 208 to delete the interlock requirement.

39 (November 21, 1974): 40857, minor revisions to FMVSS No. 301 final rule of March 21, 1974.

39 (December 6, 1974): 42692, final rule amending FMVSS No. 208 to require a 4-8 second audible warning on belt use.

40 (June 9, 1975): 24525, final rule for FMVSS No. 105-75 in passenger cars, effective January 1, 1976.

40 (July 9, 1975): 28805, final rule amending FMVSS No. 208, extending 3-point belts to LTVs.

40 (August 6, 1975): 33036, revises fuel spillage requirements in FMVSS No. 301 final rule of March 21, 1974.

40 (October 10, 1975): 47790, revises effective dates in FMVSS No. 301 final rule of March 21, 1974.

41 (August 30, 1976): 36493, final rule extending FMVSS No. 212 to LTVs and also amending the standard, allowing NHTSA to test at a wider range of temperatures.

42 (July 5, 1977): 34288, postpones until September 1, 1978 the effective date of the extension of FMVSS No. 212 to LTVs.

42 (July 5, 1977): 34289, final rule requiring automatic occupant protection, rescinded in 1981 before its effective date.

44 (November 29, 1979): 68470, final rule extending FMVSS Nos. 201, 203 and 204 to LTVs.

44 (December 13, 1979): 72131, final rule adding a 30 mph test to FMVSS No. 213.

46 (January 2, 1981): 55, final rule extending FMVSS No. 105 to LTVs

46 (January 8, 1981): 2064, final rule amending FMVSS No. 208 to add comfort and convenience standards for seat belts.

46 (February 19, 1981): 13193, Executive Order 12291 – Federal Regulation.

46 (October 29, 1981): 53419, rescission of 1977 final rule requiring automatic occupant protection.

48 (October 18, 1983): 48235, final rule amending FMVSS No. 108 to require CHMSL on passenger cars.

48 (November 16, 1983): 52065, final rule amending FMVSS No. 205 to permit the optional use of glass-plastic glazing.

49 (July 17, 1984): 28962, final rule amending FMVSS No. 208 to require automatic occupant protection in passenger cars.

50 (August 23, 1985): 34152, final rule amending FMVSS No. 208 to postpone belt comfort and convenience standards to September 1, 1986.

54 (June 14, 1989): 25275, final rule amending FMVSS No. 208 to require 3-point belts at the outboard rear seats of cars.

54 (September 25, 1989): 39183, final rule extending FMVSS No. 202 to LTVs.

54 (November 2, 1989): 46257, final rule amending FMVSS No. 208 to require 3-point belts at the outboard rear seats of LTVs.

55 (January 17, 1990): 1586, NHTSA evaluation plan for automatic occupant protection.

55 (October 30, 1990): 45752, final rule upgrading FMVSS No. 214, adding a dynamic side impact test for passenger cars.

56 (March 26, 1991): 12472, final rule amending FMVSS No. 208 to extend automatic protection to LTVs.

56 (April 17, 1991): 15510, final rule extending FMVSS No. 216 to LTVs.

56 (April 19, 1991): 16015, final rule amending FMVSS No. 108 to require CHMSL on LTVs.

56 (June 14, 1991): 27427, final rule extending FMVSS No. 214 side door strength requirement to LTVs.

57 (December 10, 1992): 58406, final rule amending FMVSS No. 108 to require conspicuity tape on heavy trailers.

58 (January 11, 1993): 3500, final rule amending FMVSS No. 108 to permit DRL on cars and LTVs.

58 (September 2, 1993): 46551, final rule amending FMVSS No. 208 to require manual 3-point belts and dual air bags in cars and LTVs.

58 (October 4, 1993): 51735, Executive Order 12866 – Regulatory Planning and Review.

59 (January 4, 1994): 281, ANPRM asking for information about the effectiveness and potential benefits of ABS technologies.

60 (April 12, 1995): 18566, ANPRM to consider upgrading FMVSS No. 301.

60 (May 23, 1995): 27233, final rule amending FMVSS No. 208 to allow manual on-off switches for passenger air bags in pickup trucks and other vehicles with small or no rear seats.

60 (July 6, 1995): 35126, final rule amending FMVSS No. 213 to use a 6-year-old dummy to test seats with higher weight limits.

60 (July 28, 1995): 38749, final rule extending the FMVSS No. 214 dynamic side impact test to LTVs.

60 (August 18, 1995): 43031, final rule – head-impact upgrade of FMVSS No. 201.

60 (September 28, 1995): 50124, final rule extending FMVSS No. 206 to the back doors of vehicles.

61 (January 24, 1996): 2004, final rule establishing FMVSS Nos. 223 and 224 to require and set performance standards for underride guards for heavy trailers.

61 (May 31, 1996): 27290, final rule amending FMVSS No. 121 to require ABS for vehicles with air brakes.

61 (July 12, 1996): 36698, ANPRM deferring indefinitely the ABS requirement for cars and LTVs.

62 (March 19, 1997): 12960, final rule modifying the FMVSS No. 208 test to permit air bags that deploy less forcefully.

62 (November 21, 1997): 62406, sets up procedures enabling the public to obtain aftermarket on-off switches for air bags.

63 (August 4, 1998): 41451, final rule reducing the FMVSS No. 201 test speed from 15 mph to 12 mph on target areas where a head air bag is stored.

64 (March 5, 1999): 10786, final rule establishing FMVSS No. 225 and amending FMVSS No. 213 to require upper and lower tethers on child safety seats.

64 (March 31, 1999): 15587, Federal Motor Carrier Safety Regulation (final rule) requiring all heavy trailers on the road on or after June 1, 2001 to be equipped or retrofitted with conspicuity tape.

65 (May 12, 2000): 30679, final rule amending FMVSS No. 208 to require advanced frontal air bags.

65 (November 13, 2000): 67693, NPRM to upgrade the rear- and lateral-impact test procedures of FMVSS No. 301.

66 (January 4, 2001): 967, NPRM to upgrade FMVSS No. 202.

66 (January 12, 2001): 3388, establishes NHTSA's rollover resistance ratings based on the static stability factor.

68 (July 25, 2003): 43964, final rule updating FMVSS No. 205 to incorporate the 1996 edition of ANSI Code Z26.1.

68 (October 14, 2003): 59250, modifies NHTSA's rollover resistance ratings by considering results of a fishhook maneuver in addition to the static stability factor.

68 (December 1, 2003): 67068, final rule upgrading the rear- and lateral-impact test procedures of FMVSS No. 301.

69 (July 16, 2004): 42595: final rule amending FMVSS No. 213 to require Hybrid III dummies for testing safety seats.

69 (December 8, 2004): 70904, final rule requiring 3-point belts for center rear seats.

69 (December 14, 2004): 74848, final rule upgrading FMVSS No. 202, “Head restraints.”

70 (April 8, 2005): 18136, final rule for FMVSS No. 138, “Tire pressure monitoring systems.”

70 (July 12, 2005): 39959, final rule establishing FMVSS No. 205(a), based on the 1977 and 1980 editions of ANSI Code Z26.1, as an alternative to FMVSS No. 205 in some situations.

71 (August 31, 2006): 57168, amends FMVSS No. 208 to increase the test speed for the belted 5th percentile female dummy from 30 mph to 35 mph.

72 (April 6, 2007): 17236, final rule for FMVSS No. 126, “Electronic stability control systems.”

72 (May 4, 2007): 25514, some amendments to the final rule upgrading FMVSS No. 202, “Head restraints.”

72 (February 6, 2007): 5385, final rule extending FMVSS No. 206 to sliding doors of vehicles and harmonizing with GTR.

72 (September 11, 2007): 51908, final rule adding a pole test to FMVSS No. 214, “Side impact protection.”

73 (July 11, 2008): 40016, NPRM to add new features to NCAP, including overall rating, pole test, information on crash avoidance technologies, 5th-percentile female dummies at some positions, and additional injury criteria.

74 (May 12, 2009): 22347, final rule upgrading FMVSS No. 216, “Roof crush resistance.”

74 (June 29, 2009): 30993, denial of petition to mandate DRL for new cars and LTVs.

74 (July 20, 2009): 35131, response to petitions for reconsideration, sets September 1, 2010, as the effective date for final rule extending FMVSS No. 206 to sliding doors of vehicles.

76 (January 19, 2011): 3212, final rule for FMVSS No. 226, “Ejection mitigation.”

76 (January 21, 2011): 3821, Executive Order 13563 – Improving Regulation and Regulatory Review.

76 (July 29, 2011): 45453, final rule to add new features to NCAP, including overall rating, pole test, information on crash avoidance technologies, 5th-percentile female dummies at some positions, and additional injury criteria.

77 (February 27, 2012): 11651, final rule amending FMVSS No. 213 to set specifications for a 10-year-old dummy to test seats for larger children.

77 (August 30, 2012): 52619, final rule extending the option of manual on-off switches for frontal air bags at the RF seating position until September 1, 2015.

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APPENDIX A

SAS Programs Used to Estimate Lives Saved by Vehicle Safety Technologies and Associated FMVSS, 1960 To 2012

Overview

LS2014CR1, LS2014CR2, and LS2014CR3 are the programs that create a census file called *LSM2014C* of the 1,625,528 fatality cases in FARS for CY 1975 through 2012, on file as of December 31, 2013.[620] It includes all fatalities: non-occupants as well as vehicle occupants; occupants of heavy trucks, unknown vehicles, and other types of vehicles as well as occupants of cars and LTVs. It includes necessary data elements about the person who was the fatality and about the crash. It contains data elements about a vehicle: the vehicle occupied by the fatality, if the fatality was an occupant, or the vehicle that hit the non-occupant. Vehicle data include an analysis of the VIN, based on a series of programs developed and maintained by NHTSA staff since 1991 for use in FMVSS evaluations and other vehicle safety analyses. If the crash is a 2-vehicle crash, data elements are obtained on the "other" vehicle. From CY 1975 to 1985, *LSM2014C* is identical to *LSM2004*, the file used in the NHTSA's 2004 report that estimated lives saved from 1960 until 2002.[621]

LS2014CR1 uses the FARS data from CY 1975 through 2012 to create an initial file *LSM2014A* of 1,625,528 fatality cases. LS2014CR1 creates a record for every fatally injured person on FARS. If the person is a non-occupant, it identifies the VEH_NO of the vehicle that struck the non-occupant. It appends some variables from the accident-level file for that ST_CASE. It appends variables from the vehicle-level file or non-transport-vehicle-level for that ST_CASE and VEH_NO (i.e., the VEH_NO of the vehicle that the occupant was riding in or that struck the non-occupant). The 2012 FARS no longer has the IMPACT2 variable (principal damage location). To establish continuity with earlier years, another file called *IMP20*, created by a program called CRSH_TEST3 helps impute an IMPACT2 based on the IMPACT1 and MDAREAS variables on 2012 FARS. LS2014CR1 uses a file called *FARS_A21* created by NHTSA's VIN-decode programs, to append the make-model codes, vehicle type, information about outboard front seat belts, frontal air bags, and curtain/side air bags for all the MY 1981-to-2011 cars and MY 1985-to-2011 LTVs that these programs consider to have fully valid VINs. If the ST_CASE and VEH_NO are not on *FARS_A21*, it defines the vehicle type based on the first three characters of the VIN, if possible, and otherwise on the BODY_TYP. If the crash involved two vehicles, it appends information on the other vehicle; furthermore, if the other vehicle is a tractor-trailer, it appends additional data elements relevant to conspicuity tape, such as what part of the tractor-trailer was hit.

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[620] On that day FARS had been complete for the full year 2012 for some time, but selected cases may still be revised in the future.

[621] Kahane (2004, October), Appendix A.

LS2014CR2 creates *LSM2014B* from *LSM2014A*. Both are files of 1,625,528 fatality cases, but the new file adds information, when possible, for some vehicles that did not have fully decoded VINs on *FARS_A21*: (1) vehicles where the FARS variable MOD_YR does not agree with the tenth character of the VIN, but the remainder of the VIN is plausible (in which case, MOD_YR is replaced by the VIN-based MY); (2) not-in-transport vehicles; (3) vehicles for which FARS has a MAK_MOD but no VIN; and (4) MY 2012 and 2013 vehicles. Based on the decoded VIN or MAK_MOD, the program defines, to the extent possible, make-model codes and information on belts and air bags comparable to *FARS_A21*. For car/LTV occupant fatalities in FARS after 1992, the make-model is completely unknown in only 0.3 percent of the cases.

LS2014CR3 uses *LSM2014B* (for CY 1986 to 2012) and the *LSM2004* file created for the 2004 report (for CY 1975 to 1985) to generate *LSM2014C*, the main analysis file. It is still a census of 1,625,528 fatality cases. The program adds information on whether vehicles (MY 1992 and later) certify to the upgrades of FMVSS Nos. 201, 214, and 301; and if they have ESC, pretensioners and load limiters, sled-certified air bags, or advanced air bags. If any of these parameters are entirely unknown for a make-model in a particular MY, LS2014 will assume they are not equipped with it; if it is unknown for a specific vehicle but the percentage optionally equipped is known for that make-model and MY (e.g., for ESC), LS2014 will use that percentage as the probability the vehicle is so equipped.

LS2014 is the main program that:

- Selects the fatality cases from *LSM2014C* that were occupants of cars, occupants of LTVs, non-occupants struck by cars /LTVs, or motorcyclists struck by cars/LTVs.
- Adjusts for missing data on vehicle type or vehicle MY.
- Replaces each case with unknown impact type, seating position or belt/safety seat use by a set of cases, one for each possible value of those variables, weighted by the probability of occurrence of that value – based on analyses of the distribution of these variables, when they are known, as a function of other variables on the file.
- “Removes” the safety technologies from each case vehicle, one-by-one, in the reverse chronological order that they were installed, calculating the increase in the fatality risk, if any, as a consequence.
- Tallies, for the entire file, the number of additional fatalities there would have been if none of the vehicles had been equipped with any safety technologies, and apportions the additional fatalities by safety standard/technology, by vehicle type, by CY (1975 to 2012), and by whether the technology was mandated by a standard already in effect or was voluntarily furnished by the manufacturer at the time the vehicle was built.

LS2014 includes both the “preprocessor” and the “main model” described in the “Summary of the Estimation Method” chapter of Part 2 of this report. Before LS2014 can be successfully operated, it is necessary to run nine auxiliary programs that provide the information the preprocessor needs to adjust or distribute the unknowns.

LS_UNK14 finds the proportion of cases in each CY where the case vehicle type and/or its model year are unknown, and it develops the factors to adjust the weights of the remaining cases after these cases are deleted from the analysis.

MC_ESC14 considers motorcyclist fatalities in two-vehicle crashes. If the other vehicle is a car or LTV, it identifies (1) if the car or LTV is culpable and (2) if it is equipped with ESC (yes, no, or optional percentage). It creates *MCESC*, which has a variable CULP_ESC if the car or LTV was culpable and it had standard or optional ESC. CULP_ESC = 1 if ESC was standard, otherwise it is the percentage of that make-model and MY equipped with optional ESC.

L_CRSH14 creates four files, *NEWCRSH1*, *NEWCRSH2*, *NEWCRSH3* and *NEWCRSH4* that state the probability distribution of CY 2003-to-2012 fatalities by crash type/impact location as a function of other variables. LS2014 will use these files, as well as the files *CRSH1*, *CRSH2*, *CRSH3* and *CRSH4* developed in the previous report for CY 1975-to-2002 fatalities to impute crash type/impact locations on *LSM2014C* cases where they are unknown. For example in single-vehicle crashes, a multinomial logistic regression (CATMOD) calibrates the probability that the crash type/impact location was frontal, side, rollover or rear/other as a function of the specific object struck, the vehicle type, the occupant's age, and the occupant's ejection status, based on cases where everything is known, and it stores these probabilities in *NEWCRSH1*.

L_SEAT14 creates a file, *NEWSEAT1* that states the probability distribution, calibrated by CATMOD, of CY 2003-to-2012 passenger fatalities by seating position as a function of the passenger's age, the vehicle type and the crash type/impact location. LS2014 will use this file, as well as the file *SEAT1* developed in the previous report for CY 1975-to-2002 fatalities, to impute seating positions when they are completely unknown, or when they are just partially known (e.g., front seat, unknown location).

L3PT14 is a binomial logistic regression (PROC LOGIST) of belt use by outboard front seat occupants 6 years or older in vehicles with integral 3-point belts (including automatic 3-point belts) at the outboard front seating positions, for fatality cases in CY 2003 to 2012 where the belt use is not reported as "unknown." It calibrates belt use (yes or no) as a function of the CY, the occupant's age and gender, the vehicle type, vehicle age, crash type/impact location, and seating position (driver or RF). The regression equation is copied into LS2014, where it will impute the belt use of occupants for whom it is unknown on 2003-to-2012 FARS. L3PT4 is the corresponding program to impute belt use in the previous report and it is still used for 1975-to-2002 FARS.

LBK3PT14 similarly calibrates belt use from 2003 to 2012 for outboard rear seat passengers and center rear seat passengers age 6+, in vehicles with integral 3-point belts at the applicable seating position, as a function of the CY, the occupant's age and gender, the vehicle type, vehicle age, crash type/impact location, and seating position (outboard or center). LBK3PT4 from the previous report is used to impute belt use from 1975 to 2002.

L2PT14 calibrates use of automatic 2-point shoulder belts from 2003 to 2012 at the outboard front seats for occupants age 6+, as a function of the type of automatic 2-point belt (motorized or non-motorized), the occupant's age and gender, the vehicle age, crash type/impact location, and seating position (driver or RF). The analysis does not investigate whether the manual lap belt, if one exists, was also used. L2PT4 from the previous report imputes automatic belt use up to CY 2002.

L_LAP14 calibrates belt use from CY 2003 to 2012 of occupants age 6+ at seating positions equipped with lap belts only or with separate lap and shoulder belts (center front in all model years; outboard front, outboard rear and center rear before the shift to integral 3-point belts), as a function of the CY, the occupant's age and gender, the vehicle type, vehicle age, crash type/impact location, and seating position (driver, center front, right front, outboard rear, or center rear). In the cars with separate lap and shoulder belts, it merely calibrates if any belt was used, and it does not distinguish between the lap belt, the shoulder belt, or both. L_LAP4 from the previous report imputes lap belt use from CY 1975 to 2002.

LKIDRES14 comprises two logistic regressions and performs two calibrations of restraint systems use from CY 2003 to 2012 by child passengers 0 to 5 years old. The first regression, excluding only the passengers whose restraint use was completely unknown (codes 9 and 99), calibrates the proportion that used any type of restraint (belts, safety seats, or "used, type not specified") versus no restraint at all. The second regression, limited to restrained children where the type of restraint was also known, calibrates the proportion in safety seats versus belts. Both regression equations, as well as those from the three preceding programs, are copied into LS2004. LKIDRES4 from the previous report performs the two corresponding logistic regressions for CY 1975 to 2002 and imputes restraint use.

OLDFA24, a program already written for the 2004 report, is the postprocessor that estimates lives saved in CY 1960 to 1974. It uses information from *Accident Facts* and other programs written in 2004 to estimate:

- How many fatalities there would have been on FARS in each calendar year, from 1960 to 1974, if FARS had existed.
- How many of them would have been car occupants, LTV occupants, or non-occupants and motorcyclists struck by cars or LTVs.
- The model-year distribution of the cars and LTVs in these crashes and, for the occupant fatalities, their distribution by the vehicle's impact location/crash type and whether or not the occupant was ejected.
- How many of the occupants were belted and how many of the vehicles were equipped with the various safety technologies that existed before 1975.

Having created these hypothetical populations of fatal crash cases, OLDFA24 runs through the same model as LS2014, removing the safety technologies from the case vehicles in the reverse chronological order that they were installed, calculating the increase in the fatality risk, if any, as a consequence, and tallying the number of additional fatalities there would have been if none of the vehicles had been equipped with any safety technologies in 1960-74.

LIFE6012 combines the estimates from LS2014 and OLDFA24 to provide a single printout of the lives saved, year-by-year, from 1960 through 2012, apportioned by FMVSS/technology, by vehicle type, and by whether the technology was mandated by a standard already in effect or was voluntarily furnished by the manufacturer at the time the vehicle was built. LIFE6012 needs to run immediately after LS2014 and OLDFA24 (without closing SAS).

TRND6012 computes occupant fatality rates per 100,000,000 VMT, based on VMT totals derived from *Traffic Safety Facts 2011, Traffic Safety Facts Research Note: 2012 Motor Vehicle Crashes*, and *Accident Facts*. It also generates all the graphs in this report.

FMVSS_PCT generates the tables in Appendix C showing the percentage of new vehicles by MY and the percentage of vehicles on the road by CY equipped with various technologies. (NCNA2084, a program written for the 2004 report, helps generate information used in FMVSS_PCT for the early belt technologies, based on NCSS and NASS data.) FMVSS_PCT identifies the median installation years for the various safety technologies. It confirmed that they are listed in the correct reverse-chronological order in LS2014. FMVSS_PCT needs to run soon after LS2014 (without closing SAS).

This overview is followed by a complete listing, with commentary, of the SAS program LS2014. A complete listing and commentary for the program OLDFA24 may be found on pp. 357-395 of NHTSA's 2004 report (available at www-nrd.nhtsa.dot.gov/Pubs/809833.PDF).[622] All the other programs are much shorter, generally self-explanatory, or are discussed within the commentary on LS2014.

[622] Kahane (2004, October).

DESCRIPTION OF THE MAIN ANALYSIS PROGRAM LS2014

Files used to run this program (file locations entered into ‘ ‘ depend on the computer system where the program will be run):

```
LIBNAME LIBRARY ' ‘;
LIBNAME LSM2014C ' ';
LIBNAME MCESC ' ';
LIBNAME CRSH1 ' ';
LIBNAME CRSH2 ' ';
LIBNAME CRSH3 ' ';
LIBNAME CRSH4 ' ';
LIBNAME NEWCRSH1 ' ';
LIBNAME NEWCRSH2 ' ';
LIBNAME NEWCRSH3 ' ';
LIBNAME NEWCRSH4 ' ';
LIBNAME SEAT1 ' ';
LIBNAME NEWSEAT1 ' ';

OPTION NOCENTER NOFMTERR OBS=5000000 LS=210 PAGESIZE=68;
/* PROGRAM NAME: LS2014.SAS                    UPDATED: 01/24/2014 */
/* LIVES SAVED BY FMVSS IN 1975-2012, CARS, LTVs, PEDS, MOTORCYCLES */
```

Codes for impact location/crash type (CRSH):

```
PROC FORMAT; VALUE CRSH 1='FRONTAL' 2='SIDE IMPACT'
 3='ROLLOVER (PRIMARY)' 4='REAR & OTHER' 9='UNKNOWN';
```

Codes for vehicle type:

```
PROC FORMAT; VALUE VTYP 1='PASSENGER CAR' 2='LTV' 3='BIG TRUCK, BUS'
 4='MOTORCYCLE' 5='OTHER' 9='UNKNOWN';

PROC FORMAT; VALUE CYGP 1='1975-81' 2='1982-90' 3='1991-2012';
PROC FORMAT; VALUE MY 1900-1954='PRE-1955' 9999='UNKNOWN';
```

Codes for streamlined seating position variable (SEAT2):

```
PROC FORMAT; VALUE NEWSEAT 11='DRIVER' 12='CENTER FRONT' 13='RIGHT FRONT' 18='OTHER FRONT'
 19='UNK FRONT' 21='OUTBOARD REAR' 22='CENTER REAR' 28='OTHER REAR'
 29='UNK REAR' 51='OTHER ENCLOSED' 52='UNENCLOSED' 99='UNK PASSENGER';

PROC FORMAT; VALUE NEWVTYP 1='CONVERTIBLE' 2='2-DOOR CAR' 4='4-DOOR CAR'
 6='STATION WAGON' 9='CAR, UNK STYLE'
 11='PICKUP TRUCK' 12='S U V' 13='VAN' 19='TRUCK, UNK STYLE';
```

Codes for streamlined restraint use variables (REST2 and REST3):

```
PROC FORMAT; VALUE NEWREST 0='UNRESTRAINED' 1='SHOULDER BELT ONLY' 2='LAP BELT ONLY'
 3='LAP+SHOULDER BELT' 4='CHILD SAFETY SEAT' 7='2-PT AUTOMATIC BELT'
 8='USED, TYPE NOT SPECIFIED' 99='UNKNOWN IF USED';
```

Special codes for analysis of air bags and child passengers:

```
PROC FORMAT; VALUE KCRSH 1='12:00 IMPACT1 OR 2' 2='11,1:00' 3='10,2:00' 4='NONFRONTAL';
PROC FORMAT; VALUE RESTGP 1='INFANT IN CRD' 2='INFANT NOT IN CRD'
 3='AGE 1-5 UNRESTRAINED' 4='AGE 1-5 IN CRD' 5='AGE 1-5 BELTED'
 6='AGE 6-10 UNRESTRAINED' 7='AGE 6-10 BELTED'
 8='AGE 11-12 UNRESTRAINED' 9='AGE 11-12 BELTED';
RUN;
```

The preprocessor section of LS2014 starts here. Selects from *LSM2014C*, the census of fatality cases, those fatalities that were occupants of cars or LTVs (OCC1), non-occupants struck by cars or LTVs (PED1) or motorcyclists struck by cars or LTVs (MC1).

```
/* ------------------------------------------------------------------------ */
/* ------------------------------------------------------------------------ */
/* SUBDIVIDES THE FATALITIES INTO (1) OCCUPANTS OF CARS/LTVs                */
/* (2) NONOCCUPANTS KILLED BY CARS/LTVS (3) MOTORCYCLISTS KILLED BY CAR/LTVs */
/* ADJUSTS ALL NUMBERS UPWARD FOR MISSING DATA ON VEHICLE TYPE OR MODEL YEAR */
/* MY = 0-9 IN CY < 1982 ARE HIGHLY SUSPECT AND WILL BE CONSIDERED MISSING   */
/* ------------------------------------------------------------------------ */
/* ------------------------------------------------------------------------ */

DATA OCC1(KEEP=ORIGWT WEIGHTFA CY MY VTYP IMPACT1 IMPACT2 ROLLOVER HARM_EV MAN_COLL
 BOD2 TRKTYP BODY_TYP V1-V8 AGE SEX VE_FORMS CYGP NEWVTYP EJECTION
 SEAT_POS REST_USE AUT_REST PER_TYP LGT_COND CRSH PASSIVE MAK2 MM2 CG
 MAKE MAK_MOD PER_NO OVTYP OIMPACT2 OVCONFIG STATE MONTH M_HARM TAPECASE
 AIR_BAG BELT22 BOD3 CAC CURT_TORS DR_CF1 DR_CF2 DR_CF3 DR_CF4 DR_SF1 DR_SF2 DR_SF3 DR_SF4
 ESC FIRE_EXP FMVSS201 FMVSS214 FMVSS301 MAK3 MM3 MY_FARS NEW_COMBO NEW_CURTAIN NEW_TORSO
 PRETENLL P_CRASH1 REDES ROLLCURT VEH_MAN VE_TOTAL XBOD2 XMAK2 XMM2 XMY TRAV_SP)
 PED1(KEEP=ORIGWT WEIGHTFA CY XMY VTYP)
 MC1(KEEP=ORIGWT WEIGHTFA CY ST_CASE VEH_NO OMY OVTYP);
SET LSM2014C.LSM2014C;
```

Deletes cases with unknown vehicle type, unknown model year, or that did not involve a car/LTV.

Note: XMY is the "working" model year on LSM2014C and it is the one that will be used throughout this program. Similarly, XMM2 is the working make-model variable on that file.

```
IF VTYP=. THEN VTYP=9;
IF VTYP IN (1,2) OR (VTYP=4 AND OVTYP IN (1,2));
IF VTYP IN (1,2) AND (XMY GT CY+1 OR XMY=9999 OR 0 LE XMY LE 1909) THEN DELETE;
IF VTYP=4 AND (OMY GT CY+1 OR OMY=9999 OR OMY=. OR 0 LE OMY LE 1909) THEN DELETE;

IF VTYP=4 THEN GOTO MCWATE;
IF PER_TYP IN (1,2,9) THEN GOTO OCCWATE;

/* DELETE (AND ADJUST FOR) PARKED-VEHICLE OCC IN CY 1975-2004 SINCE VTYP/MY UNKNOWN */
IF (CY LE 1981 AND PER_TYP=5) OR (CY IN (1982:2004) AND PER_TYP=3) THEN DELETE;

/* ------------------------------------------------------------------------ */
/* ADJUSTMENT FACTORS FOR NONOCCUPANTS - OBTAINED BY RUNNING LS_UNK14       */
/* ------------------------------------------------------------------------ */
```

Creates the two weight-factor variables, ORIGWT and WEIGHTFA that will stay with each fatality case as it proceeds through the model. ORIGWT is the original weight assigned to each fatality case. WEIGHTFA is the inflated weight denoting how many fatalities there would have been if safety technologies were removed from the vehicle. Throughout the preprocessor, WEIGHTFA = ORIGWT.

Having deleted all the cases with unknown vehicle type or model year, must give all the remaining cases an ORIGWT higher than 1, so that the ORIGWTs will add up to the original fatality count, including an allowance for all cases deleted due to missing XMY, and an allowance for a portion of the cases with unknown vehicle type – as computed by the program LS_UNK14.

For example, suppose there are 10,000 fatality cases in cars/LTVs with known MY, 100 cases in cars/LTVs with unknown MY, and 200 fatality cases in vehicles of unknown type. Assume also that, when the vehicle type is known, 80 percent are cars/LTVs and 20 percent are heavy trucks, motorcycles or other known types. Then the inflation factor computed by LS_UNK14 would be:

$$[10{,}000 + 100 + (.80\text{x}200)] / 10{,}000 = 1.026$$

The vehicle's model year or type is unknown in 9-19 percent of pedestrian crashes, primarily because many of them are hit-and-run.

```
IF CY=1975 THEN WEIGHTFA=1.15080; ELSE IF CY=1976 THEN WEIGHTFA=1.16331;
 ELSE IF CY=1977 THEN WEIGHTFA=1.16595; ELSE IF CY=1978 THEN WEIGHTFA=1.16998;
 ELSE IF CY=1979 THEN WEIGHTFA=1.17921; ELSE IF CY=1980 THEN WEIGHTFA=1.18698;
 ELSE IF CY=1981 THEN WEIGHTFA=1.20951; ELSE IF CY=1982 THEN WEIGHTFA=1.13142;
 ELSE IF CY=1983 THEN WEIGHTFA=1.11566; ELSE IF CY=1984 THEN WEIGHTFA=1.11156;
 ELSE IF CY=1985 THEN WEIGHTFA=1.12026; ELSE IF CY=1986 THEN WEIGHTFA=1.11675;
 ELSE IF CY=1987 THEN WEIGHTFA=1.11661; ELSE IF CY=1988 THEN WEIGHTFA=1.11150;
 ELSE IF CY=1989 THEN WEIGHTFA=1.12336; ELSE IF CY=1990 THEN WEIGHTFA=1.11176;
 ELSE IF CY=1991 THEN WEIGHTFA=1.11633; ELSE IF CY=1992 THEN WEIGHTFA=1.10640;
 ELSE IF CY=1993 THEN WEIGHTFA=1.10764; ELSE IF CY=1994 THEN WEIGHTFA=1.10666;
 ELSE IF CY=1995 THEN WEIGHTFA=1.10142; ELSE IF CY=1996 THEN WEIGHTFA=1.10452;
 ELSE IF CY=1997 THEN WEIGHTFA=1.09975; ELSE IF CY=1998 THEN WEIGHTFA=1.09372;
 ELSE IF CY=1999 THEN WEIGHTFA=1.09176; ELSE IF CY=2000 THEN WEIGHTFA=1.09530;
 ELSE IF CY=2001 THEN WEIGHTFA=1.10463; ELSE IF CY=2002 THEN WEIGHTFA=1.10775;
 ELSE IF CY=2003 THEN WEIGHTFA=1.10558; ELSE IF CY=2004 THEN WEIGHTFA=1.10881;
 ELSE IF CY=2005 THEN WEIGHTFA=1.11887; ELSE IF CY=2006 THEN WEIGHTFA=1.11554;
 ELSE IF CY=2007 THEN WEIGHTFA=1.10483; ELSE IF CY=2008 THEN WEIGHTFA=1.10672;
 ELSE IF CY=2009 THEN WEIGHTFA=1.09630; ELSE IF CY=2010 THEN WEIGHTFA=1.09645;
 ELSE IF CY=2011 THEN WEIGHTFA=1.09908; ELSE IF CY=2012 THEN WEIGHTFA=1.09269;
 ORIGWT=WEIGHTFA;
 OUTPUT PED1; RETURN;

/* ------------------------------------------------------------------------ */
/* ADJUSTMENT FACTORS FOR MOTORCYCLISTS - OBTAINED BY RUNNING LS_UNK14       */
/* ------------------------------------------------------------------------ */

MCWATE: IF CY=1975 THEN WEIGHTFA=1.03029; ELSE IF CY=1976 THEN WEIGHTFA=1.03235;
 ELSE IF CY=1977 THEN WEIGHTFA=1.02838; ELSE IF CY=1978 THEN WEIGHTFA=1.01218;
 ELSE IF CY=1979 THEN WEIGHTFA=1.00780; ELSE IF CY=1980 THEN WEIGHTFA=1.00795;
 ELSE IF CY=1981 THEN WEIGHTFA=1.01466; ELSE IF CY=1982 THEN WEIGHTFA=1.01772;
 ELSE IF CY=1983 THEN WEIGHTFA=1.01923; ELSE IF CY=1984 THEN WEIGHTFA=1.02307;
 ELSE IF CY=1985 THEN WEIGHTFA=1.02295; ELSE IF CY=1986 THEN WEIGHTFA=1.01925;
 ELSE IF CY=1987 THEN WEIGHTFA=1.02438; ELSE IF CY=1988 THEN WEIGHTFA=1.01733;
 ELSE IF CY=1989 THEN WEIGHTFA=1.01430; ELSE IF CY=1990 THEN WEIGHTFA=1.02179;
 ELSE IF CY=1991 THEN WEIGHTFA=1.02657; ELSE IF CY=1992 THEN WEIGHTFA=1.00806;
 ELSE IF CY=1993 THEN WEIGHTFA=1.01338; ELSE IF CY=1994 THEN WEIGHTFA=1.01456;
 ELSE IF CY=1995 THEN WEIGHTFA=1.01058; ELSE IF CY=1996 THEN WEIGHTFA=1.01134;
 ELSE IF CY=1997 THEN WEIGHTFA=1.01541; ELSE IF CY=1998 THEN WEIGHTFA=1.01121;
 ELSE IF CY=1999 THEN WEIGHTFA=1.01471; ELSE IF CY=2000 THEN WEIGHTFA=1.01026;
 ELSE IF CY=2001 THEN WEIGHTFA=1.01652; ELSE IF CY=2002 THEN WEIGHTFA=1.01278;
 ELSE IF CY=2003 THEN WEIGHTFA=1.01447; ELSE IF CY=2004 THEN WEIGHTFA=1.01478;
 ELSE IF CY=2005 THEN WEIGHTFA=1.01976; ELSE IF CY=2006 THEN WEIGHTFA=1.01166;
 ELSE IF CY=2007 THEN WEIGHTFA=1.01797; ELSE IF CY=2008 THEN WEIGHTFA=1.00905;
 ELSE IF CY=2009 THEN WEIGHTFA=1.01489; ELSE IF CY=2010 THEN WEIGHTFA=1.01409;
 ELSE IF CY=2011 THEN WEIGHTFA=1.01328; ELSE IF CY=2012 THEN WEIGHTFA=1.01986;
 ORIGWT=WEIGHTFA;
 OUTPUT MC1; RETURN;

/* ------------------------------------------------------------------------ */
/* ADJUSTMENT FACTORS FOR CAR/LTV OCCUPANTS - OBTAINED BY RUNNING LS_UNK14   */
/* INCLUDES OCCUPANTS OF PARKED VEHICLES UNTIL CY 2004                      */
/* ------------------------------------------------------------------------ */
```

In recent years, the vehicle type and model year have been known in well over 99 percent of the occupant fatality cases on FARS.

```
OCCWATE: IF CY=1975 THEN WEIGHTFA=1.02596; ELSE IF CY=1976 THEN WEIGHTFA=1.02452;
 ELSE IF CY=1977 THEN WEIGHTFA=1.02496; ELSE IF CY=1978 THEN WEIGHTFA=1.01685;
 ELSE IF CY=1979 THEN WEIGHTFA=1.01236; ELSE IF CY=1980 THEN WEIGHTFA=1.01104;
 ELSE IF CY=1981 THEN WEIGHTFA=1.01537; ELSE IF CY=1982 THEN WEIGHTFA=1.01228;
 ELSE IF CY=1983 THEN WEIGHTFA=1.00685; ELSE IF CY=1984 THEN WEIGHTFA=1.00814;
 ELSE IF CY=1985 THEN WEIGHTFA=1.01133; ELSE IF CY=1986 THEN WEIGHTFA=1.00816;
 ELSE IF CY=1987 THEN WEIGHTFA=1.00888; ELSE IF CY=1988 THEN WEIGHTFA=1.00633;
 ELSE IF CY=1989 THEN WEIGHTFA=1.00794; ELSE IF CY=1990 THEN WEIGHTFA=1.00637;
 ELSE IF CY=1991 THEN WEIGHTFA=1.00580; ELSE IF CY=1992 THEN WEIGHTFA=1.00435;
 ELSE IF CY=1993 THEN WEIGHTFA=1.00641; ELSE IF CY=1994 THEN WEIGHTFA=1.00494;
 ELSE IF CY=1995 THEN WEIGHTFA=1.00546; ELSE IF CY=1996 THEN WEIGHTFA=1.00640;
 ELSE IF CY=1997 THEN WEIGHTFA=1.00619; ELSE IF CY=1998 THEN WEIGHTFA=1.00470;
 ELSE IF CY=1999 THEN WEIGHTFA=1.00450; ELSE IF CY=2000 THEN WEIGHTFA=1.00394;
 ELSE IF CY=2001 THEN WEIGHTFA=1.00405; ELSE IF CY=2002 THEN WEIGHTFA=1.00505;
```

```
 ELSE IF CY=2003 THEN WEIGHTFA=1.00517; ELSE IF CY=2004 THEN WEIGHTFA=1.00425;
 ELSE IF CY=2005 THEN WEIGHTFA=1.00523; ELSE IF CY=2006 THEN WEIGHTFA=1.00359;
 ELSE IF CY=2007 THEN WEIGHTFA=1.00271; ELSE IF CY=2008 THEN WEIGHTFA=1.00223;
 ELSE IF CY=2009 THEN WEIGHTFA=1.00297; ELSE IF CY=2010 THEN WEIGHTFA=1.00287;
 ELSE IF CY=2011 THEN WEIGHTFA=1.00335; ELSE IF CY=2012 THEN WEIGHTFA=1.00360;
 ORIGWT=WEIGHTFA;

/* DEFINES THE CRASH CONFIGURATION      */
```

The CRSH variable (1 = frontal, 2 = side, 3 = rollover, 4 = rear/other) is critically important because the effectiveness of many of the safety technologies varies by crash type. First-harmful-event fires, immersions and other non-collision types are included in the rear/other category. If the principal impact (IMPACT2) is unknown, rely on the initial impact (IMPACT1). Some FARS variables have been added, deleted, or changed over the years. CRSH is defined so as to preserve continuity. The fractional values of IMPACT2 (e.g., 8.5) exist only in 2012, where there is no IMPACT2 in FARS, just an imputed value that sometimes falls halfway between two clock points.

```
IF IMPACT2=13 OR HARM_EV=1 OR (CY=2012 AND IMPACT2=24 AND ROLLOVER IN (1,2,9))   THEN CRSH=3;
  ELSE IF 2 LE HARM_EV LE 6           THEN CRSH=4;
  ELSE IF 5 LE IMPACT2 LE 7           THEN CRSH=4;
  ELSE IF IMPACT2 IN (8,8.5,9,9.5,10,26,61:63)  THEN CRSH=2;   /* NEW VALUES OF IMPACT2 FOR SIDE IMPACTS START-
ING 2010 */
  ELSE IF IMPACT2 IN (2,2.5,3,3.5,4,81:83)      THEN CRSH=2;
  ELSE IF IMPACT2 IN (.5,1,11,11.5,12)   THEN CRSH=1;  /* NEW VALUES OF IMPUTED IMPACT2 STARTING 2012 */
  ELSE IF HARM_EV=7                   THEN CRSH=4;
  ELSE IF IMPACT1=13                  THEN CRSH=3;
  ELSE IF 5 LE IMPACT1 LE 7           THEN CRSH=4;
  ELSE IF IMPACT1 IN (8:10,61:63)     THEN CRSH=2;
  ELSE IF IMPACT1 IN (2:4,81:83)      THEN CRSH=2;
  ELSE IF IMPACT1 IN (1,11,12)        THEN CRSH=1;

/*  (HEAD-ON COLLISION INVOLVMENTS ARE ASSUMED TO BE FRONTAL IMPACTS) */
  ELSE IF MAN_COLL=2                  THEN CRSH=1;

  ELSE                              CRSH=9;

/* DEFINES THE CALENDAR YEAR GROUPS (MAJOR CHANGES IN FARS DATA DEFINITIONS) */
IF 1975 LE CY LE 1981 THEN CYGP=1;
  ELSE IF 1982 LE CY LE 1990 THEN CYGP=2;
  ELSE IF CY GE 1991 THEN CYGP=3;

/* DEFINES THE VEHICLE BODY TYPE (N OF CAR DOORS, PICKUP, SUV, VAN)   */
IF VTYP=1 THEN DO;
IF BOD2 IN (1,2,4,6,9) THEN NEWVTYP=BOD2;
  ELSE IF BOD2 IN (3,7) THEN NEWVTYP=2;
  ELSE IF BOD2 IN (5,8) THEN NEWVTYP=4;
  ELSE IF CYGP=1 THEN DO;
    IF BODY_TYP IN (1,2,6,9) THEN NEWVTYP=BODY_TYP;
    ELSE IF BODY_TYP=3 THEN NEWVTYP=4; ELSE NEWVTYP=9; END;
  ELSE IF CYGP IN (2,3) THEN DO;
    IF BODY_TYP IN (1,2,4,6,9) THEN NEWVTYP=BODY_TYP;
    ELSE IF BODY_TYP=3 THEN NEWVTYP=2;
        ELSE IF CY GE 2010 AND BODY_TYP=17 THEN NEWVTYP=2;
    ELSE IF BODY_TYP=5 THEN NEWVTYP=4; ELSE NEWVTYP=9; END; END;

ELSE IF VTYP=2 THEN DO;
IF TRKTYP IN (1,2) THEN NEWVTYP=11;
  ELSE IF TRKTYP IN (3,4) THEN NEWVTYP=12;
  ELSE IF TRKTYP IN (5,6) THEN NEWVTYP=13;
  ELSE IF TRKTYP IN (7,8,9) THEN NEWVTYP=19;
  ELSE IF CYGP=1 THEN DO;
    IF BODY_TYP=50 THEN NEWVTYP=11;
    ELSE IF BODY_TYP IN (43,52) THEN NEWVTYP=12;
    ELSE IF BODY_TYP=51 THEN NEWVTYP=13; ELSE NEWVTYP=19; END;
  ELSE IF CYGP=2 THEN DO;
    IF BODY_TYP IN (50,51) THEN NEWVTYP=11;
    ELSE IF BODY_TYP IN (12,55,56) THEN NEWVTYP=12;
    ELSE IF BODY_TYP=40 THEN NEWVTYP=13; ELSE NEWVTYP=19; END;
```

```
  ELSE IF CYGP=3 THEN DO;
    IF BODY_TYP IN (30,31,32,39) THEN NEWVTYP=11;
    ELSE IF BODY_TYP IN (14,15,16,19) THEN NEWVTYP=12;
    ELSE IF BODY_TYP IN (20,21) THEN NEWVTYP=13; ELSE NEWVTYP=19; END; END;
OUTPUT OCC1;
RUN;
```

Next is the main analysis section for non-occupant fatalities: pedestrians, bicyclists and other non-motorists that were struck by cars or LTVs. Two safety technologies, dual master cylinders (105A) and front disc brakes (105B) saved non-occupant lives because they enabled car/LTV drivers to avoid hitting the non-occupants. The model is simpler here because it involves just those two technologies, but the setup is basically the same as for car and LTV occupant fatalities.

```
/* ------------------------------------------------------------------ */
/* ------------------------------------------------------------------ */
/* ANALYZES EFFECT OF BRAKE IMPROVEMENTS ON NONOCCUPANT FATALITIES    */
/* ------------------------------------------------------------------ */
/* ------------------------------------------------------------------ */

DATA PED2; SET PED1;
/* IMPLEMENTATION OF FRONT DISC BRAKES IN THE VEHICLES THAT HIT THESE PEDESTRIANS */
```

Proceed in reverse chronological order: disc brakes first because they were installed later. Ideally, we should determine if the vehicle (that hit the pedestrian) was equipped with front disc brakes. However, we do not know whether specific vehicles were equipped or not equipped. We only know, based on the vehicle's model year, what percent of vehicles were equipped in that model year. PS105B + PV105B is the percentage of vehicles, in any given model year, that had front disc brakes; PS105B are the installations after FMVSS No. 105 was amended, effective January 1, 1976 in cars and September 1, 1983, in LTVs, to include performance tests most easily met with disc brakes; PV105B are any disc-brake installations before the standard was amended. PS = "proportion, standard" PV = "proportion voluntary"

```
 IF XMY GE 1984 THEN DO; PS105B=1; PV105B=0; END;
  ELSE IF XMY LE 1964 THEN DO; PS105B=0; PV105B=0; END;
  ELSE IF XMY=1965 THEN DO; PS105B=0; PV105B=.02; END;
  ELSE IF XMY=1966 THEN DO; PS105B=0; PV105B=.03; END;
  ELSE IF XMY=1967 THEN DO; PS105B=0; PV105B=.06; END;
  ELSE IF XMY=1968 THEN DO; PS105B=0; PV105B=.13; END;
  ELSE IF XMY=1969 THEN DO; PS105B=0; PV105B=.28; END;
  ELSE IF XMY=1970 THEN DO; PS105B=0; PV105B=.41; END;
  ELSE IF XMY=1971 THEN DO; PS105B=0; PV105B=.63; END;
  ELSE IF XMY=1972 THEN DO; PS105B=0; PV105B=.74; END;
  ELSE IF XMY=1973 THEN DO; PS105B=0; PV105B=.86; END;
  ELSE IF XMY=1974 THEN DO; PS105B=0; PV105B=.84; END;
  ELSE IF XMY=1975 THEN DO; PS105B=0; PV105B=.93; END;
  ELSE IF XMY=1976 AND CY=1975 THEN DO; PS105B=0; PV105B=.99; END;
  ELSE IF XMY=1976 AND VTYP=1 THEN DO; PS105B=.50; PV105B=.49; END;
  ELSE IF XMY=1976 AND VTYP=2 THEN DO; PS105B=0; PV105B=.99; END;
  ELSE IF 1977 LE XMY LE 1983 AND VTYP=1 THEN DO; PS105B=1; PV105B=0; END;
  ELSE IF 1977 LE XMY LE 1983 AND VTYP=2 THEN DO; PS105B=0; PV105B=1; END;
```

Thus, for example, in MY 1971, PV105B = .63 because 63 percent of cars (and we assume also LTVs) were equipped with front disc brakes, voluntarily, before the amendment to FMVSS No. 105. Note that PV105B > 0 even in MY 1976, because nearly half of MY 1976 cars were produced before January 1,1976.

```
/* IMPLEMENTATION OF DUAL MASTER CYLINDERS IN THE VEHICLES THAT HIT THESE PEDESTRIANS */
 IF XMY GE 1984 THEN DO; PS105A=1; PV105A=0; END;
  ELSE IF XMY LE 1961 THEN DO; PS105A=0; PV105A=0; END;
  ELSE IF XMY IN (1962,1963) THEN DO; PS105A=0; PV105A=.09; END;
  ELSE IF XMY IN (1964,1965) THEN DO; PS105A=0; PV105A=.07; END;
  ELSE IF XMY=1966 THEN DO; PS105A=0; PV105A=.54; END;
  ELSE IF XMY=1967 THEN DO; PS105A=0; PV105A=1; END;
```

```
  ELSE IF XMY=1968 AND VTYP=1 THEN DO; PS105A=.5; PV105A=.5; END;
  ELSE IF XMY=1968 AND VTYP=2 THEN DO; PS105A=0; PV105A=1; END;
  ELSE IF 1969 LE XMY LE 1983 AND VTYP=1 THEN DO; PS105A=1; PV105A=0; END;
  ELSE IF 1969 LE XMY LE 1983 AND VTYP=2 THEN DO; PS105A=0; PV105A=1; END;
```

Here is the basic routine for estimating lives saved by a safety technology, specifically non-occupant lives saved by front disc brakes. All effectiveness estimates are derived from NHTSA evaluation reports and discussed in Part 1 of this report. NHTSA's evaluation estimated that front disc brakes reduced fatal crash involvements by 0.17 percent. Effectiveness, E = .0017. P = PS105B + PV105B is the probability that the case vehicle was equipped with front disc brakes (based on its model year). Up to this point in the model, this case has a weight of WEIGHTFA fatalities, renamed OLDWTFA. There would have been OLDWTFA / (1 – E x P) fatalities if the vehicle had no front disc brakes at all rather than a P probability of disc brakes. That becomes the new value of WEIGHTFA. S = OLDWTFA x E x P / (1 – E x P) is the difference between the new WEIGHTFA and the OLDWTFA, and it is the increase in fatalities that would have occurred in the complete absence of front disc brakes. S is apportioned between lives saved by post-standard installations of disc brakes (PLS105B) and voluntary installations of disc brakes (PLV105B). The new value of WEIGHTFA here will become the old value (OLDWTFA) in the next step (dual master cylinders).

PLV105B: "P" = pedestrian, "L" = lives saved, "V" = voluntary, "105B" = front disc brakes

```
/* PEDESTRIAN LIVES SAVED BY FRONT DISC BRAKES */
  OLDWTFA=WEIGHTFA;
  IF PS105B GT 0 OR PV105B GT 0 THEN DO;
    E=.0017;
    P=PS105B+PV105B;
    S=OLDWTFA*E*P / (1 - E*P);
    PLS105B=S*PS105B/P;
    PLV105B=S*PV105B/P;
    WEIGHTFA=OLDWTFA+PLS105B+PLV105B; END;
  ELSE DO; PLS105B=0; PLV105B=0; END;
```

NHTSA's evaluation estimated that dual master cylinders reduced fatal crash involvements by 0.7 percent.

```
/* PEDESTRIAN LIVES SAVED BY DUAL MASTER CYLINDERS */
  OLDWTFA=WEIGHTFA;
  IF PS105A GT 0 OR PV105A GT 0 THEN DO;
    E=.007;
    P=PS105A+PV105A;
    S=OLDWTFA*E*P / (1 - E*P);
    PLS105A=S*PS105A/P;
    PLV105A=S*PV105A/P;
    WEIGHTFA=OLDWTFA+PLS105A+PLV105A; END;
  ELSE DO; PLS105A=0; PLV105A=0; END;
  PLS=PLS105A+PLS105B; PLV=PLV105A+PLV105B;
  PL105A=PLS105A+PLV105A; PL105B=PLS105B+PLV105B; PL=PLS+PLV;
```

At this point, the model has "removed" all applicable safety technologies from the vehicles, and WEIGHTFA indicates the implicit number of non-occupant fatalities in the absence of front disc brakes and dual master cylinders on the case car/LTV.

```
RUN;
```

Adds up the actual fatality cases (ORIGWT), the estimate of how many fatalities there would have been if all safety technologies had been removed from the vehicles (WEIGHTFA), and the lives saved by each technology, by calendar year. PLV = total non-occupant lives saved (voluntary installations). PLS = total non-occupant lives saved (post-standard installations). PL = PLV + PLS = total non-occupant lives saved by all technologies.

```
PROC MEANS SUM NOPRINT DATA=PED2; BY CY;
 VAR ORIGWT WEIGHTFA PLV105B PLS105B PL105B PLV105A PLS105A PL105A PLV PLS PL;
 OUTPUT OUT=PED3
  SUM=P_ORIGWT P_WTFA PLV105B PLS105B PL105B PLV105A PLS105A PL105A PLV PLS PL;
```

Prints out the totals for each calendar year, and the sum for all years, 1975 to 2012.

```
PROC PRINT DATA=PED3;
 FORMAT P_ORIGWT P_WTFA PLV105B PLS105B PL105B PLV105A PLS105A PL105A PLV PLS PL 9.0;
 ID CY; VAR P_ORIGWT P_WTFA PLV105B PLS105B PL105B PLV105A PLS105A PL105A PLV PLS PL;
 SUM P_ORIGWT P_WTFA PLV105B PLS105B PL105B PLV105A PLS105A PL105A PLV PLS PL;
TITLE1 'PEDESTRIANS SAVED BY CAR/LTV DISC BRAKES AND DUAL MASTER CYLINDERS, 1975-2012';
TITLE2 ' ';
TITLE3 '...105B = FRONT DISC BRAKES (MEDIAN INSTALLATION YEAR 1971, FMVSS EFFECTIVE 1/1/76 OR 9/1/83)';
TITLE4 '...105A = DUAL MASTER CYLINDERS (MEDIAN INSTALLATION YEAR LATE 1966, FMVSS EFFECTIVE 1/1/68 OR 9/1/83)';
TITLE5 '...V = VOLUNTARY INSTALLATIONS, BEFORE EFFECTIVE DATE';
TITLE6 '...S = STANDARD INSTALLATIONS, AFTER EFFECTIVE DATE';
TITLE7 'P_ORIGWT = ACTUAL PED/BIKE/NONMOTORIST FATALITIES';
TITLE8 'P_WTFA = FATALITIES THAT WOULD HAVE OCCURRED WITHOUT THESE SAFETY IMPROVEMENTS';
TITLE9 'PL = OVERALL PED/BIKE/NONMOTORIST LIVES SAVED BY BRAKE IMPROVEMENTS IN CARS/LTVs';
RUN;

/* ---------------------------------------------------------------- */
/* ---------------------------------------------------------------- */
/* EFFECT OF CAR/LTV ESC & BRAKE IMPROVEMENTS ON MOTORCYCLIST FATALS  */
/* ---------------------------------------------------------------- */
/* ---------------------------------------------------------------- */
```

Next is the main analysis for motorcyclist fatalities in collisions with cars/LTVs. The model is similar as the one for non-occupants, except that ESC in cars and LTVs reduces collisions with motorcycles and that lives-saved estimates are named “MLV105B” instead of “PLV105B,” etc. (“M” = motorcyclist) OMY = the model year of the car/LTV that hit the motorcycle.

First step is to merge the data with MCESC, the file that indicates if a car or LTV equipped with ESC hit a motorcycle and if that car or LTV was culpable.

```
DATA MC1A; MERGE MC1(IN=MCYCLE) MCESC.MCESC; BY CY ST_CASE; /* ADD INFO ON WHETHER THE CAR/LTV THAT HIT THE MC
HAD ESC & WAS CULPABLE */
IF MCYCLE;
RUN;

DATA MC2; SET MC1A;
/* IMPLEMENTATION OF ESC IN THE VEHICLES THAT HIT THESE MOTORCYCLES */
MS126=0; MV126=0;
IF OMY GE 2009 AND CULP_ESC GT 0 THEN MS126=CULP_ESC; /* GENERAL RULE: PHASE-IN PERIOD ALREADY COUNTS AS "POST-
STANDARD" */
  ELSE IF 1998 LE OMY LE 2008 AND CULP_ESC GT 0 THEN MV126=CULP_ESC;
/* IMPLEMENTATION OF FRONT DISC BRAKES IN THE VEHICLES THAT HIT THESE MOTORCYCLES */
  IF OMY GE 1984 THEN DO; MS105B=1; MV105B=0; END;
    ELSE IF OMY LE 1964 THEN DO; MS105B=0; MV105B=0; END;
    ELSE IF OMY=1965 THEN DO; MS105B=0; MV105B=.02; END;
    ELSE IF OMY=1966 THEN DO; MS105B=0; MV105B=.03; END;
    ELSE IF OMY=1967 THEN DO; MS105B=0; MV105B=.06; END;
    ELSE IF OMY=1968 THEN DO; MS105B=0; MV105B=.13; END;
    ELSE IF OMY=1969 THEN DO; MS105B=0; MV105B=.28; END;
    ELSE IF OMY=1970 THEN DO; MS105B=0; MV105B=.41; END;
    ELSE IF OMY=1971 THEN DO; MS105B=0; MV105B=.63; END;
    ELSE IF OMY=1972 THEN DO; MS105B=0; MV105B=.74; END;
    ELSE IF OMY=1973 THEN DO; MS105B=0; MV105B=.86; END;
    ELSE IF OMY=1974 THEN DO; MS105B=0; MV105B=.84; END;
    ELSE IF OMY=1975 THEN DO; MS105B=0; MV105B=.93; END;
    ELSE IF OMY=1976 AND CY=1975 THEN DO; MS105B=0; MV105B=.99; END;
    ELSE IF OMY=1976 AND OVTYP=1 THEN DO; MS105B=.50; MV105B=.49; END;
    ELSE IF OMY=1976 AND OVTYP=2 THEN DO; MS105B=0; MV105B=.99; END;
    ELSE IF 1977 LE OMY LE 1983 AND OVTYP=1 THEN DO; MS105B=1; MV105B=0; END;
    ELSE IF 1977 LE OMY LE 1983 AND OVTYP=2 THEN DO; MS105B=0; MV105B=1; END;
/* IMMLEMENTATION OF DUAL MASTER CYLINDERS IN THE VEHICLES THAT HIT THESE MOTORCYCLES */
  IF OMY GE 1984 THEN DO; MS105A=1; MV105A=0; END;
```

```
    ELSE IF OMY LE 1961 THEN DO; MS105A=0; MV105A=0; END;
    ELSE IF OMY IN (1962,1963) THEN DO; MS105A=0; MV105A=.09; END;
    ELSE IF OMY IN (1964,1965) THEN DO; MS105A=0; MV105A=.07; END;
    ELSE IF OMY=1966 THEN DO; MS105A=0; MV105A=.54; END;
    ELSE IF OMY=1967 THEN DO; MS105A=0; MV105A=1; END;
    ELSE IF OMY=1968 AND OVTYP=1 THEN DO; MS105A=.5; MV105A=.5; END;
    ELSE IF OMY=1968 AND OVTYP=2 THEN DO; MS105A=0; MV105A=1; END;
    ELSE IF 1969 LE OMY LE 1983 AND OVTYP=1 THEN DO; MS105A=1; MV105A=0; END;
    ELSE IF 1969 LE OMY LE 1983 AND OVTYP=2 THEN DO; MS105A=0; MV105A=1; END;
/* MOTORCYLIST LIVES SAVED BY ESC */
  OLDWTFA=WEIGHTFA;
  IF MS126 GT 0 OR MV126 GT 0 THEN DO;
    IF OVTYP=2 THEN E=.1615; ELSE E=.1607;  /* NEW ESTIMATES OF ESC EFFECTIVENESS IN PREVENTING CULPABLE IN-
VOLVEMENTS IN MULTIVEH CRASHES */
    P=MS126+MV126;
    S=OLDWTFA*E*P / (1 - E*P);
    MLS126=S*MS126/P;
    MLV126=S*MV126/P;
    WEIGHTFA=OLDWTFA+MLS126+MLV126; END;
  ELSE DO; MLS126=0; MLV126=0; END;
/* MOTORCYLIST LIVES SAVED BY FRONT DISC BRAKES */
  OLDWTFA=WEIGHTFA;
  IF MS105B GT 0 OR MV105B GT 0 THEN DO;
    E=.0017;
    P=MS105B+MV105B;
    S=OLDWTFA*E*P / (1 - E*P);
    MLS105B=S*MS105B/P;
    MLV105B=S*MV105B/P;
    WEIGHTFA=OLDWTFA+MLS105B+MLV105B; END;
  ELSE DO; MLS105B=0; MLV105B=0; END;
/* MOTORCYCLIST LIVES SAVED BY DUAL MASTER CYLINDERS */
  OLDWTFA=WEIGHTFA;
  IF MS105A GT 0 OR MV105A GT 0 THEN DO;
    E=.007;
    P=MS105A+MV105A;
    S=OLDWTFA*E*P / (1 - E*P);
    MLS105A=S*MS105A/P;
    MLV105A=S*MV105A/P;
    WEIGHTFA=OLDWTFA+MLS105A+MLV105A; END;
  ELSE DO; MLS105A=0; MLV105A=0; END;
  MLS=MLS126+MLS105A+MLS105B; MLV=MLV126+MLV105A+MLV105B;
  ML105A=MLS105A+MLV105A; ML105B=MLS105B+MLV105B; ML126=MLS126+MLV126; ML=MLS+MLV;
RUN;

PROC MEANS SUM NOPRINT DATA=MC2; BY CY;
  VAR ORIGWT WEIGHTFA MLV126 MLS126 ML126 MLV105B MLS105B ML105B MLV105A MLS105A ML105A MLV MLS ML;
  OUTPUT OUT=MC3
    SUM=M_ORIGWT M_WTFA MLV126 MLS126 ML126 MLV105B MLS105B ML105B MLV105A MLS105A ML105A MLV MLS ML;
RUN;

PROC PRINT DATA=MC3;
  FORMAT M_ORIGWT M_WTFA MLV126 MLS126 ML126 MLV105B MLS105B ML105B MLV105A MLS105A ML105A MLV MLS ML 9.0;
  ID CY; VAR M_ORIGWT M_WTFA MLV126 MLS126 ML126 MLV105B MLS105B ML105B MLV105A MLS105A ML105A MLV MLS ML;
  SUM M_ORIGWT M_WTFA MLV126 MLS126 ML126 MLV105B MLS105B ML105B MLV105A MLS105A ML105A MLV MLS ML;
TITLE1 'MOTORCYCLISTS SAVED BY CAR/LTV ESC, DISC BRAKES AND DUAL MASTER CYLINDERS, 1975-2012';
TITLE2 ' ';
TITLE3 '...126  = ESC (MEDIAN INSTALLATION YEAR 2010, FMVSS EFFECTIVE 9/1/2011)';
TITLE4 '...105B = FRONT DISC BRAKES (MEDIAN INSTALLATION YEAR 1971, FMVSS EFFECTIVE 1/1/1976 OR 9/1/1983)';
TITLE5 '...105A = DUAL MASTER CYLINDERS (MEDIAN INSTALLATION YEAR LATE 1966, FMVSS EFFECTIVE 1/1/1968 OR
9/1/1983)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, AFTER EFFECTIVE DATE';
TITLE8 'M_ORIGWT = ACTUAL MOTORCYLIST FATALITIES IN COLLISIONS WITH A CAR OR LTV';
TITLE9 'M_WTFA = FATALITIES THAT WOULD HAVE OCCURRED WITHOUT THESE SAFETY IMPROVEMENTS';
TITLE10 'ML = OVERALL MOTORCYCLIST LIVES SAVED BY ESC AND BRAKE IMPROVEMENTS IN CARS/LTVs';
RUN;
```

The program now turns to car/LTV occupant fatalities, and it returns to the pre-processor section, splitting cases with unknown crash mode, seating position or restraint use into two or more cases with known, imputed values for these variables.

```
/* ---------------------------------------------------------------- */
/* ---------------------------------------------------------------- */
/*  THE ANALYSIS OF OCCUPANT FATALITIES BEGINS HERE                 */
/*  FIRST TASK IS TO IMPUTE ALL UNKOWN CRASHMODES, SEAT POS, BELT USE */
/* ---------------------------------------------------------------- */
/* ---------------------------------------------------------------- */


proc freq data=occ1; weight origwt; format crsh crsh.; tables crsh;
TITLE 'UNKNOWN CRSH IN OCC1';
run;
```

Checks that distribution of CRSH has continuity from year to year despite changes in the FARS variables:

```
proc freq data=occ1; weight origwt; format crsh crsh.;
 tables cy * crsh / nocol nopercent;
run;
```

Splits the file OCC1 into OCC2, UNKCRSH1, and NEW_UNKCRSH1. OCC2 are the cases with known impact location/crash type (CRSH) and are left alone. UNKCRSH1 contains the CY 1975-2002 cases with unknown crash mode (CRSH = 9); UNKCRSH2 contains the CY 2003-2012 cases.

```
DATA OCC2 UNKCRSH1 NEW_UNKCRSH1; SET OCC1;
IF CRSH=9 THEN DO; IF 1975 LE CY LE 2002 THEN OUTPUT UNKCRSH1; ELSE OUTPUT NEW_UNKCRSH1; END;
ELSE OUTPUT OCC2;
RUN;

/* ------------------------------------------------------------------ */
/* ------------------------------------------------------------------ */
/*  DISTRIBUTES AND IMPUTES CRASH MODES WHEN THEY ARE UNKNOWN         */
/*  SEPARATE IMPUTATIONS FOR FIXED OBJECT, ANGLE, REAR-END AND OTHER  */
/*  CRASHES USING CATMOD MODELS CREATED BY L_CRSH4 OR L_CRASH14.SAS   */
/*  (HEAD-ON COLLISION INVOLVMENTS ARE ASSUMED TO BE FRONTAL IMPACTS) */
/*                                                                    */
/*  SEPARATE IMPUTATIONS FOR CY 1975-2002 AND CY 2003-2012            */
/* ------------------------------------------------------------------ */
/* ------------------------------------------------------------------ */

/* ------------------------------------------------------------------ */
/*  IMPUTATION FOR CY 1975-2002: SAME AS IN 2004 REPORT (L_CRSH4.SAS) */
/* ------------------------------------------------------------------ */
```

UNKCRSH1, in turn, is split into FIXOBJ, ANGLE, REAR, OTH; the first consists of single-vehicle crashes with unknown crash mode; the second, multivehicle crashes described as “angle collisions” (MAN_COLL = 1,3); the third, rear-end collisions; the fourth, all other crash involvements. Defines various subgroups of first harmful event and seating position/age/gender. These groupings, together with vehicle type and occupant ejection, are good predictors of whether the impact was frontal, side, rollover, or rear/other.

```
DATA FIXOBJ ANGLE REAR OTH;
SET UNKCRSH1;
IF HARM_EV IN (10,11,12,14,18,24,30,34,35,42,43,99) THEN EVENT1=HARM_EV;
  ELSE IF HARM_EV IN (8,9,15,44,47) THEN EVENT1=99;
  ELSE IF HARM_EV=13 THEN EVENT1=12;
  ELSE IF HARM_EV IN (16,19,22,48) THEN EVENT1=34;
  ELSE IF HARM_EV=17 THEN EVENT1=18;
  ELSE IF HARM_EV IN (20,23,26) THEN EVENT1=24;
  ELSE IF HARM_EV IN (21,25,32,36,37,38,39,46) THEN EVENT1=35;
  ELSE IF HARM_EV IN (27,29,40) THEN EVENT1=42;
  ELSE IF HARM_EV=28 THEN EVENT1=30;
  ELSE IF HARM_EV IN (31,33,41) THEN EVENT1=43;
  ELSE IF HARM_EV=45 THEN EVENT1=14;
  ELSE IF HARM_EV=49 THEN EVENT1=11;
  ELSE EVENT1=99;
```

```
IF EVENT1=12 THEN DO;
    IF MAN_COLL IN (1,3) THEN EVENT2=12.1;
    ELSE IF MAN_COLL=4 THEN EVENT2=12.2;
    ELSE IF MAN_COLL IN (5,6,7) THEN EVENT2=12.3;
    ELSE EVENT2=99; END;
  ELSE EVENT2=EVENT1;
IF EJECTION IN (1,2) THEN EJECT=1; ELSE EJECT=0;
IF PER_TYP=2 THEN DO; AGEGP3=1;
    IF 0 LE AGE LE 15 THEN AGEGP4=1; ELSE AGEGP4=2; END;
  ELSE DO; IF 14 LE AGE LE 29 THEN AGEGP3=2;
      ELSE IF 30 LE AGE LE 49 THEN AGEGP3=3;
      ELSE IF 50 LE AGE LE 97 THEN AGEGP3=4;
      ELSE AGEGP3=2;
    IF SEX=1 THEN AGEGP4=3; ELSE IF SEX=2 THEN AGEGP4=4; END;
IF 14 LE EVENT2 LE 43 THEN OUTPUT FIXOBJ;
  ELSE IF EVENT2 IN (10,12.2) THEN OUTPUT ANGLE;
  ELSE IF EVENT2=12.1 THEN OUTPUT REAR;
  ELSE OUTPUT OTH;
RUN;

/* -------------------------------------------------------------------- */
/*  CRSH1.CRSH1 ASSIGNS FIXED-OBJECT CRASHES TO FRONTAL, SIDE, ROLLOVER   */
/*  OR REAR BASED ON FIRST HARMFUL EVENT, EJECTION, DRV/PAS AGE, CAR/LTRK */
/* -------------------------------------------------------------------- */
```

CRSH1 was generated by the program L_CRSH4 by a CATMOD analysis of the cases with known crash modes. For each combination of EVENT2, EJECT, AGEGP3 and VTYP, CATMOD calibrates the proportions of fatalities that are frontal, side, rollover and rear/other, and it stores these proportions in *CRSH1*. For example, a typical record on *CRSH1* could look like:

Event2	Eject	Agegp3	Vtyp	Frontal	Side	Roll	Rearothr
42 (tree)	0	2 (young drv)	1 (car)	.58	.35	.05	.02

In other words, when a young car driver initially hits a tree, and is fatally injured but not ejected, 58 percent of the crashes with known crash type are frontals, 35 percent are side impacts, 5 percent are classified as rollovers for the purpose of this model because the principal impact location is the top of the car (due to a subsequent rollover), and 2 percent are rear/other.

```
PROC SORT DATA=FIXOBJ; BY EVENT2 EJECT AGEGP3 VTYP;
```

The information from *CRSH1* is added to each case.

```
DATA FIXOBJ2; MERGE FIXOBJ(IN=OCC) CRSH1.CRSH1;
 BY EVENT2 EJECT AGEGP3 VTYP; IF OCC;
```

Now each original case with unknown crash mode is split into four separate cases with known crash modes. For example, if the original case had a weight factor (ORIGWT = WEIGHTFA) of 1, and it was a young non-ejected car driver who hit a tree, create four cases, with the same values as the original case on all variables except CRSH, ORIGWT and WEIGHTFA. The first case will have CRSH = 1 (frontal) and ORIGWT = WEIGHTFA = .58. The second case will have CRSH = 2 (side) and ORIGWT = WEIGHTFA = .35. The third case will have CRSH = 3 (rollover) and ORIGWT = WEIGHTFA = .05. The fourth case will have CRSH = 4 (rear/other) and ORIGWT = WEIGHTFA = .02. The four cases together will have ORIGWTs adding up to 1, like the initial case.

```
DATA FIXOBJ3; SET FIXOBJ2;
O1=ORIGWT; W1=WEIGHTFA;
CRSH=1; ORIGWT=FRONTAL * O1; WEIGHTFA=FRONTAL * W1; OUTPUT;
CRSH=2; ORIGWT=SIDE * O1; WEIGHTFA=SIDE * W1; OUTPUT;
CRSH=3; ORIGWT=ROLL * O1; WEIGHTFA=ROLL * W1; OUTPUT;
CRSH=4; ORIGWT=REAROTHR* O1; WEIGHTFA=REAROTHR* W1; OUTPUT;
```

```
/* ------------------------------------------------------------------ */
/* CRSH2.CRSH2 ASSIGNS MULTIVEH ANGLE COLLISIONS TO FRONTAL, SIDE, ROLL   */
/* OR REAR BASED ON FIRST HARMFUL EVENT, EJECTION, DRV/PAS AGE, CAR/LTRK  */
/* ------------------------------------------------------------------ */

PROC SORT DATA=ANGLE; BY EVENT2 EJECT AGEGP4 VTYP;
DATA ANGLE2; MERGE ANGLE(IN=OCC) CRSH2.CRSH2;
 BY EVENT2 EJECT AGEGP4 VTYP; IF OCC;
DATA ANGLE3; SET ANGLE2;
O1=ORIGWT; W1=WEIGHTFA;
CRSH=1; ORIGWT=FRONTAL * O1; WEIGHTFA=FRONTAL * W1; OUTPUT;
CRSH=2; ORIGWT=SIDE * O1; WEIGHTFA=SIDE * W1; OUTPUT;
CRSH=3; ORIGWT=ROLL * O1; WEIGHTFA=ROLL * W1; OUTPUT;
CRSH=4; ORIGWT=REAROTHR* O1; WEIGHTFA=REAROTHR* W1; OUTPUT;
/* ------------------------------------------------------------------ */
/* CRSH3.CRSH3 ASSIGNS MULTIVEH REAR-END COLLSNS TO FRONTAL, SIDE, ROLL   */
/* OR REAR BASED ON EJECTION, DRV/PAS AGE, CAR/LTRK                       */
/* ------------------------------------------------------------------ */

PROC SORT DATA=REAR; BY EVENT2 EJECT AGEGP4 VTYP;
DATA REAR2; MERGE REAR(IN=OCC) CRSH3.CRSH3;
 BY EVENT2 EJECT AGEGP4 VTYP; IF OCC;
DATA REAR3; SET REAR2;
O1=ORIGWT; W1=WEIGHTFA;
CRSH=1; ORIGWT=FRONTAL * O1; WEIGHTFA=FRONTAL * W1; OUTPUT;
CRSH=2; ORIGWT=SIDE * O1; WEIGHTFA=SIDE * W1; OUTPUT;
CRSH=3; ORIGWT=ROLL * O1; WEIGHTFA=ROLL * W1; OUTPUT;
CRSH=4; ORIGWT=REAROTHR* O1; WEIGHTFA=REAROTHR* W1; OUTPUT;

/* ------------------------------------------------------------------ */
/* CRSH4.CRSH4 ASSIGNS OTHER-EVENT CRASHES TO FRONTAL, SIDE, ROLLOVER     */
/* OR REAR BASED ON FIRST HARMFUL EVENT, EJECTION                         */
/* ------------------------------------------------------------------ */

PROC SORT DATA=OTH; BY EVENT2 EJECT;
DATA OTH2; MERGE OTH(IN=OCC) CRSH4.CRSH4;
 BY EVENT2 EJECT; IF OCC;
DATA OTH3; SET OTH2;
O1=ORIGWT; W1=WEIGHTFA;
CRSH=1; ORIGWT=FRONTAL * O1; WEIGHTFA=FRONTAL * W1; OUTPUT;
CRSH=2; ORIGWT=SIDE * O1; WEIGHTFA=SIDE * W1; OUTPUT;
CRSH=3; ORIGWT=ROLL * O1; WEIGHTFA=ROLL * W1; OUTPUT;
CRSH=4; ORIGWT=REAROTHR* O1; WEIGHTFA=REAROTHR* W1; OUTPUT;
```

UNKCRSH2 contains all the newly created CY 1975-2002 cases with known crash modes.

```
DATA UNKCRSH2; SET FIXOBJ3 ANGLE3 REAR3 OTH3;
DROP EVENT1 EVENT2 AGEGP3 AGEGP4 FRONTAL SIDE ROLL REAROTHR EJECT O1 W1 N;
RUN;
```

Imputation for CY 2003 to 2012 is the same as above, except it uses the imputation factors from the files NEWCRSH1-NEWCRSH4 instead of CRSH1-CRSH4.

```
/* --------------------------------------------------------------- */
/*  IMPUTATION FOR CY 2003-2012: NEW MODELS FROM L_CRSH14.SAS        */
/* --------------------------------------------------------------- */

DATA FIXOBJ ANGLE REAR OTH;
SET NEW_UNKCRSH1;
IF HARM_EV IN (10,11,12,14,18,24,30,34,35,42,43,99) THEN EVENT1=HARM_EV;
  ELSE IF HARM_EV IN (8,9,15,44,47) THEN EVENT1=99;
  ELSE IF HARM_EV=13 THEN EVENT1=12;
  ELSE IF HARM_EV IN (16,19,22,48,58) THEN EVENT1=34;
  ELSE IF HARM_EV=17 THEN EVENT1=18;
  ELSE IF HARM_EV IN (20,23,26,52,57) THEN EVENT1=24;
  ELSE IF HARM_EV IN (21,25,32,36,37,38,39,46) THEN EVENT1=35;
  ELSE IF HARM_EV IN (27,29,40,59) THEN EVENT1=42;
  ELSE IF HARM_EV=28 THEN EVENT1=30;
```

```
  ELSE IF HARM_EV IN (31,33,41,53) THEN EVENT1=43;
  ELSE IF HARM_EV=45 THEN EVENT1=14;
  ELSE IF HARM_EV=49 THEN EVENT1=11;
  ELSE EVENT1=99;
IF EVENT1=12 THEN DO;
    IF MAN_COLL IN (1,10) THEN EVENT2=12.1;
    ELSE IF MAN_COLL IN (3:6) THEN EVENT2=12.2;
    ELSE IF MAN_COLL IN (7:9) THEN EVENT2=12.3;
    ELSE EVENT2=99; END;
  ELSE EVENT2=EVENT1;
IF EJECTION IN (1:3) THEN EJECT=1; ELSE EJECT=0;
IF PER_TYP=2 THEN DO; AGEGP3=1;
    IF 0 LE AGE LE 15 THEN AGEGP4=1; ELSE AGEGP4=2; END;
  ELSE DO; IF 14 LE AGE LE 29 THEN AGEGP3=2;
      ELSE IF 30 LE AGE LE 49 THEN AGEGP3=3;
      ELSE IF 50 LE AGE LE 97 THEN AGEGP3=4;
      ELSE AGEGP3=2;
    IF SEX=1 THEN AGEGP4=3; ELSE IF SEX=2 THEN AGEGP4=4; END;
IF 14 LE EVENT2 LE 43 THEN OUTPUT FIXOBJ;
  ELSE IF EVENT2 IN (10,12.2) THEN OUTPUT ANGLE;
  ELSE IF EVENT2=12.1 THEN OUTPUT REAR;
  ELSE OUTPUT OTH;
RUN;

/* -------------------------------------------------------------------- */
/*  NEWCRSH1.NEWCRSH1 ASSIGNS FIX-OBJ CRASHES TO FRONTAL, SIDE, ROLLOVER  */
/*  OR REAR BASED ON FIRST HARMFUL EVENT, EJECTION, DRV/PAS AGE, CAR/LTV  */
/* -------------------------------------------------------------------- */

PROC SORT DATA=FIXOBJ; BY EVENT2 EJECT AGEGP3 VTYP;
DATA FIXOBJ2; MERGE FIXOBJ(IN=OCC) NEWCRSH1.NEWCRSH1;
  BY EVENT2 EJECT AGEGP3 VTYP; IF OCC;
DATA FIXOBJ3; SET FIXOBJ2;
O1=ORIGWT; W1=WEIGHTFA;
CRSH=1; ORIGWT=FRONTAL * O1; WEIGHTFA=FRONTAL * W1; OUTPUT;
CRSH=2; ORIGWT=SIDE    * O1; WEIGHTFA=SIDE    * W1; OUTPUT;
CRSH=3; ORIGWT=ROLL    * O1; WEIGHTFA=ROLL    * W1; OUTPUT;
CRSH=4; ORIGWT=REAROTHR* O1; WEIGHTFA=REAROTHR* W1; OUTPUT;

/* -------------------------------------------------------------------- */
/*  NEWCRSH2.NEWCRSH2 ASSIGNS MULTIVEH ANGLE COLLISIONS                   */
/*  TO FRONTAL, SIDE, ROLLOVER, OR REAR                                   */
/*  BASED ON FIRST HARMFUL EVENT, EJECTION, DRV/PAS AGE, CAR/LTV          */
/* -------------------------------------------------------------------- */

PROC SORT DATA=ANGLE; BY EVENT2 EJECT AGEGP4 VTYP;
DATA ANGLE2; MERGE ANGLE(IN=OCC) NEWCRSH2.NEWCRSH2;
  BY EVENT2 EJECT AGEGP4 VTYP; IF OCC;
DATA ANGLE3; SET ANGLE2;
O1=ORIGWT; W1=WEIGHTFA;
CRSH=1; ORIGWT=FRONTAL * O1; WEIGHTFA=FRONTAL * W1; OUTPUT;
CRSH=2; ORIGWT=SIDE    * O1; WEIGHTFA=SIDE    * W1; OUTPUT;
CRSH=3; ORIGWT=ROLL    * O1; WEIGHTFA=ROLL    * W1; OUTPUT;
CRSH=4; ORIGWT=REAROTHR* O1; WEIGHTFA=REAROTHR* W1; OUTPUT;

/* -------------------------------------------------------------------- */
/*  NEWCRSH3.NEWCRSH3 ASSIGNS MULTIVEH REAR-END COLLSNS TO FRONTAL, SIDE, */
/*  ROLL, OR REAR BASED ON EJECTION, DRV/PAS AGE, CAR/LTV                 */
/* -------------------------------------------------------------------- */

PROC SORT DATA=REAR; BY EVENT2 EJECT AGEGP4 VTYP;
DATA REAR2; MERGE REAR(IN=OCC) NEWCRSH3.NEWCRSH3;
  BY EVENT2 EJECT AGEGP4 VTYP; IF OCC;
DATA REAR3; SET REAR2;
O1=ORIGWT; W1=WEIGHTFA;
CRSH=1; ORIGWT=FRONTAL * O1; WEIGHTFA=FRONTAL * W1; OUTPUT;
CRSH=2; ORIGWT=SIDE    * O1; WEIGHTFA=SIDE    * W1; OUTPUT;
CRSH=3; ORIGWT=ROLL    * O1; WEIGHTFA=ROLL    * W1; OUTPUT;
CRSH=4; ORIGWT=REAROTHR* O1; WEIGHTFA=REAROTHR* W1; OUTPUT;
```

```
/* -------------------------------------------------------------------- */
/*  NEWCRSH4.NEWCRSH4 ASSIGNS OTHER-EVENT CRASHES TO FRONTAL, SIDE,      */
/*  ROLLOVER, OR REAR BASED ON FIRST HARMFUL EVENT, EJECTION            */
/* -------------------------------------------------------------------- */

PROC SORT DATA=OTH; BY EVENT2 EJECT;
DATA OTH2; MERGE OTH(IN=OCC) NEWCRSH4.NEWCRSH4;
  BY EVENT2 EJECT; IF OCC;
DATA OTH3; SET OTH2;
O1=ORIGWT; W1=WEIGHTFA;
CRSH=1; ORIGWT=FRONTAL * O1; WEIGHTFA=FRONTAL * W1; OUTPUT;
CRSH=2; ORIGWT=SIDE    * O1; WEIGHTFA=SIDE    * W1; OUTPUT;
CRSH=3; ORIGWT=ROLL    * O1; WEIGHTFA=ROLL    * W1; OUTPUT;
CRSH=4; ORIGWT=REAROTHR* O1; WEIGHTFA=REAROTHR* W1; OUTPUT;
```

NEW_UNKCRSH2 contains all the newly created CY 2003-2012 cases with known crash modes.

```
DATA NEW_UNKCRSH2; SET FIXOBJ3 ANGLE3 REAR3 OTH3;
DROP EVENT1 EVENT2 AGEGP3 AGEGP4 FRONTAL SIDE ROLL REAROTHR EJECT O1 W1 N;
RUN;
```

UNKCRSH2 and NEW_UNKCRSH2 are appended to OCC2, the original cases with known crash modes, creating OCC3, a file on which all cases have known crash modes.

```
DATA OCC3; SET OCC2 UNKCRSH2 NEW_UNKCRSH2;
```

The next step is to replace unknown seating positions with known seating positions. All drivers (PER_TYP = 1) are assumed to be in the left-front seat. Passengers (PER_TYP = 2) might have an unknown seating position. A special case is vehicles where multiple people were ejected and killed, and it is unknown who was the driver (PER_TYP = 9).

```
/* WHEN THERE ARE MULTIPLE (EJECTED) OCCUPANTS, UNKNOWN WHO WAS THE DRIVER,  */
/* ARBITRARILY SAY PER_NO 1 IS THE DRIVER, SINCE IT HARDLY AFFECTS OUR MODEL */
IF PER_TYP=9 THEN DO;
 IF 0 LE AGE LE 14 THEN PER_TYP=2;
  ELSE IF SEAT_POS NE 1 AND SEAT_POS NE 11 AND SEAT_POS NE 19 AND
   SEAT_POS NE 99 THEN PER_TYP=2;
  ELSE IF PER_NO=1 THEN PER_TYP=1;
  ELSE PER_TYP=2; END;
```

Before the imputation of seating positions, some simplifications of the SEAT_POS variable on FARS are needed. (For example, before 1982, FARS coded seating positions 1, 2, 3, 4, 5, 6 rather than 11, 12, 13, 21, 22, 23.)

```
/* ------------------------------------------------------------------------ */
/* STREAMLINES SEAT_POS CATEGORIES AND MAKES UNIFORM ACROSS 3 GENERATIONS OF FARS */
/* IN VANS, ETC., 3rd AND 4th ROW OF SEATS ARE TREATED AS REAR SEATS            */
/* ------------------------------------------------------------------------ */

IF PER_TYP=1 AND 0 LE AGE LE 9 THEN DO; PER_TYP=2; SEAT_POS=17; END;
  ELSE IF PER_TYP=1 THEN SEAT_POS=11;
  ELSE IF PER_TYP=2 AND
    ((CYGP IN (2,3) AND SEAT_POS=11) OR (CYGP=1 AND SEAT_POS=1)) THEN SEAT_POS=17;
  ELSE IF PER_TYP=2 AND CYGP=1 THEN DO;
    IF 2 LE SEAT_POS LE 3 THEN SEAT_POS=SEAT_POS+10;
    ELSE IF 4 LE SEAT_POS LE 6 THEN SEAT_POS=SEAT_POS+17;
    ELSE IF 7 LE SEAT_POS LE 9 THEN SEAT_POS=SEAT_POS+24;
    ELSE IF SEAT_POS=10 THEN SEAT_POS=18;
    ELSE IF SEAT_POS=11 THEN SEAT_POS=28;
    ELSE IF SEAT_POS=12 THEN SEAT_POS=38;
    ELSE IF SEAT_POS=13 THEN SEAT_POS=51;
    ELSE IF SEAT_POS=14 THEN SEAT_POS=50;
    ELSE IF SEAT_POS=15 THEN SEAT_POS=55; END;

IF VTYP=1 THEN DO; IF SEAT_POS IN (11,12,13,18,19,51,99) THEN SEAT2=SEAT_POS;
  ELSE IF SEAT_POS=17 THEN SEAT2=18;
  ELSE IF SEAT_POS IN (21,23) THEN SEAT2=21;
```

```
  ELSE IF SEAT_POS IN (22,31,32,33) THEN SEAT2=22;
  ELSE IF SEAT_POS IN (28,38,41,42,43,48,49) THEN SEAT2=28;
  ELSE IF SEAT_POS IN (29,39) THEN SEAT2=29;
  ELSE IF SEAT_POS IN (50,52,53,54,55) THEN SEAT2=52;
  ELSE IF SEAT_POS=98 AND CY GE 2010 THEN SEAT2=99; END;            /* NEW CODE FOR SEATING POSITION */
ELSE DO; IF SEAT_POS IN (11,12,13,18,19,51,99) THEN SEAT2=SEAT_POS;
  ELSE IF SEAT_POS=17 THEN SEAT2=18;
  ELSE IF SEAT_POS IN (21,23,31,33,41,43) THEN SEAT2=21;
  ELSE IF SEAT_POS IN (22,32,42) THEN SEAT2=22;
  ELSE IF SEAT_POS IN (28,38,48) THEN SEAT2=28;
  ELSE IF SEAT_POS IN (29,39,49) THEN SEAT2=29;
  ELSE IF SEAT_POS IN (50,52,53,54,55) THEN SEAT2=52;
  ELSE IF SEAT_POS=98 AND CY GE 2010 THEN SEAT2=99; END;
RUN;
```

The SEAT2 codes are: 11=driver 12=center front 13=right front 18=other front 19=unknown front 21=outboard rear 22=center rear 28=other rear 29=unknown rear 51=other enclosed 52=unenclosed 99=unknown passenger. Note: a child sitting on the driver's lap is coded 18, "other front."

```
proc freq data=occ3; weight origwt; format crsh crsh.; tables crsh;
TITLE 'CRSH DISTRIBUTION IN OCC3 AFTER IMPUTING AND DISTRIBUTING UNKNOWNS';
run;
```

Check for year-to-year continuity:

```
proc freq data=occ3; weight origwt; format crsh crsh.;
tables cy * crsh / nocol nopercent;
run;

proc freq data=occ3; weight origwt; format seat2 newseat.; tables seat2;
TITLE 'UNKNOWN SEAT2 IN OCC3';
run;
```

The imputation of seating position is quite similar to the procedure for imputing crash modes. The file OCC3 is split into OCC4, UNKSEAT1, and NEW_UNKSEAT1. OCC4 are the cases with known seating position (SEAT2) and are left alone. UNKSEAT1 contains the cases with unknown seating position (SEAT2 = 19, 29, 99) in CY 1975 to 2002, NEW_UNKSEAT1 in 2003 to 2012.

```
DATA OCC4 UNKSEAT1 NEW_UNKSEAT1; SET OCC3;
IF SEAT2 IN (19,29,99) THEN DO; IF 1975 LE CY LE 2002 THEN OUTPUT UNKSEAT1; ELSE OUTPUT NEW_UNKSEAT1; END;
ELSE OUTPUT OCC4;
RUN;

/* ----------------------------------------------------------------- */
/*  DISTRIBUTES AND IMPUTES PASSENGER SEATING POSITIONS WHEN UNKNOWN. */
/*  SEPARATE IMPUTATIONS FOR TOTALLY UNKNOWN, FRONT-UNKNOWN AND       */
/*  REAR-UNKNOWN PASSENGERS, BASED ON CATMOD MODELS                   */
/*                                                                    */
/*  SEPARATELY FOR 1975-2002 (L_SEAT4) & 2003-2012 (L_SEAT14)         */
/* ----------------------------------------------------------------- */

/* ----------------------------------------------------------------- */
/*  IMPUTATION FOR CY 1975-2002: SAME AS IN 2004 REPORT (L_SEAT4.SAS) */
/* ----------------------------------------------------------------- */
```

UNKSEAT1 is further split into the cases where the seating position is entirely unknown (SEAT2 = 99) and the cases where it is known that the occupant was in the front seat, or in a rear seat, but the exact location is unknown.

```
DATA USEAT119 USEAT129 USEAT199; SET UNKSEAT1;
IF AGE=0 THEN AGEGP2=1;
 ELSE IF 1 LE AGE LE 4 THEN AGEGP2=2;
 ELSE IF 5 LE AGE LE 10 THEN AGEGP2=3;
 ELSE IF 11 LE AGE LE 15 THEN AGEGP2=4;
 ELSE IF 16 LE AGE LE 19 THEN AGEGP2=5;
 ELSE IF 20 LE AGE LE 29 THEN AGEGP2=6;
```

```
 ELSE IF 30 LE AGE LE 97 THEN AGEGP2=7; ELSE AGEGP2=6;
IF SEAT2=19 THEN OUTPUT USEAT119;
 ELSE IF SEAT2=29 THEN OUTPUT USEAT129;
 ELSE IF SEAT2=99 THEN OUTPUT USEAT199;
RUN;
```

The program L_SEAT4 uses CATMOD to calibrate the distribution of passengers' known seating positions by detailed vehicle type (NEWVTYP), passengers' age group (AGEGP2), and CRSH. On a file *SEAT1*, it stores the proportions of passengers who are in the center-front seat, the RF seat, and at any of the other known seating positions included in SEAT2, and it stores them in the data elements SEAT12, SEAT13, etc. These are the proportions that will be imputed if the seating position is completely unknown.

However, if we know the passenger was in the front seat, but we do not know exactly where, we can impute them by the proportions SEAT12 / (SEAT12 + SEAT13 + SEAT18), etc.

```
DATA PSEAT19; SET SEAT1.SEAT1;
P1=SEAT12+SEAT13+SEAT18;
SEAT12=SEAT12/P1; SEAT13=SEAT13/P1; SEAT18=SEAT18/P1;
KEEP NEWVTYP AGEGP2 CRSH SEAT12 SEAT13 SEAT18;

DATA PSEAT29; SET SEAT1.SEAT1;
P2=SEAT21+SEAT22+SEAT28;
SEAT21=SEAT21/P2; SEAT22=SEAT22/P2; SEAT28=SEAT28/P2;
KEEP NEWVTYP AGEGP2 CRSH SEAT21 SEAT22 SEAT28;
RUN;
```

Just as in the imputation of crash modes, split each case with unknown seating position into multiple cases with known seating position, each weighted by the probability that the passenger was in that position.

```
PROC SORT DATA=USEAT119; BY NEWVTYP AGEGP2 CRSH;
DATA USEAT219; MERGE USEAT119(IN=OCC) PSEAT19;
 BY NEWVTYP AGEGP2 CRSH; IF OCC;
DATA USEAT319; SET USEAT219;
O1=ORIGWT; W1=WEIGHTFA;
SEAT2=12; ORIGWT=SEAT12 * O1; WEIGHTFA=SEAT12 * W1; OUTPUT;
SEAT2=13; ORIGWT=SEAT13 * O1; WEIGHTFA=SEAT13 * W1; OUTPUT;
SEAT2=18; ORIGWT=SEAT18 * O1; WEIGHTFA=SEAT18 * W1; OUTPUT;

PROC SORT DATA=USEAT129; BY NEWVTYP AGEGP2 CRSH;
DATA USEAT229; MERGE USEAT129(IN=OCC) PSEAT29;
 BY NEWVTYP AGEGP2 CRSH; IF OCC;
DATA USEAT329; SET USEAT229;
O1=ORIGWT; W1=WEIGHTFA;
SEAT2=21; ORIGWT=SEAT21 * O1; WEIGHTFA=SEAT21 * W1; OUTPUT;
SEAT2=22; ORIGWT=SEAT22 * O1; WEIGHTFA=SEAT22 * W1; OUTPUT;
SEAT2=28; ORIGWT=SEAT28 * O1; WEIGHTFA=SEAT28 * W1; OUTPUT;

PROC SORT DATA=USEAT199; BY NEWVTYP AGEGP2 CRSH;
DATA USEAT299; MERGE USEAT199(IN=OCC) SEAT1.SEAT1;
 BY NEWVTYP AGEGP2 CRSH; IF OCC;
DATA USEAT399; SET USEAT299;
O1=ORIGWT; W1=WEIGHTFA;
SEAT2=12; ORIGWT=SEAT12 * O1; WEIGHTFA=SEAT12 * W1; OUTPUT;
SEAT2=13; ORIGWT=SEAT13 * O1; WEIGHTFA=SEAT13 * W1; OUTPUT;
SEAT2=18; ORIGWT=SEAT18 * O1; WEIGHTFA=SEAT18 * W1; OUTPUT;
SEAT2=21; ORIGWT=SEAT21 * O1; WEIGHTFA=SEAT21 * W1; OUTPUT;
SEAT2=22; ORIGWT=SEAT22 * O1; WEIGHTFA=SEAT22 * W1; OUTPUT;
SEAT2=28; ORIGWT=SEAT28 * O1; WEIGHTFA=SEAT28 * W1; OUTPUT;
SEAT2=51; ORIGWT=SEAT51 * O1; WEIGHTFA=SEAT51 * W1; OUTPUT;
SEAT2=52; ORIGWT=SEAT52 * O1; WEIGHTFA=SEAT52 * W1; OUTPUT;
```

UNKSEAT2 contains all the newly created cases with known seating positions in CY 1975 to 2002.

```
DATA UNKSEAT2; SET USEAT319 USEAT329 USEAT399;
DROP AGEGP2 SEAT12 SEAT13 SEAT18 SEAT21 SEAT22 SEAT28 SEAT51 SEAT52 O1 W1;
RUN;
```

Imputation for CY 2003 to 2012 is similar, except it uses imputation factors from the file NEWSEAT1 instead of SEAT1 and it creates NEW_UNKSEAT2.

```
/* -------------------------------------------------------------------- */
/*  IMPUTATION FOR CY 2003-2012: BASED ON L_SEAT14.SAS                   */
/* -------------------------------------------------------------------- */

DATA USEAT119 USEAT129 USEAT199; SET NEW_UNKSEAT1;
IF AGE=0 THEN AGEGP2=1;
  ELSE IF  1 LE AGE LE  4 THEN AGEGP2=2;
  ELSE IF  5 LE AGE LE 10 THEN AGEGP2=3;
  ELSE IF 11 LE AGE LE 15 THEN AGEGP2=4;
  ELSE IF 16 LE AGE LE 19 THEN AGEGP2=5;
  ELSE IF 20 LE AGE LE 29 THEN AGEGP2=6;
  ELSE IF 30 LE AGE LE 97 THEN AGEGP2=7; ELSE AGEGP2=6;
IF SEAT2=19 THEN OUTPUT USEAT119;
  ELSE IF SEAT2=29 THEN OUTPUT USEAT129;
  ELSE IF SEAT2=99 THEN OUTPUT USEAT199;
RUN;

DATA PSEAT19; SET NEWSEAT1.NEWSEAT1;
P1=SEAT12+SEAT13+SEAT18;
SEAT12=SEAT12/P1; SEAT13=SEAT13/P1; SEAT18=SEAT18/P1;
KEEP NEWVTYP AGEGP2 CRSH SEAT12 SEAT13 SEAT18;

DATA PSEAT29; SET NEWSEAT1.NEWSEAT1;
P2=SEAT21+SEAT22+SEAT28;
SEAT21=SEAT21/P2; SEAT22=SEAT22/P2; SEAT28=SEAT28/P2;
KEEP NEWVTYP AGEGP2 CRSH SEAT21 SEAT22 SEAT28;
RUN;

PROC SORT DATA=USEAT119; BY NEWVTYP AGEGP2 CRSH;
DATA USEAT219; MERGE USEAT119(IN=OCC) PSEAT19;
  BY NEWVTYP AGEGP2 CRSH; IF OCC;
DATA USEAT319; SET USEAT219;
O1=ORIGWT; W1=WEIGHTFA;
SEAT2=12; ORIGWT=SEAT12 * O1; WEIGHTFA=SEAT12 * W1; OUTPUT;
SEAT2=13; ORIGWT=SEAT13 * O1; WEIGHTFA=SEAT13 * W1; OUTPUT;
SEAT2=18; ORIGWT=SEAT18 * O1; WEIGHTFA=SEAT18 * W1; OUTPUT;

PROC SORT DATA=USEAT129; BY NEWVTYP AGEGP2 CRSH;
DATA USEAT229; MERGE USEAT129(IN=OCC) PSEAT29;
  BY NEWVTYP AGEGP2 CRSH; IF OCC;
DATA USEAT329; SET USEAT229;
O1=ORIGWT; W1=WEIGHTFA;
SEAT2=21; ORIGWT=SEAT21 * O1; WEIGHTFA=SEAT21 * W1; OUTPUT;
SEAT2=22; ORIGWT=SEAT22 * O1; WEIGHTFA=SEAT22 * W1; OUTPUT;
SEAT2=28; ORIGWT=SEAT28 * O1; WEIGHTFA=SEAT28 * W1; OUTPUT;

PROC SORT DATA=USEAT199; BY NEWVTYP AGEGP2 CRSH;
DATA USEAT299; MERGE USEAT199(IN=OCC) NEWSEAT1.NEWSEAT1;
  BY NEWVTYP AGEGP2 CRSH; IF OCC;
DATA USEAT399; SET USEAT299;
O1=ORIGWT; W1=WEIGHTFA;
SEAT2=12; ORIGWT=SEAT12 * O1; WEIGHTFA=SEAT12 * W1; OUTPUT;
SEAT2=13; ORIGWT=SEAT13 * O1; WEIGHTFA=SEAT13 * W1; OUTPUT;
SEAT2=18; ORIGWT=SEAT18 * O1; WEIGHTFA=SEAT18 * W1; OUTPUT;
SEAT2=21; ORIGWT=SEAT21 * O1; WEIGHTFA=SEAT21 * W1; OUTPUT;
SEAT2=22; ORIGWT=SEAT22 * O1; WEIGHTFA=SEAT22 * W1; OUTPUT;
SEAT2=28; ORIGWT=SEAT28 * O1; WEIGHTFA=SEAT28 * W1; OUTPUT;
SEAT2=51; ORIGWT=SEAT51 * O1; WEIGHTFA=SEAT51 * W1; OUTPUT;
SEAT2=52; ORIGWT=SEAT52 * O1; WEIGHTFA=SEAT52 * W1; OUTPUT;

DATA NEW_UNKSEAT2; SET USEAT319 USEAT329 USEAT399;
DROP AGEGP2 SEAT12 SEAT13 SEAT18 SEAT21 SEAT22 SEAT28 SEAT51 SEAT52 O1 W1;
RUN;
```

UNKSEAT2 and NEW_UNKSEAT2 are appended to OCC4, the original cases with known seating positions, creating OCC5, a file on which all cases have known seating positions (and crash modes).

The next step is to replace unknown belt (or safety seat) use with known restraint use. Before the imputation of restraint use, it is necessary to determine exactly what sort(s) of belt systems were installed at each seat. For outboard front seats of cars starting in MY 1981 and LTVs in 1985, a detailed VIN analysis has already been performed on the FARS cases, and the information is stored in the variable PASSIVE that is already on the file *LSM2004* and carried over to OCC5. For the other vehicles/seating positions, restraint availability is determined from the VIN-based make-model codes MAK2, CG and MM2, or from the FARS codes MAKE and MAK_MOD. The information is encoded in the variables FTLS (for the outboard front seats), BKLS (for the outboard rear seats), and the already existing variable BELT22 (for the center rear seats). In vans, the "rear" seats include the third and fourth rows as well as the second. The "lap belts only" code really means "lap belts only, if anything." Center-front seats in all cars and third seats in station wagons are assumed to have lap belts only.

```
/* ----------------------------------------------------------------- */
/*  FTLS: 3=OUTBOARD FRONT SEATS HAVE 3-POINT BELTS                  */
/*        2=AUTOMATIC 2-POINT BELTS                                  */
/*        1=LAP BELTS ONLY                                           */
/*        4=3-POINT BELTS FOR DRIVER, AUTOMATIC 2-POINT BELTS FOR RF  */
/*        5=SEPARATE MANUAL LAP AND TORSO BELTS                      */
/*        6=MIX OF 3-POINT BELTS AND LAP-ONLY BELTS                  */
/*        7=MIX OF SEPARATE LAP AND TORSO BELTS AND LAP-ONLY BELTS    */
/*        8=MIX OF 3-POINT BELTS AND 2-POINT AUTOMATIC BELTS         */
/*                                                                   */
/*  BKLS: 3=OUTBOARD REAR SEATS HAVE 3-POINT BELTS                   */
/*        1=LAP BELTS ONLY                                           */
/*                                                                   */
/* CBKLS: NOW A SEPARATE VARIABLE BELT22 ALREADY ON LSM2014C         */
/*                                                                   */
/*  CENTER FRONT SEATS AND STATION-WAGON 3RD SEATS: LAP BELT ONLY     */
/*  OTHER (NONSTANDARD) SEATS HAVE NO BELTS AT ALL                   */
/*  KIDS UNDER 6 CAN ONLY USE SAFETY SEATS OR LAP BELTS              */
/*  PEOPLE AGE 10 OR OLDER ARE NEVER IN CHILD SAFETY SEATS           */
/* ----------------------------------------------------------------- */

DATA OCC5; SET OCC4 UNKSEAT2 NEW_UNKSEAT2;
```

The program now edits the original restraint use code on FARS, REST_USE in three steps, generating REST1, then REST2, then REST3, comprising the following codes: 0=unrestrained 1=shoulder belt only 2=lap belt only 3=lap + shoulder belt 4=child safety seat 7=2-pt automatic belt 8=used, type not specified 99=unknown if used.

```
/* ----------------------------------------------------------------- */
/* STREAMLINE REST_USE CODES AND DISALLOW IMPLAUSIBLE CODES          */
/* ----------------------------------------------------------------- */
```

REST1 is a slight streamlining of REST_USE, changing codes used in earlier versions of FARS to current codes. Children < 6 years old will be considered protected by "lap belts only" when FARS says they wore lap and shoulder belts.

```
IF REST_USE=13 AND PER_TYP=2 AND 0 LE AGE LE 5 THEN REST1=2;
 ELSE IF REST_USE=13 THEN REST1=8;
 ELSE IF REST_USE=14 THEN REST1=4;
 ELSE IF CY GE 2008 AND REST_USE IN (10,11,12) THEN REST1=4; /* NEW CODES FOR SAFETY SEATS STARTING IN 2008 FARS
*/
 ELSE IF REST_USE=9 THEN REST1=99;
 ELSE IF CY GE 2010 AND REST_USE=7 THEN REST1=0; /* NEW CODE FOR UNBELTED OCCUPANTS STARTING IN 2010 FARS */
 ELSE REST1=REST_USE;
IF (1977 LE CY LE 1979 AND AUT_REST=5) OR
 (1980 LE CY LE 1989 AND AUT_REST=1) THEN REST1=7;
```

REST2 edits REST1, taking into account what types of belts were actually in the vehicle and modifying implausible codes. Anybody age 10 or older will be considered to have unknown restraint use if FARS says they were in a child safety seat. “Motorcycle helmet” will always be recoded “unknown” for car/LTV occupants. People in non-designated seating positions (e.g., unenclosed areas) are assumed to be unrestrained.

```
IF SEAT2 IN (17,18,28,51,52) THEN REST2=0;
 ELSE IF REST1 IN (5,6,15,16,17,96,97,98) THEN REST2=99;
 ELSE IF REST1=4 AND AGE GE 10 THEN REST2=99;
 ELSE REST2=REST1;
```

Belt type installed in outboard front seats, passenger cars. In 1969-73, VW, Audi, BMW, Mercedes and Volvo are assumed to have 3-point belts, while other makes had separate lap and shoulder belts.

```
/* ----------------------------------------------------------------- */
/* TYPE OF BELTS AT THE OUTBOARD FRONT SEATING POSITIONS             */
/* ----------------------------------------------------------------- */

IF VTYP=1 THEN DO;
 IF PASSIVE IN (303,404,606,707,1303,1404,1606,1313) THEN FTLS=2;
 ELSE IF PASSIVE IN (1003,1004,1006) THEN FTLS=4;
 ELSE IF MAK_MOD IN (3006,3036,30036) AND 1975 LE XMY LE 1980 THEN FTLS=8;
 ELSE IF 1974 LE XMY LE 2013 THEN FTLS=3;
 ELSE IF 1969 LE XMY LE 1973 AND MAKE IN (30,32,34,42,51) THEN FTLS=3;
 ELSE IF 1965 LE XMY LE 1968 AND MAKE=51 THEN FTLS=3;
 ELSE IF 1969 LE XMY LE 1973 THEN FTLS=5;
 ELSE IF XMY=1968 AND MAKE IN (30,32,34,42) THEN FTLS=6;
 ELSE IF XMY=1968 THEN FTLS=7;
 ELSE FTLS=1; END;
```

Belt type installed in outboard front seats, LTVs. All LTVs had 3-point belts from MY 1981 onwards. All pickup trucks from 1977 onwards. All LTVs had only lap belts (if anything) up to 1968; SUVs and vans up to 1973. In 1969-80, LTVs could have lap belts, or 3-point belts, or a mix of the two, depending on the make, MY and vehicle type. In the absence of specific evidence, a mix of the two is assumed.

```
ELSE IF VTYP=2 THEN DO;
  IF 1981 LE XMY LE 2013 THEN FTLS=3;
    ELSE IF XMY LE 1968 THEN FTLS=1;
    ELSE IF MAKE=30 THEN FTLS=3;
    ELSE IF NEWVTYP=11 THEN DO;
      IF 1977 LE XMY LE 1980 THEN FTLS=3;
        ELSE IF 2 LE MAKE LE 29 AND 1974 LE XMY LE 1976 THEN FTLS=6;
        ELSE IF 2 LE MAKE LE 29 THEN FTLS=1;
        ELSE IF 31 LE MAKE LE 84 AND 1975 LE XMY LE 1976 THEN FTLS=3;
        ELSE IF 31 LE MAKE LE 84 AND 1972 LE XMY LE 1974 THEN FTLS=6;
        ELSE IF 31 LE MAKE LE 84 THEN FTLS=1;
        ELSE IF 1972 LE XMY LE 1976 THEN FTLS=6; ELSE FTLS=1; END;
    ELSE IF NEWVTYP=12 THEN DO;
      IF 1969 LE XMY LE 1973 THEN FTLS=1;
        ELSE IF MAKE IN (1,2,3,29,84) THEN FTLS=6;
        ELSE IF MAKE IN (7,9,20,23) AND 1974 LE XMY LE 1976 THEN FTLS=6;
        ELSE IF MAKE IN (7,9,20,23) THEN FTLS=3;
        ELSE IF MAKE=12 AND 1974 LE XMY LE 1977 THEN FTLS=6;
        ELSE IF MAKE=12 THEN FTLS=3;
        ELSE IF MAKE=49 AND 1974 LE XMY LE 1975 THEN FTLS=1;
        ELSE IF MAKE=49 THEN FTLS=3; ELSE FTLS=6; END;
    ELSE IF 1969 LE XMY LE 1973 THEN FTLS=1;
    ELSE IF 1974 LE XMY LE 1979 THEN FTLS=6;
    ELSE IF XMY=1980 THEN FTLS=3; END;
```

TY = first model year with 3-point belts at the back outboard seats. These dates are documented in NHTSA’s evaluation of rear seat belts.

```
/* ---------------------------------------------------------------- */
/*  TRANSITION YEAR TO 3-POINT BELTS IN THE OUTBOARD REAR SEATS      */
/* ---------------------------------------------------------------- */

IF MAK2=51 OR (MAK2=. AND MAKE=51) THEN TY=1971;
    ELSE IF VTYP=1 AND (MAK2=42 OR (MAK2=. AND MAKE=42)) THEN TY=1974;
    ELSE IF MM2=39032 THEN TY=1977;
    ELSE IF VTYP=1 AND
     (MAK2 IN (34,44,45,47) OR MAK2=. AND MAKE IN (34,44,45,47)) THEN TY=1981;
    ELSE IF MM2 IN (37032,32035) THEN TY=1982;
    ELSE IF MM2=30041 OR MAK2=32 OR (MAK2=. AND MAKE=32) THEN TY=1983;
    ELSE IF MAK2=56 OR (MAK2=. AND MAKE=56) THEN TY=1986;
    ELSE IF MM2=30040 THEN TY=1985;
    ELSE IF MM2=54032 THEN TY=1986;
    ELSE IF MM2 IN (35039,54032,61031,39031) THEN TY=1987;
    ELSE IF MM2 IN (6018,7018,12017,14017,13005,18005,19005,19014,21005,20019,
      30042,30044,54031,37031,37033,41035,41037,41043,41044,46044,49040,49035,
      60031,22031) OR (MM2=19003 AND CG=18042) OR
      (CG=18052 AND MM2 IN (18002,21002,22002)) THEN TY=1988;
    ELSE IF MM2 IN (7017,9017,7019,9019,12004,14004,18016,20016,22016,20009,22009,
      18017,20017,21017,22017,18003,19003,21003,18018,21018,22018,18020,20020,21020,
      22020,35042,35032,41034,49032,49034,49033,49038,7034,9034,52035,6035,52031,
      7044,9044,52034,10034,20034,53034,55033) OR CG IN (18039,18040,18048)
      THEN TY=1989;
  ELSE IF VTYP=1 THEN TY=1990;
    ELSE IF CG=38301 AND V7='8' THEN TY=1987;
    ELSE IF CG IN (18402,18403,38301,38303,38304) THEN TY=1988;
    ELSE IF CG IN (18301,18303,18304,18401,41401,49301,49302,49401,52301,53302,53303)
      THEN TY=1989;
    ELSE IF CG IN (18302,18404,18405,35301) THEN TY=1990;
    ELSE IF CG IN (1303,1304,1305,6301,6402,6403,6405,6406,18305,49303,49402)
      THEN TY=1991;
  ELSE IF VTYP=2 THEN TY=1992;
IF XMY GE TY THEN BKLS=3; ELSE BKLS=1;
DROP TY;
RUN;

proc freq data=occ5; weight origwt; format seat2 newseat.; tables seat2;
TITLE 'SEAT2 IN OCC5 AFTER IMPUTING AND DISTRIBUTING UNKNOWNS';
run;

proc freq data=occ5; weight origwt; format rest2 newrest.; tables rest2;
TITLE 'UNKNOWN REST2 IN OCC5';
run;
```

OCC5 is split into OCC6, UNKBELT1, and NEW_UNKBELT1. OCC6 are the cases with known restraint use (REST2) and are left alone. UNKBELT1 contains the CY 1975-2002 cases with unknown restraint use (REST2 = 99), plus child passengers known to be restrained, but unknown if they were in a safety seat or just belts. NEW_UNKBELT1 contains the CY 2003-2012 cases

```
DATA OCC6 UNKBELT1 NEW_UNKBELT1; SET OCC5;
IF REST2=99 OR (0 LE AGE LE 5 AND PER_TYP=2 AND REST2=8) THEN DO;
    IF 1975 LE CY LE 2002 THEN OUTPUT UNKBELT1; ELSE OUTPUT NEW_UNKBELT1; END;
  ELSE OUTPUT OCC6;
RUN;
/* ---------------------------------------------------------------- */
/*  DISTRIBUTES AND IMPUTES BELT USE WHEN UNKNOWN; SEPARATELY FOR     */
/*  FRONT-SEAT 3-POINT, AUTOMATIC 2-POINT, REAR-SEAT 3-POINT, LAP,    */
/*  INFANT-TODDLER (IN 2 STEPS: USED/NOT-USED BELT/SAFETY-SEAT)       */
/*                                                                   */
/*  SEPARATE IMPUTATIONS FOR CY 1975-2002 AND 2003-2012              */
/* ---------------------------------------------------------------- */

/* ---------------------------------------------------------------- */
/*  IMPUTATION FOR CY 1975-2002 BASED ON LOGISTIC REGRESSION MODELS   */
/*  FROM L3PT4, L2PT4, LBK3PT4, L_LAP4, & LKIDRES4                    */
/*  (CARRYOVER FROM 2004 REPORT)                                      */
/* ---------------------------------------------------------------- */
```

UNKBELT1 is further subdivided into: occupants of outboard front seats equipped with 3-point belts (UNK3PT1), with 2-point automatic belts (UNK2PT1), rear seats equipped with 3-point belts (UNKBK31), any seats equipped with lap belts or separate lap and shoulder belts (UNKLAP1), child passengers < 6 years old with completely unknown restraint use (UNKKID1), and child passengers < 6 known to be restrained, but unknown what type of restraint (UNKKID2). FTLS = 8 is primarily 3-point belts with some 2-point, and is sent to UNK3PT1; other mixes are sent to UNKLAP1.

```
/* ----------------------------------------------------------------- */
/*  DISTRIBUTES AND IMPUTES BELT USE WHEN UNKNOWN; SEPARATELY FOR     */
/*  FRONT-SEAT 3-POINT, AUTOMATIC 2-POINT, REAR-SEAT 3-POINT, LAP,    */
/*  INFANT-TODDLER (IN 2 STEPS: USED/NOT-USED BELT/SAFETY-SEAT)       */
/*  BASED ON LOGISTIC REGRESSION MODELS FROM L3PT4, L2PT4, LBK3PT4,   */
/*  L_LAP4, & LKIDRES4                                                */
/* ----------------------------------------------------------------- */

DATA UNK3PT1 UNK2PT1 UNKBK31 UNKLAP1 UNKKID1 UNKKID2;
SET UNKBELT1;
GENDER=SEX; IF GENDER NE 2 THEN GENDER=1;
IF 0 LE AGE LE 97 THEN NEWAGE=AGE; ELSE NEWAGE=30;
  IF PER_TYP=1 AND AGE LT 14 THEN NEWAGE=30;
IF 0 LE AGE LE 5 AND PER_TYP=2 AND REST2=8 THEN OUTPUT UNKKID2;
ELSE IF SEAT2=11 THEN DO;
  IF FTLS=2 THEN OUTPUT UNK2PT1;
  ELSE IF FTLS IN (3,4,8) THEN OUTPUT UNK3PT1;
  ELSE OUTPUT UNKLAP1; END;
ELSE IF SEAT2=13 THEN DO;
  IF 0 LE AGE LE 5 THEN OUTPUT UNKKID1;
  ELSE IF FTLS IN (2,4) THEN OUTPUT UNK2PT1;
  ELSE IF FTLS IN (3,8) THEN OUTPUT UNK3PT1;
  ELSE OUTPUT UNKLAP1; END;
ELSE IF SEAT2=21 THEN DO;
  IF 0 LE AGE LE 5 THEN OUTPUT UNKKID1;
  ELSE IF BKLS=3 THEN OUTPUT UNKBK31;
  ELSE OUTPUT UNKLAP1; END;
ELSE IF SEAT2=22 THEN DO;
  IF 0 LE AGE LE 5 THEN OUTPUT UNKKID1;
  ELSE IF BELT22=1 THEN OUTPUT UNKBK31;
  ELSE OUTPUT UNKLAP1; END;
ELSE IF SEAT2=12 THEN DO;
  IF 0 LE AGE LE 5 THEN OUTPUT UNKKID1;
  ELSE OUTPUT UNKLAP1; END;
RUN;
```

The program L3PT4 is a logistic regression that calibrates belt use of outboard front seat occupants in vehicles with 3-point belts, based on cases where belt use is known, as a function of the calendar year, the occupant's age and gender, the vehicle type, vehicle age, crash mode and seating position. The code here defines the independent variables used in L3PT4 and copies the regression equation obtained there, in order to impute the belt use of occupants for whom it is unknown on FARS.

```
/* IMPUTES FRONT-SEAT 3-POINT BELT USE BASED ON LOGISTIC REGRESSION EQUATION */

DATA UNK3PT2; SET UNK3PT1;
IF NEWAGE GE 17 THEN FEMALE=GENDER-1;
 ELSE IF 6 LE NEWAGE LE 13 THEN FEMALE=.5;
 ELSE IF 14 LE NEWAGE LE 16 THEN FEMALE=.5*GENDER-.25;
PRETEEN=0; TEEN=0; ADULT=0; OLD=0;
 IF 6 LE NEWAGE LE 12 THEN PRETEEN=1;
 ELSE IF 13 LE NEWAGE LE 20 THEN TEEN=20-NEWAGE;
 ELSE IF 30 LE NEWAGE LE 79 THEN ADULT=NEWAGE-30;
 ELSE IF 80 LE NEWAGE LE 97 THEN OLD=1;
CONVRTBL=0; TWODOOR=0; STAWAGON=0; UNK_CAR=0; PICKUP=0; SUV=0; VAN=0; UNK_LTRK=0;
 IF NEWVTYP=1 THEN CONVRTBL=1;
 ELSE IF NEWVTYP=2 THEN TWODOOR=1;
 ELSE IF NEWVTYP=6 THEN STAWAGON=1;
 ELSE IF NEWVTYP=9 THEN UNK_CAR=1;
 ELSE IF NEWVTYP=11 THEN PICKUP=1;
 ELSE IF NEWVTYP=12 THEN SUV=1;
```

```
 ELSE IF NEWVTYP=13 THEN VAN=1;
 ELSE IF NEWVTYP=19 THEN UNK_LTRK=1;
CY7576=0; CY7778=0; CY7980=0; CY81=0; CY82=0; CY83=0; CY84=0;
 CY85=0; CY86=0; CY87=0; CY88=0; CY89=0; CY90=0; CY91=0;
 CY92=0; CY93=0; CY94=0; CY95=0; CY96=0; CY97=0; CY98=0;
 CY2000=0; CY2001=0; CY2002=0;
IF CY IN (1975,1976) THEN CY7576=1;
 ELSE IF CY IN (1977,1978) THEN CY7778=1;
 ELSE IF CY IN (1979,1980) THEN CY7980=1;
 ELSE IF CY=1981 THEN CY81=1; ELSE IF CY=1982 THEN CY82=1;
 ELSE IF CY=1983 THEN CY83=1; ELSE IF CY=1984 THEN CY84=1;
 ELSE IF CY=1985 THEN CY85=1; ELSE IF CY=1986 THEN CY86=1;
 ELSE IF CY=1987 THEN CY87=1; ELSE IF CY=1988 THEN CY88=1;
 ELSE IF CY=1989 THEN CY89=1; ELSE IF CY=1990 THEN CY90=1;
 ELSE IF CY=1991 THEN CY91=1; ELSE IF CY=1992 THEN CY92=1;
 ELSE IF CY=1993 THEN CY93=1; ELSE IF CY=1994 THEN CY94=1;
 ELSE IF CY=1995 THEN CY95=1; ELSE IF CY=1996 THEN CY96=1;
 ELSE IF CY=1997 THEN CY97=1; ELSE IF CY=1998 THEN CY98=1;
 ELSE IF CY=2000 THEN CY2000=1; ELSE IF CY=2001 THEN CY2001=1;
 ELSE IF CY=2002 THEN CY2002=1;
RTFRONT=0; IF SEAT2=13 THEN RTFRONT=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;
VEH_AGE=CY-XMY; IF VEH_AGE LT 0 THEN VEH_AGE=0;

Z=-.2954+.7226*PRETEEN+.0292*TEEN+.0202*ADULT+.9100*OLD+.4728*FEMALE;
Z=Z-.1273*CONVRTBL-.2593*TWODOOR+.1047*STAWAGON-.0414*UNK_CAR;
Z=Z-.7998*PICKUP-.3697*SUV-.1141*VAN-.4421*UNK_LTRK-.0647*VEH_AGE;
Z=Z-2.4205*CY7576-2.9491*CY7778-3.2598*CY7980-3.3202*CY81-3.2030*CY82;
Z=Z-2.9786*CY83-2.6736*CY84-1.8587*CY85-1.3004*CY86-1.0471*CY87;
Z=Z-.9215*CY88-.8555*CY89-.7852*CY90-.6234*CY91-.4971*CY92-.3323*CY93;
Z=Z-.2301*CY94-.2192*CY95-.1221*CY96-.0760*CY97-.0047*CY98;
Z=Z+.1102*CY2000+.1544*CY2001+.2124*CY2002;
Z=Z+.4169*SIDE-.4605*ROLL+.1482*REAROTHR-.0332*RTFRONT;
```

Based on the logistic regression equation, BELTED is the probability that the occupant was belted; UNBELTED is the probability they were unrestrained. Each case with unknown belt use is split into two cases with known belt use: one yes, weighted by the probability that the occupant was belted; the other no, weighted by UNBELTED.

```
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT;
RUN;

/* IMPUTES AUTOMATIC 2-POINT BELT USE BASED ON LOGISTIC REGRESSION EQUATION */

DATA UNK2PT2; SET UNK2PT1;
IF PASSIVE IN (606,707,1606) THEN MOTOR=0; ELSE MOTOR=1;
IF NEWAGE GE 17 THEN FEMALE=GENDER-1;
 ELSE IF 6 LE NEWAGE LE 13 THEN FEMALE=.5;
 ELSE IF 14 LE NEWAGE LE 16 THEN FEMALE=.5*GENDER-.25;
PRETEEN=0; TEEN=0; ADULT=0; OLD=0;
 IF 6 LE NEWAGE LE 12 THEN PRETEEN=1;
 ELSE IF 13 LE NEWAGE LE 20 THEN TEEN=20-NEWAGE;
 ELSE IF 30 LE NEWAGE LE 79 THEN ADULT=NEWAGE-30;
 ELSE IF 80 LE NEWAGE LE 97 THEN OLD=1;
RTFRONT=0; IF SEAT2=13 THEN RTFRONT=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;
VEH_AGE=CY-XMY; IF VEH_AGE LT 0 THEN VEH_AGE=0;

Z=-.2911+.6194*MOTOR+.5819*PRETEEN+.0323*TEEN+.0289*ADULT+1.4860*OLD+.4928*FEMALE;
Z=Z-.0199*VEH_AGE+.1496*SIDE-.7183*ROLL-.0317*REAROTHR-.0732*RTFRONT;
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT;
RUN;
```

```
/* IMPUTES REAR-SEAT 3-POINT BELT USE BASED ON LOGISTIC REGRESSION EQUATION */

DATA UNKBK32; SET UNKBK31;
IF NEWAGE GE 17 THEN FEMALE=GENDER-1;
 ELSE IF 6 LE NEWAGE LE 13 THEN FEMALE=.5;
 ELSE IF 14 LE NEWAGE LE 16 THEN FEMALE=.5*GENDER-.25;
PRETEEN=0; TEEN=0; ADULT=0; OLD=0;
 IF 6 LE NEWAGE LE 12 THEN PRETEEN=1;
 ELSE IF 13 LE NEWAGE LE 20 THEN TEEN=20-NEWAGE;
 ELSE IF 30 LE NEWAGE LE 79 THEN ADULT=NEWAGE-30;
 ELSE IF 80 LE NEWAGE LE 97 THEN OLD=1;
TWODOOR=0; VAN=0; OTHR_TRK=0;
 IF NEWVTYP IN (1,2) THEN TWODOOR=1;
 ELSE IF NEWVTYP=9 THEN TWODOOR=.5;
 ELSE IF NEWVTYP IN (11,12,19) THEN OTHR_TRK=1;
 ELSE IF NEWVTYP=13 THEN VAN=1;
CY7589=0; CY9094=0; CY9599=0;
IF 1975 LE CY LE 1989 THEN CY7589=1;
 ELSE IF 1990 LE CY LE 1994 THEN CY9094=1;
 ELSE IF 1995 LE CY LE 1999 THEN CY9599=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;
VEH_AGE=CY-XMY; IF VEH_AGE LT 0 THEN VEH_AGE=0;
CENREAR=0; IF SEAT2=22 THEN CENREAR=1;

Z=-1.4715+1.5495*PRETEEN+.1042*TEEN+.0294*ADULT+1.3595*OLD+.3314*FEMALE;
Z=Z-.1506*TWODOOR+.0012*VAN-.3215*OTHR_TRK-.0303*VEH_AGE;
Z=Z-.7777*CY7589-.4001*CY9094-.2469*CY9599;
Z=Z+.2107*SIDE-.6045*ROLL+.2894*REAROTHR-.6754*CENREAR;
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT;
RUN;

/* IMPUTES LAP BELT USE BASED ON LOGISTIC REGRESSION EQUATION */

DATA UNKLAP2; SET UNKLAP1;
PRE_STD=0;
 IF SEAT2 IN (11,13) AND XMY LT 1964 THEN PRE_STD=1;
 ELSE IF SEAT2=21 AND XMY LT 1966 THEN PRE_STD=1;
 ELSE IF SEAT2 IN (12,22) AND XMY LT 1968 THEN PRE_STD=1;
IF NEWAGE GE 17 THEN FEMALE=GENDER-1;
 ELSE IF 6 LE NEWAGE LE 13 THEN FEMALE=.5;
 ELSE IF 14 LE NEWAGE LE 16 THEN FEMALE=.5*GENDER-.25;
PRETEEN=0; TEEN=0; ADULT=0; OLD=0;
 IF 6 LE NEWAGE LE 12 THEN PRETEEN=1;
 ELSE IF 13 LE NEWAGE LE 20 THEN TEEN=20-NEWAGE;
 ELSE IF 30 LE NEWAGE LE 79 THEN ADULT=NEWAGE-30;
 ELSE IF 80 LE NEWAGE LE 97 THEN OLD=1;
TWODOOR=0; PICKUP=0; SUV_VAN=0;
 IF NEWVTYP IN (1,2) THEN TWODOOR=1;
 ELSE IF NEWVTYP=9 THEN TWODOOR=.63;
 ELSE IF NEWVTYP=11 THEN PICKUP=1;
 ELSE IF NEWVTYP IN (12,13) THEN SUV_VAN=1;
 ELSE IF NEWVTYP=19 THEN DO; PICKUP=.72; SUV_VAN=.28; END;
CY7579=0; CY8084=0; CY8589=0; CY9094=0; CY9599=0;
IF 1975 LE CY LE 1979 THEN CY7579=1;
 ELSE IF 1980 LE CY LE 1984 THEN CY8084=1;
 ELSE IF 1985 LE CY LE 1989 THEN CY8589=1;
 ELSE IF 1990 LE CY LE 1994 THEN CY9094=1;
 ELSE IF 1995 LE CY LE 1999 THEN CY9599=1;
CENFRONT=0; RTFRONT=0; OUTBRD_R=0; CENREAR=0;
 IF SEAT2=12 THEN CENFRONT=1;
 ELSE IF SEAT2=13 THEN RTFRONT=1;
 ELSE IF SEAT2=21 THEN OUTBRD_R=1;
 ELSE IF SEAT2=22 THEN CENREAR=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;
VEH_AGE=CY-XMY; IF VEH_AGE LT 0 THEN VEH_AGE=0;
```

```
Z=-.3189+1.1862*PRETEEN+.0323*TEEN+.0204*ADULT+1.1997*OLD;
Z=Z-.2945*PRE_STD-1.2292*CENFRONT-.1795*RTFRONT-.7338*OUTBRD_R-1.6522*CENREAR;
Z=Z+.4191*FEMALE-.0717*TWODOOR-.8322*PICKUP-.0642*SUV_VAN-.0535*VEH_AGE;
Z=Z-3.0443*CY7579-3.2209*CY8084-1.4020*CY8589-.7785*CY9094-.3090*CY9599;
Z=Z+.0432*SIDE-.1522*ROLL+.0675*REAROTHR;
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT;
RUN;
```

The imputation procedure for child passengers < 6 years old is performed in two steps. First, each case with completely unknown restraint use is split into two cases based on the first logistic regression equation in LKIDRES4: one unrestrained, one restrained, type unknown. Next, the restrained cases generated from this procedure, plus the already existing cases of children that were restrained, type unknown are split into two cases based on the second equation in LKIDRES4: one in a safety seat, one in a lap belt only.

```
/* IMPUTES RESTRAINED AND UNRESTRAINED INFANTS/TODDLERS */

DATA UNKKID3 UNKKID4; SET UNKKID1 UNKKID2(IN=KID2);
INFANT=0; AGE1=0; AGE2=0; AGE3=0; AGE4=0;
 IF NEWAGE=0 THEN INFANT=1; ELSE IF NEWAGE=1 THEN AGE1=1;
 ELSE IF NEWAGE=2 THEN AGE2=1; ELSE IF NEWAGE=3 THEN AGE3=1;
 ELSE IF NEWAGE=4 THEN AGE4=1;
IF VTYP=2 THEN LTRK=1; ELSE LTRK=0;
CY7576=0; CY7778=0; CY7980=0; CY81=0; CY82=0; CY83=0; CY84=0;
 CY85=0; CY86=0; CY87=0; CY88=0; CY89=0; CY90=0; CY91=0;
 CY92=0; CY93=0; CY94=0; CY95=0; CY96=0; CY97=0; CY98=0;
 CY2000=0; CY2001=0; CY2002=0;
IF CY IN (1975,1976) THEN CY7576=1;
 ELSE IF CY IN (1977,1978) THEN CY7778=1;
 ELSE IF CY IN (1979,1980) THEN CY7980=1;
 ELSE IF CY=1981 THEN CY81=1; ELSE IF CY=1982 THEN CY82=1;
 ELSE IF CY=1983 THEN CY83=1; ELSE IF CY=1984 THEN CY84=1;
 ELSE IF CY=1985 THEN CY85=1; ELSE IF CY=1986 THEN CY86=1;
 ELSE IF CY=1987 THEN CY87=1; ELSE IF CY=1988 THEN CY88=1;
 ELSE IF CY=1989 THEN CY89=1; ELSE IF CY=1990 THEN CY90=1;
 ELSE IF CY=1991 THEN CY91=1; ELSE IF CY=1992 THEN CY92=1;
 ELSE IF CY=1993 THEN CY93=1; ELSE IF CY=1994 THEN CY94=1;
 ELSE IF CY=1995 THEN CY95=1; ELSE IF CY=1996 THEN CY96=1;
 ELSE IF CY=1997 THEN CY97=1; ELSE IF CY=1998 THEN CY98=1;
 ELSE IF CY=2000 THEN CY2000=1; ELSE IF CY=2001 THEN CY2001=1;
 ELSE IF CY=2002 THEN CY2002=1;
IF SEAT2 IN (12,13,21,22);
 CENFRONT=0; RTFRONT=0; CENREAR=0;
 IF SEAT2=12 THEN CENFRONT=1;
 ELSE IF SEAT2=13 THEN RTFRONT=1;
 ELSE IF SEAT2=22 THEN CENREAR=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;

IF KID2 THEN DO; OUTPUT UNKKID4; RETURN; END;
ELSE DO;
Z=.3711+.7837*INFANT+.8726*AGE1+.5193*AGE2+.1485*AGE3+.1024*AGE4;
Z=Z-.0472*LTRK-3.4784*CY7576-3.5735*CY7778-3.0285*CY7980;
Z=Z-2.7536*CY81-2.4664*CY82-2.0078*CY83-1.5532*CY84-1.1660*CY85;
Z=Z-1.1936*CY86-1.0132*CY87-1.0726*CY88-1.0026*CY89- .9834*CY90;
Z=Z-.7092*CY91-.5285*CY92-.6801*CY93-.3309*CY94-.2090*CY95;
Z=Z-.0455*CY96-.0201*CY97+.0808*CY98;
Z=Z+.2306*CY2000+.1098*CY2001+.1525*CY2002;
Z=Z+.2874*SIDE-.5541*ROLL-.2060*REAROTHR;
Z=Z-1.4496*CENFRONT-.7022*RTFRONT-.7946*CENREAR;
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT UNKKID3;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT UNKKID4; END;
RUN;
```

```
/* IMPUTES IF THE RESTRAINED INFANTS/TODDLERS WERE IN CHILD SEATS OR LAP BELTS */

DATA UNKKID5; SET UNKKID4;
Z=-1.6869+5.6002*INFANT+4.5930*AGE1+3.4650*AGE2+2.7264*AGE3+1.2914*AGE4;
Z=Z-.0439*LTRK-1.2118*CY7576-1.5049*CY7778-1.0482*CY7980;
Z=Z- .9440*CY81- .5881*CY82- .2602*CY83- .3824*CY84- .3179*CY85;
Z=Z- .9094*CY86- .8220*CY87-1.1240*CY88- .7704*CY89- .4048*CY90;
Z=Z-.2422*CY91-.1682*CY92-.6909*CY93-.7306*CY94-.4925*CY95;
Z=Z-.4550*CY96-.3514*CY97-.6729*CY98;
Z=Z+.1257*CY2000-.1710*CY2001+.0451*CY2002;
Z=Z+.0723*SIDE+.0479*ROLL+.2250*REAROTHR;
Z=Z-.7766*CENFRONT-1.0595*RTFRONT+.0752*CENREAR;
KIDSEAT=EXP(Z)/(1+EXP(Z)); LAPBELT=1-KIDSEAT;
O1=ORIGWT; W1=WEIGHTFA;
REST2=2; ORIGWT=LAPBELT * O1; WEIGHTFA=LAPBELT * W1; OUTPUT;
REST2=4; ORIGWT=KIDSEAT * O1; WEIGHTFA=KIDSEAT * W1; OUTPUT;
RUN;
```

UNKBELT2 contains all the newly created CY 1975-2002 cases with known restraint use.

```
DATA UNKBELT2;
SET UNK3PT2 UNK2PT2 UNKBK32 UNKLAP2 UNKKID3 UNKKID5;
DROP GENDER NEWAGE Z BELTED UNBELTED O1 W1 PRETEEN TEEN ADULT OLD FEMALE
 CONVRTBL TWODOOR STAWAGON UNK_CAR PICKUP SUV VAN UNK_LTRK
 VEH_AGE CY7576 CY7778 CY7980 CY81-CY98 CY2000 CY2001 SIDE ROLL REAROTHR RTFRONT
 MOTOR OTHR_TRK CY7589 CY9094 PRE_STD CENFRONT OUTBRD_R CENREAR SUV_VAN
 CY7579 CY8084 CY8589 KIDSEAT LAPBELT;
RUN;
```

Same imputation approach for CY 2003 to 2012, except the regression formulas are based on the programs L3PT14, L2PT14, LBK3PT14, L_LAP14, & LKIDRES14, which use 2003-2012 data and create NEW_UNKBELT2.

```
/* ----------------------------------------------------------------- */
/* IMPUTATION FOR CY 2003-2012 BASED ON LOGISTIC REGRESSION MODELS    */
/* FROM L3PT14, L2PT14, LBK3PT14, L_LAP14, & LKIDRES14                */
/* ----------------------------------------------------------------- */

DATA UNK3PT1 UNK2PT1 UNKBK31 UNKLAP1 UNKKID1 UNKKID2;
SET NEW_UNKBELT1;
GENDER=SEX; IF GENDER NE 2 THEN GENDER=1;
IF 0 LE AGE LE 97 THEN NEWAGE=AGE; ELSE NEWAGE=30;
 IF PER_TYP=1 AND AGE LT 14 THEN NEWAGE=30;
IF 0 LE AGE LE 5 AND PER_TYP=2 AND REST2=8 THEN OUTPUT UNKKID2;
ELSE IF SEAT2=11 THEN DO;
 IF FTLS=2 THEN OUTPUT UNK2PT1;
 ELSE IF FTLS IN (3,4,8) THEN OUTPUT UNK3PT1;
 ELSE OUTPUT UNKLAP1; END;
ELSE IF SEAT2=13 THEN DO;
 IF 0 LE AGE LE 5 THEN OUTPUT UNKKID1;
 ELSE IF FTLS IN (2,4) THEN OUTPUT UNK2PT1;
 ELSE IF FTLS IN (3,8) THEN OUTPUT UNK3PT1;
 ELSE OUTPUT UNKLAP1; END;
ELSE IF SEAT2=21 THEN DO;
 IF 0 LE AGE LE 5 THEN OUTPUT UNKKID1;
 ELSE IF BKLS=3 THEN OUTPUT UNKBK31;
 ELSE OUTPUT UNKLAP1; END;
ELSE IF SEAT2=22 THEN DO;
 IF 0 LE AGE LE 5 THEN OUTPUT UNKKID1;
 ELSE IF BELT22=1 THEN OUTPUT UNKBK31;
 ELSE OUTPUT UNKLAP1; END;
ELSE IF SEAT2=12 THEN DO;
 IF 0 LE AGE LE 5 THEN OUTPUT UNKKID1;
 ELSE OUTPUT UNKLAP1; END;
RUN;

/* IMPUTES FRONT-SEAT 3-POINT BELT USE BASED ON LOGISTIC REGRESSION EQUATION */

DATA UNK3PT2; SET UNK3PT1;
```

```
IF NEWAGE GE 17 THEN FEMALE=GENDER-1;
 ELSE IF 6 LE NEWAGE LE 13 THEN FEMALE=.5;
 ELSE IF 14 LE NEWAGE LE 16 THEN FEMALE=.5*GENDER-.25;
PRETEEN=0; TEEN=0; ADULT=0; OLD=0;
 IF 6 LE NEWAGE LE 12 THEN PRETEEN=1;
 ELSE IF 13 LE NEWAGE LE 20 THEN TEEN=20-NEWAGE;
 ELSE IF 30 LE NEWAGE LE 79 THEN ADULT=NEWAGE-30;
 ELSE IF 80 LE NEWAGE LE 97 THEN OLD=1;
CONVRTBL=0; TWODOOR=0; STAWAGON=0; UNK_CAR=0; PICKUP=0; SUV=0; VAN=0; UNK_LTRK=0;
 IF NEWVTYP=1 THEN CONVRTBL=1;
 ELSE IF NEWVTYP=2 THEN TWODOOR=1;
 ELSE IF NEWVTYP=6 THEN STAWAGON=1;
 ELSE IF NEWVTYP=9 THEN UNK_CAR=1;
 ELSE IF NEWVTYP=11 THEN PICKUP=1;
 ELSE IF NEWVTYP=12 THEN SUV=1;
 ELSE IF NEWVTYP=13 THEN VAN=1;
 ELSE IF NEWVTYP=19 THEN UNK_LTRK=1;
CY2004=0; CY2005=0; CY2006=0; CY2007=0; CY2008=0; CY2009=0; CY2010=0; CY2011=0; CY2012=0;
IF CY=2004 THEN CY2004=1; ELSE IF CY=2005 THEN CY2005=1;
 ELSE IF CY=2006 THEN CY2006=1; ELSE IF CY=2007 THEN CY2007=1;
 ELSE IF CY=2008 THEN CY2008=1; ELSE IF CY=2009 THEN CY2009=1;
 ELSE IF CY=2010 THEN CY2010=1; ELSE IF CY=2011 THEN CY2011=1;
 ELSE IF CY=2012 THEN CY2012=1;
RTFRONT=0; IF SEAT2=13 THEN RTFRONT=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;
VEH_AGE=CY-XMY; IF VEH_AGE LT 0 THEN VEH_AGE=0;

Z=-.3301+.8845*PRETEEN+.0723*TEEN+.0260*ADULT+1.3019*OLD+.4328*FEMALE;
Z=Z+.0143*CONVRTBL-.1102*TWODOOR+.1951*STAWAGON-.2871*UNK_CAR;
Z=Z-.6507*PICKUP-.3576*SUV-.0934*VAN-.5956*UNK_LTRK-.0407*VEH_AGE;
Z=Z+.0590*CY2004+.0763*CY2005+.1175*CY2006+.1726*CY2007+.1537*CY2008;
Z=Z+.2329*CY2009+.3171*CY2010+.3133*CY2011+.3470*CY2012;
Z=Z+.4141*SIDE-.4559*ROLL+.1510*REAROTHR+.0305*RTFRONT;
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT;
RUN;

/* IMPUTES AUTOMATIC 2-POINT BELT USE BASED ON LOGISTIC REGRESSION EQUATION */

DATA UNK2PT2; SET UNK2PT1;
IF PASSIVE IN (606,707,1006,1606) THEN MOTOR=0; ELSE MOTOR=1;
IF NEWAGE GE 17 THEN FEMALE=GENDER-1;
 ELSE IF 6 LE NEWAGE LE 13 THEN FEMALE=.5;
 ELSE IF 14 LE NEWAGE LE 16 THEN FEMALE=.5*GENDER-.25;
PRETEEN=0; TEEN=0; ADULT=0; OLD=0;
 IF 6 LE NEWAGE LE 12 THEN PRETEEN=1;
 ELSE IF 13 LE NEWAGE LE 20 THEN TEEN=20-NEWAGE;
 ELSE IF 30 LE NEWAGE LE 79 THEN ADULT=NEWAGE-30;
 ELSE IF 80 LE NEWAGE LE 97 THEN OLD=1;
RTFRONT=0; IF SEAT2=13 THEN RTFRONT=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;
VEH_AGE=CY-XMY; IF VEH_AGE LT 0 THEN VEH_AGE=0;

Z=-.6405+.2666*MOTOR+.9827*PRETEEN+.0693*TEEN+.0264*ADULT+1.6522*OLD+.3554*FEMALE;
Z=Z+.0321*VEH_AGE+.2200*SIDE-.7342*ROLL-.0231*REAROTHR-.0336*RTFRONT;
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT;
RUN;

/* IMPUTES REAR-SEAT 3-POINT BELT USE BASED ON LOGISTIC REGRESSION EQUATION */

DATA UNKBK32; SET UNKBK31;
IF NEWAGE GE 17 THEN FEMALE=GENDER-1;
 ELSE IF 6 LE NEWAGE LE 13 THEN FEMALE=.5;
 ELSE IF 14 LE NEWAGE LE 16 THEN FEMALE=.5*GENDER-.25;
PRETEEN=0; TEEN=0; ADULT=0; OLD=0;
```

```
 IF 6 LE NEWAGE LE 12 THEN PRETEEN=1;
 ELSE IF 13 LE NEWAGE LE 20 THEN TEEN=20-NEWAGE;
 ELSE IF 30 LE NEWAGE LE 79 THEN ADULT=NEWAGE-30;
 ELSE IF 80 LE NEWAGE LE 97 THEN OLD=1;
TWODOOR=0; VAN=0; OTHR_TRK=0;
 IF NEWVTYP IN (1,2) THEN TWODOOR=1;
 ELSE IF NEWVTYP=9 THEN TWODOOR=.5;
 ELSE IF NEWVTYP IN (11,12,19) THEN OTHR_TRK=1;
 ELSE IF NEWVTYP=13 THEN VAN=1;
CY0608=0; CY0912=0;
IF 2006 LE CY LE 2008 THEN CY0608=1;
 ELSE IF 2009 LE CY LE 2012 THEN CY0912=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;
VEH_AGE=CY-XMY; IF VEH_AGE LT 0 THEN VEH_AGE=0;
CENREAR=0; IF SEAT2=22 THEN CENREAR=1;

Z=-1.4160+1.7773*PRETEEN+.1264*TEEN+.0305*ADULT+1.5817*OLD+.3170*FEMALE;
Z=Z-.1508*TWODOOR-0.0586*VAN-.4501*OTHR_TRK-.0377*VEH_AGE;
Z=Z+.2172*CY0608+.3897*CY0912;
Z=Z+.2822*SIDE-.5554*ROLL+.3564*REAROTHR-.9219*CENREAR;
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT;
RUN;

/* IMPUTES LAP BELT USE BASED ON LOGISTIC REGRESSION EQUATION */

DATA UNKLAP2; SET UNKLAP1;
PRE_STD=0;
 IF SEAT2 IN (11,13) AND XMY LT 1964 THEN PRE_STD=1;
 ELSE IF SEAT2=21 AND XMY LT 1966 THEN PRE_STD=1;
 ELSE IF SEAT2 IN (12,22) AND XMY LT 1968 THEN PRE_STD=1;
IF NEWAGE GE 17 THEN FEMALE=GENDER-1;
 ELSE IF 6 LE NEWAGE LE 13 THEN FEMALE=.5;
 ELSE IF 14 LE NEWAGE LE 16 THEN FEMALE=.5*GENDER-.25;
PRETEEN=0; TEEN=0; ADULT=0; OLD=0;
 IF 6 LE NEWAGE LE 12 THEN PRETEEN=1;
 ELSE IF 13 LE NEWAGE LE 20 THEN TEEN=20-NEWAGE;
 ELSE IF 30 LE NEWAGE LE 79 THEN ADULT=NEWAGE-30;
 ELSE IF 80 LE NEWAGE LE 97 THEN OLD=1;
TWODOOR=0; PICKUP=0; SUV_VAN=0;
 IF NEWVTYP IN (1,2) THEN TWODOOR=1;
 ELSE IF NEWVTYP=9 THEN TWODOOR=.63;
 ELSE IF NEWVTYP=11 THEN PICKUP=1;
 ELSE IF NEWVTYP IN (12,13) THEN SUV_VAN=1;
 ELSE IF NEWVTYP=19 THEN DO; PICKUP=.72; SUV_VAN=.28; END;
CY0608=0; CY0912=0;
IF 2006 LE CY LE 2008 THEN CY0608=1;
 ELSE IF 2009 LE CY LE 2012 THEN CY0912=1;
CENFRONT=0; RTFRONT=0; OUTBRD_R=0; CENREAR=0;
 IF SEAT2=12 THEN CENFRONT=1;
 ELSE IF SEAT2=13 THEN RTFRONT=1;
 ELSE IF SEAT2=21 THEN OUTBRD_R=1;
 ELSE IF SEAT2=22 THEN CENREAR=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;
VEH_AGE=CY-XMY; IF VEH_AGE LT 0 THEN VEH_AGE=0;

Z=-.9533+1.8735*PRETEEN+.0504*TEEN+.0282*ADULT+1.5075*OLD;
Z=Z-.7446*PRE_STD-0.7579*CENFRONT+.0681*RTFRONT-1.0133*OUTBRD_R-1.4237*CENREAR;
Z=Z+.3207*FEMALE-.0618*TWODOOR-.6806*PICKUP-.2776*SUV_VAN-.0117*VEH_AGE;
Z=Z+.0115*CY0608+.2717*CY0912;
Z=Z+.1322*SIDE-.4537*ROLL+.3580*REAROTHR;
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT;
RUN;
```

```
/* IMPUTES RESTRAINED AND UNRESTRAINED INFANTS/TODDLERS */

DATA UNKKID3 UNKKID4; SET UNKKID1 UNKKID2(IN=KID2);
INFANT=0; AGE1=0; AGE2=0; AGE3=0; AGE4=0;
 IF NEWAGE=0 THEN INFANT=1; ELSE IF NEWAGE=1 THEN AGE1=1;
 ELSE IF NEWAGE=2 THEN AGE2=1; ELSE IF NEWAGE=3 THEN AGE3=1;
 ELSE IF NEWAGE=4 THEN AGE4=1;
IF VTYP=2 THEN LTRK=1; ELSE LTRK=0;
CY0608=0; CY0912=0;
IF 2006 LE CY LE 2008 THEN CY0608=1;
 ELSE IF 2009 LE CY LE 2012 THEN CY0912=1;
IF SEAT2 IN (12,13,21,22);
 CENFRONT=0; RTFRONT=0; CENREAR=0;
 IF SEAT2=12 THEN CENFRONT=1;
 ELSE IF SEAT2=13 THEN RTFRONT=1;
 ELSE IF SEAT2=22 THEN CENREAR=1;
SIDE=0; ROLL=0; REAROTHR=0;
 IF CRSH=2 THEN SIDE=1; ELSE IF CRSH=3 THEN ROLL=1; ELSE IF CRSH=4 THEN REAROTHR=1;

IF KID2 THEN DO; OUTPUT UNKKID4; RETURN; END;
ELSE DO;
Z=.7520+.9713*INFANT+.7628*AGE1+.4524*AGE2+.2176*AGE3+.2814*AGE4;
Z=Z-.3275*LTRK+.1299*CY0608+.2196*CY0912;
Z=Z+.3172*SIDE-.6467*ROLL+.4361*REAROTHR;
Z=Z-1.5824*CENFRONT-1.3781*RTFRONT-.5325*CENREAR;
BELTED=EXP(Z)/(1+EXP(Z)); UNBELTED=1-BELTED;
O1=ORIGWT; W1=WEIGHTFA;
REST2=0; ORIGWT=UNBELTED* O1; WEIGHTFA=UNBELTED* W1; OUTPUT UNKKID3;
REST2=8; ORIGWT= BELTED * O1; WEIGHTFA= BELTED * W1; OUTPUT UNKKID4; END;
RUN;

/* IMPUTES IF THE RESTRAINED INFANTS/TODDLERS WERE IN CHILD SEATS OR LAP BELTS */

DATA UNKKID5; SET UNKKID4;
Z=-.2707+3.6780*INFANT+2.7431*AGE1+2.2772*AGE2+1.6875*AGE3+.6911*AGE4;
Z=Z+.1787*LTRK+.2294*CY0608+.7423*CY0912;
Z=Z+.1267*SIDE+.2249*ROLL-.1351*REAROTHR;
Z=Z-1.0683*CENFRONT-1.6816*RTFRONT-.2425*CENREAR;
KIDSEAT=EXP(Z)/(1+EXP(Z)); LAPBELT=1-KIDSEAT;
O1=ORIGWT; W1=WEIGHTFA;
REST2=2; ORIGWT=LAPBELT * O1; WEIGHTFA=LAPBELT * W1; OUTPUT;
REST2=4; ORIGWT=KIDSEAT * O1; WEIGHTFA=KIDSEAT * W1; OUTPUT;
RUN;

DATA NEW_UNKBELT2;
SET UNK3PT2 UNK2PT2 UNKBK32 UNKLAP2 UNKKID3 UNKKID5;
DROP GENDER NEWAGE Z BELTED UNBELTED O1 W1 PRETEEN TEEN ADULT OLD FEMALE
 CONVRTBL TWODOOR STAWAGON UNK_CAR PICKUP SUV VAN UNK_LTRK
 CY2004 CY2005 CY2006 CY2007 CY2008 CY2009 CY2010 CY2011
 VEH_AGE CY0608 CY0911 SIDE ROLL REAROTHR RTFRONT
 MOTOR OTHR_TRK PRE_STD CENFRONT OUTBRD_R CENREAR SUV_VAN
 KIDSEAT LAPBELT;
RUN;
```

UNKBELT2 and NEW_UNKBELT2 are appended to OCC6, the original cases with known restraint use, creating OCC7, a file on which all cases have known restraint use (and seating positions and crash modes).

REST3 edits REST2, assigning a specific restraint type to every restrained occupant on the file (and REST3 = 0 for unrestrained occupants).

- Every restrained child < 6 years old is either in a child safety seat (REST3 = 4) or in a lap belt (REST3 = 2), without distinguishing if the seat was correctly used; even if the belt is a 3-point belt, it will be considered “lap belt only” for children that age.

- Children age 6-9 that FARS explicitly states were in child safety seats (REST_USE = 4) will be considered in booster seats (REST3 = 4). All other children age 6 to 9 will be included with "adults" in the remaining categories.
- Every restrained adult in a seat equipped with integral (manual or automatic) 3-point belts will be considered as restrained with a 3-point belt (REST3 = 3), without distinguishing that some of these may have been incorrectly worn and, in effect, acted like just a lap belt.
- Every restrained adult in a seat equipped with automatic 2-point belts will be considered as restrained with a 2-point belt (REST3 = 7), without distinguishing between people who also wore the manual lap belt, if one was available, and those who did not.
- In seats equipped with separate lap and shoulder belts, restrained adults will only be considered as having worn both belts (REST3 = 3) if FARS explicitly stated that the lap and shoulder belts were used (REST_USE = 3). All other restrained adults, including the imputed cases will be assumed to have worn only the lap belt (REST3 = 2). These assumptions are most consistent with observational surveys that showed separate shoulder belts were only used by about 15-25 percent of the people who buckled the lap belt.
- Restrained adults in 1975-80 VW Rabbits – vehicles where it is impossible to tell if they had 3-point or 2-point belts, but the 3-point belts were more common – will only be considered as 2-point belted if REST_USE = 1,8 or AUT_REST = 1,5.
- And, of course, in seats equipped only with lap belts, restrained adults will be considered lap-belted.

```
/* ----------------------------------------------------------------- */
/* EVERY OCCUPANT CASE IS NOW ASSIGNED A SPECIFIC BELT TYPE, REST3     */
/* (OR UNRESTRAINED) ACCORDING TO REST2, SEAT2, FTLS, BKLS, & BELT22   */
/* ----------------------------------------------------------------- */

DATA OCC7; SET OCC6 UNKBELT2 NEW_UNKBELT2;
IF REST2 IN (0,4) THEN REST3=REST2;
 ELSE IF 0 LE AGE LE 5 THEN REST3=2;
 ELSE IF SEAT2=12 THEN REST3=2;
 ELSE IF SEAT2=22 AND BELT22=1 THEN REST3=3;
 ELSE IF SEAT2=22 THEN REST3=2;
 ELSE IF SEAT2=21 AND BKLS=3 THEN REST3=3;
 ELSE IF SEAT2=21 THEN REST3=2;
 ELSE IF FTLS=3 THEN REST3=3;
 ELSE IF FTLS=2 THEN REST3=7;
 ELSE IF FTLS=1 THEN REST3=2;
 ELSE IF FTLS=4 AND SEAT2=11 THEN REST3=3;
 ELSE IF FTLS=4 AND SEAT2=13 THEN REST3=7;
 ELSE IF FTLS IN (5,6,7) AND REST2=3 THEN REST3=3;
 ELSE IF FTLS IN (5,6,7) THEN REST3=2;
 ELSE IF FTLS=8 AND REST2 IN (1,7,8) THEN REST3=7;
 ELSE IF FTLS=8 THEN REST3=3;
```

The two variables RESTGP and KCRSH are used for estimating the effect of frontal air bags on the risk of a child passenger. Note: KCRSH = 1 to 4 with barrier-certified air bags, 11 to 14 with sled-certified, 21 to 24 with advanced.

```
/* ----------------------------------------------------------------- */
/* CLASSIFICATION OF CHILD FRONT-SEAT PASSENGERS EXPOSED TO AIR BAGS   */
/* BY AGE, RESTRAINT USE, IMPACT LOCATION, & TYPE OF AIR BAG           */
/* ----------------------------------------------------------------- */

IF 0 LE AGE LE 12 AND SEAT2 IN (12,13,18) AND PASSIVE IN (2,3,1313) THEN DO;
  IF AGE=0 AND REST3=4 THEN RESTGP=1;
    ELSE IF AGE=0 AND REST3 IN (0,2,3,7) THEN RESTGP=2;
    ELSE IF 1 LE AGE LE 5 AND REST3=0 THEN RESTGP=3;
    ELSE IF 1 LE AGE LE 5 AND REST3=4 THEN RESTGP=4;
    ELSE IF 1 LE AGE LE 5 AND REST3 IN (2,3,7) THEN RESTGP=5;
    ELSE IF 6 LE AGE LE 10 AND REST3=0 THEN RESTGP=6;
```

```
     ELSE IF 6 LE AGE LE 10 AND REST3 IN (2,3,4,7) THEN RESTGP=7;
     ELSE IF 11 LE AGE LE 12 AND REST3=0 THEN RESTGP=8;
     ELSE IF 11 LE AGE LE 12 AND REST3 IN (2,3,7) THEN RESTGP=9;

   IF REDES=0 OR XMY LE 1991 THEN DO;   /* 1st GENERATION AIR BAGS: FOR CALCULATING ACTUAL INCREASE IN CHILD
PASSENGER FATALITIES */
      IF IMPACT2=12 OR IMPACT1=12 THEN KCRSH=1;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR IMPACT1 IN (1,11) THEN KCRSH=2;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR IMPACT1 IN (2,10) THEN KCRSH=3;
      ELSE KCRSH=4; END;
   ELSE IF REDES=1 AND CAC=0 THEN DO;   /* SLED-CERTIFIED AIR BAGS: ACTUAL INCREASE; ALSO SAVINGS REL TO 1st
GENERATION */
      IF IMPACT2=12 OR IMPACT1=12 THEN KCRSH=11;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR IMPACT1 IN (1,11) THEN KCRSH=12;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR IMPACT1 IN (2,10) THEN KCRSH=13;
      ELSE KCRSH=14; END;
   ELSE IF CAC=1 THEN DO;              /* CAC AIR BAGS: HYPOTHETICAL INCREASES IF BAGS HAD STILL BEEN 1st GENER-
ATION OR SLED-CERTIFIED */
      IF IMPACT2=12 OR IMPACT1=12 THEN KCRSH=21;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR IMPACT1 IN (1,11) THEN KCRSH=22;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR IMPACT1 IN (2,10) THEN KCRSH=23;
      ELSE KCRSH=24; END; END;
```

List of make-models that had manual on-off switches for passenger air bags at some time but then dropped them when the make-model received advanced (CAC) air bags or some years after that.

```
/* ------------------------------------------------------------------ */
/* MAKE-MODELS THAT HAD ON-OFF SWITCHES BUT DROPPED THEM AFTER CAC     */
/* FOR CALCULATING HYPOTHETICAL ADULT FATALITIES IF SWITCH WERE OFF    */
/* ------------------------------------------------------------------ */

IF CAC=1 AND (MM2=2321 OR XMM2 IN (20004,32045,41045,
  2321,7200:7203,7210,7211,7220,7221,7230,7231,7236,7237,7520,7521,7530,7531,7536,7537,
  12200:12205,12210:12213,12220:12223,12230:12233,12520:12523,12530:12533,
  20038,20200:20203,20210:20213,20220:20223,20230:20233,20520:20523,20530:20533,
  23200:23203,23210:23213,23218,23220:23223,23230:23233,23520:23523,23530:23533,
  35202,35203,35212,35213,41200:41205,49200:49203,49210:49213,52202,52203)) THEN SWITCH_MM=1; ELSE SWITCH_MM=0;
RUN;

proc freq data=occ7; weight origwt; format rest2 REST3 newrest. CRSH CRSH. SEAT2 NEWSEAT.;
 tables rest2 REST3 CRSH SEAT2;
TITLE 'REST2, REST3, SEAT2 & CRSH IN OCC7 AFTER IMPUTING AND DISTRIBUTING UNKNOWNS';
run;

PROC FREQ DATA=OCC7; WEIGHT ORIGWT; FORMAT REST3 NEWREST.;
 TABLES CY * REST3 / NOCOL NOPERCENT;
TITLE 'RESTRAINT USE BY CALENDAR YEAR, 1975-2012 AFTER IMPUTING AND DISTRIBUTING UNKNOWNS';
run;

PROC FREQ DATA=OCC7; WEIGHT ORIGWT; FORMAT SEAT2 NEWSEAT. REST3 NEWREST.;
 TABLES SEAT2 * REST3 / NOCOL NOPERCENT;
TITLE 'RESTRAINT USE BY SEATING POSITION, 1975-2012 AFTER IMPUTING AND DISTRIBUTING UNKNOWNS';
run;
```

This completes the preprocessor. OCC7 is a file in which every record has non-missing values for all the variables needed to estimate lives saved by safety technologies, and whose ORIGWTs (and WEIGHTFAs) add up to the total number of car and LTV occupant fatalities from 1975 to 2012.

```
/* ----------------------------------------------------------------- */
/* SPLIT THE CAR AND LIGHT-TRUCK OCCUPANT CASES INTO SEPARATE FILES   */
/* ----------------------------------------------------------------- */
```

OCC7 is split into CAR1 and TRK1 because the main model is run separately for cars and for LTVs (because the safety technologies were introduced in a different chronological order, and the effectiveness is sometimes different in cars and LTVs). Also, the preprocessor changed the order of the cases because the imputed cases were, at each step, appended at the end of the file. In order to tally up lives saved by calendar year, it is necessary to sort CAR1 and TRK1 by CY.

```
DATA CAR1 TRK1; SET OCC7;
IF VTYP=1 THEN OUTPUT CAR1; ELSE OUTPUT TRK1;
RUN;

PROC SORT DATA=CAR1; BY CY;
RUN;

PROC SORT DATA=TRK1; BY CY;
RUN;

/* ---------------------------------------------------------------- */
/* ---------------------------------------------------------------- */
/*  THE OCCUPANT CASES ARE NOW FREE OF UNKNOWNS ON ANY VARIABLES      */
/*  AND WEIGHTED TO TOTAL UP TO THE ORIGINAL SAMPLE SIZE              */
/*                                                                    */
/*  WE MAY NOW CALCULATE THE LIVES SAVED BY THE VEHICLE SAFETY        */
/*  STANDARDS IN THE REVERSE ORDER OF THEIR IMPLEMENTATION            */
/*                                                                    */
/*  PASSENGER CARS FIRST                                              */
/* ---------------------------------------------------------------- */
/* ---------------------------------------------------------------- */
```

When the notes mention "NHTSA evaluations" and "effectiveness estimates," they are generally discussed in Part 1 of this report, in the chapter for that FMVSS and subsection for that technology. Footnotes/references are provided here only for analyses not discussed in Part 1.

Three "tags" of information accompany each case as it processes through the model:

- ORIGWT, the original case weight defined by the preprocessor, remains unchanged in the main model.
- WEIGHTFA, the inflated case weight, grows as safety technologies are "removed" from the vehicle. The existence of ORIGWT fatalities in a vehicle equipped with safety technologies implies that there would have been WEIGHTFA fatalities if the vehicle had no safety technologies at all, in the sense that the combined effectiveness of these technologies would reduce WEIGHTFA fatalities to ORIGWT fatalities.
- EJECT2, the probability that an occupant was ejected. Initially, EJECT2 is either 1 (if the occupant was ejected) or 0 (if not ejected or unknown[623]). However, some safety technologies, such as belts, can reduce the probability of ejection, whereas other technologies, such as improved door locks, are effective only if the occupant was ejected. Thus, it is necessary to track the occupant's changing probability of ejection as technologies are removed from the vehicle one-by-one.

```
DATA CAR2; SET CAR1;
IF EJECTION IN (1,2) OR (CY GE 2008 AND EJECTION=3) THEN EJECT2=1; ELSE EJECT2=0; /* NEW VALUE FOR EJECTION */
```

Curtains that deploy in rollovers, already available in many LTVs and some passenger cars even before the phase-in of FMVSS No. 226, "Ejection mitigation," are the most recent safety technology for which an effectiveness estimate is available, so they will be the first technology that the model "removes" from the car. The basic procedure of the model was discussed in detail, above, in the analysis the effect of brake improvements on pedestrian crashes.

```
/* ---------------------------------------------------------------- */
/*  226 ROLLOVER CURTAINS                                             */
/*  MEDIAN INSTALLATION YEAR: AFTER 2011  PHASE-IN STARTS MY 2014     */
/* ---------------------------------------------------------------- */
```

[623] Tabulation of EJECTION by calendar year suggests that, in the early years, especially 1975-76, "unknown" essentially means not ejected. From 1985 onward, well under 1 percent are unknown if ejected.

The variable ROLLCURT on LSM2014C equals 1 if the car has rollover curtains, 0 if it does not, or some fraction x if they were optional equipment (not VIN-identifiable) on that proportion of the cars of that make-model and model year. Because it is still before the MY 2014 start of the phase-in of FMVSS No. 226, PS226 = 0 in 1975 to 2013, and only PV2226 can be > 0. PV226 = ROLLCURT if the occupant was a driver or RF passenger in a first-event rollover and PV226 = 0 for all other occupants. Because NHTSA's evaluation only showed the curtains were effective in first-event rollovers, it is necessary to have a detailed definition of such rollovers rather than using CRSH = 3 (which would have included some subsequent-event rollovers).

```
/* IDENTIFIES CARS WITH ROLLOVER CURTAINS: DRIVERS & RF PASSENGERS IN FIRST-EVENT ROLLOVERS */
 PV226=0; PS226=0;
 IF ROLLCURT GT 0 AND SEAT2 IN (11,13) AND
   ((HARM_EV=1 AND VE_FORMS=1) OR (VE_FORMS=1 AND M_HARM=1 AND HARM_EV IN (33,34,38,41,44,48,53,54,59,60,72)))
        THEN PV226=ROLLCURT;
```

NHTSA's evaluation found a 41.3-percent reduction in fatalities in first-event rollovers.

```
/* LIVES SAVED IN FIRST-EVENT ROLLOVERS BY ROLLOVER CURTAINS */
  OLDWTFA=WEIGHTFA;
  IF PV226 OR PS226 GT 0 THEN DO;
    IF CY GE 2005 AND PER_TYP=3 AND AIR_BAG IN (.,0,20,28:32,97:99) THEN E=0;
   /* OCCUPANT OF A PARKED OR NON-TRANSPORT CAR: ASSUME NO BENEFIT UNLESS FARS SAYS DEPLOYMENT */
    ELSE E=.413;
    P=PV226+PS226;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS226=S*PS226/P;
    CLV226=S*PV226/P;
    WEIGHTFA=OLDWTFA+CLS226+CLV226; END;
  ELSE DO; CLV226=0; CLS226=0; END;
  CL226=CLS226+CLV226;
  CLS=CLS226; CLV=CLV226; CL=CL226;
```

CLV2226: "C" = car, "L" = lives saved, "V" = voluntary, "226" = rollover curtain
Note: CLS226, CLV226, CL226 are lives saved by rollover curtains; these results are stored and not changed again in this data step. WEIGHTFA, CLS, CLV, and CL are variables that will be changed repeatedly in this data step, at each point adding the fatalities attributable to removing a safety technology.

```
/* ------------------------------------------------------------------ */
/* 126 ELECTRONIC STABILITY CONTROL                                   */
/* MEDIAN INSTALLATION YEAR: 2010 PHASE-IN STARTED MY 2009            */
/* ------------------------------------------------------------------ */
```

ESC is a variable on LSM2014C whose values are always 0, 1, or a fraction in between. The phase-in of FMVSS No. 126 began in MY 2009.

```
/* IDENTIFIES CARS WITH ESC */
 PV126=0; PS126=0;
 IF ESC GT 0 THEN DO; IF 1998 LE XMY LE 2008 THEN PV126=ESC; ELSE IF 2009 LE XMY LE 2013 THEN PS126=ESC; END;
```

NHTSA's evaluation has fatal-crash reduction estimates for (1) first-event rollovers (59.54%); (2) all other single-vehicle crashes without non-occupants involved (31.26%); and (3) culpable involvements in multivehicle crashes (16.07%).

```
/* LIVES SAVED BY ESC IN CRASHES WHERE ESC IS BENEFICIAL */
  OLDWTFA=WEIGHTFA;
  IF PV126 OR PS126 GT 0 THEN DO;
/* IDENTIFY FIRST-EVENT ROLLOVERS, OTHER RUN-OFF-ROAD CRASHES, AND CULPABLE MULTI-VEHICLE INVOLVEMENTS */
    DRCF=0;         /* IN MULTI-VEHICLE CRASHES, DRCF=0 MEANS NOT CULPABLE, DRCF=1 MEANS CULPABLE */
    IF CY LE 2009 AND (DR_CF1 IN (3,6,8,26,27,28,30,31,33,35,36,38,39,44,46,47,48,50,51,57,58,79,87)
```

```
      OR DR_CF2 IN (3,6,8,26,27,28,30,31,33,35,36,38,39,44,46,47,48,50,51,57,58,79,87)
      OR DR_CF3 IN (3,6,8,26,27,28,30,31,33,35,36,38,39,44,46,47,48,50,51,57,58,79,87)
      OR DR_CF4 IN (3,6,8,26,27,28,30,31,33,35,36,38,39,44,46,47,48,50,51,57,58,79,87))
      THEN DRCF=1;
    ELSE IF CY GE 2010 AND (DR_SF1 IN (6,8,18,26:30,33:36,38,39,41,47,48,50,51,57,58)
      OR DR_SF2 IN (6,8,18,26:30,33:36,38,39,41,47,48,50,51,57,58)
      OR DR_SF3 IN (6,8,18,26:30,33:36,38,39,41,47,48,50,51,57,58)
      OR DR_SF4 IN (6,8,18,26:30,33:36,38,39,41,47,48,50,51,57,58))
      THEN DRCF=1;

    IF HARM_EV=1 AND VE_FORMS=1 THEN ESC_CRSH=1; /* FIRST-EVENT ROLLOVER */
        ELSE IF VE_FORMS=1 AND M_HARM=1 AND HARM_EV IN (33,34,38,41,44,48,53,54,58,59,60,72) THEN ESC_CRSH=1;
/* ALSO "1st EVENT ROLLOVER": CURB, DITCH, FENCE, SHRUBBERY, PAVEMENT IRREGULARITY, SNOWBANK, MAILBOX,
FALLING CARGO, GROUND, CARGO SHIFT IS 1st EVENT AND ROLLOVER IS MOST HARMFUL EVENT */
      ELSE IF HARM_EV IN (8,9,11,49) THEN ESC_CRSH=0;         /* PED/BIKE/ANIMAL (ESC NOT EFFECTIVE) */
      ELSE IF VE_FORMS=1 AND HARM_EV IN
(14,17,19,20,21,22,23,25,26,27,28,29,30,31,32,35,36,37,39,40,42,43,46,50,52,57,59)
         THEN ESC_CRSH=2;  /* RUN-OFF ROAD CRASH THAT IS NOT A 1st EVENT ROLLOVER */
/* FIXED-OBJECT COLLISIONS: 1st IMPACT WITH PARKED VEH, BOULDER, BUILDING, IMPACT ATTENUATOR, BRIDGE (ANY PART),
BARRIER (ANY TYPE), HIGHWAY SIGN POST, OVERHEAD SIGN, LIGHT SUPPORT, UTILITY POLE, OTHER    POST/POLE, CULVERT,
EMBANKMENT (ANY MATERIAL), WALL, FIRE HYDRANT, TREE, OTHER FIXED OBJECT, TRAFFIC  SIGNAL SUPPORT, BRIDGE OVER-
HEAD STRUCTURE - REGARDLESS OF SUBSEQUENT EVENTS */
       ELSE IF VE_FORMS=1 AND HARM_EV IN (24,33,34,38,41,44,48,53,57,58) AND
         M_HARM IN (24,33,34,38,41,48,52,53,57,14,17,19:23,25:32,35:37,39,40,42,43,46,50) THEN ESC_CRSH=2;
/* ALSO FIXED-OBJECT COLLISION: GUARDRAIL FACE, CURB, DITCH, FENCE, SHRUBBERY, PAVEMENT IRREGULARITY, SNOWBANK,
GUARDRAIL END, MAILBOX, CABLE BARRIER IS 1st EVENT AND MOST HARMFUL EVENT IS ONE OF THESE EXCEPT PAVEMENT IRREG-
ULARITY) OR ONE OF THE FIXED OBJECTS LISTED ABOVE */
       ELSE IF VE_FORMS=1 AND HARM_EV IN (3,24,52,33,34,38,41,53) THEN ESC_CRSH=2;
/* RAN-OFF-ROAD, NOT NECESSARILY FIXED OBJECT OR 1st EVENT ROLLOVER: IMMERSION, VARIOUS OFF-ROAD OBJECTS */
      ELSE IF CY LE 2009 AND (VEH_MAN IN (4,7) OR TRAV_SP=0) THEN ESC_CRSH=0;      /* STOPPED/PARKED (ESC NOT
EFFECTIVE) */
      ELSE IF CY GE 2010 AND (P_CRASH1 IN (5,7) OR TRAV_SP=0) THEN ESC_CRSH=0;      /* STOPPED/PARKED (ESC NOT
EFFECTIVE) */
          ELSE IF CY GE 2005 AND PER_TYP=3 THEN ESC_CRSH=0;                      /* OCCS OF PARKED VEHS (ESC NOT
EFFECTIVE) */
      ELSE IF CY LE 2009 AND (VEH_MAN IN (3,6,8,15) OR 1 LE TRAV_SP LE 10)
        THEN ESC_CRSH=0;                            /* BACKING/PARKING/LO-SPEED (ESC NOT EFFECTIVE) */
      ELSE IF CY GE 2010 AND (P_CRASH1 IN (4,8,9,13) OR 1 LE TRAV_SP LE 10)
        THEN ESC_CRSH=0;                            /* BACKING/PARKING/LO-SPEED (ESC NOT EFFECTIVE) */
      ELSE IF IMPACT1 IN (5,6,7) THEN ESC_CRSH=0;            /* REAR-END STRUCK (ESC NOT EFFECTIVE) */
      ELSE IF DRCF=1 THEN ESC_CRSH=3;                   /* CULPABLE VEHICLE IN A MULTI-VEHICLE CRASH */

    IF ESC_CRSH=1 THEN E=.5954;                /* CARS: NEW ESTIMATE OF ESC EFFECTIVENESS IN FIRST-EVENT ROLLO-
VERS */
      ELSE IF ESC_CRSH=2 THEN E=.3126;          /* CARS: NEW ESTIMATE OF ESC EFFECTIVENESS IN OTHER RUN-OFF-ROAD
CRASHES */
      ELSE IF ESC_CRSH=3 THEN E=.1607;          /* CARS: NEW ESTIMATE OF ESC EFFECTIVENESS IN CULPABLE MULTI-
VEHICLE INVOLVEMENTS */
      ELSE E=0;

    P=PV126+PS126;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS126=S*PS126/P;
    CLV126=S*PV126/P;
    WEIGHTFA=OLDWTFA+CLS126+CLV126; END;
  ELSE DO; CLV126=0; CLS126=0; END;
  CL126=CLS126+CLV126;
  CLS=CLS+CLS126; CLV=CLV+CLV126; CL=CL+CL126;
```

Note how CLS126 is added to the previous CLS, cumulating lives saved by ESC and the previous safety technology.

```
/* ------------------------------------------------------------------ */
/*  301 FUEL SYSTEM INTEGRITY - REAR IMPACT UPGRADE                   */
/*  MEDIAN INSTALLATION YEAR: 2008  PHASE-IN STARTED MY 2007          */
/* ------------------------------------------------------------------ */

/* IDENTIFIES CARS CERTIFIED TO FMVSS 301 REAR-IMPACT UPGRADE: REAR IMPACTS WITH FIRE  */
  PV301=0; PS301=0;
  IF (5 LE IMPACT2 LE 7 OR (CRSH=4 AND IMPACT1 IN (5,6,7))) AND FIRE_EXP=1 AND FMVSS301=1 THEN DO;
    IF XMY=2006 THEN PV301=1; ELSE IF 2007 LE XMY LE 2013 THEN PS301=1; END;
```

35.19-percent fatality reduction in rear impacts with post-crash fires:

```
/* LIVES SAVED IN REAR-IMPACT FIRES BY FMVSS 301 REAR-IMPACT UPGRADE */
  OLDWTFA=WEIGHTFA;
  IF PV301 OR PS301 GT 0 THEN DO;
    E=.3519;
    P=PV301+PS301;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS301=S*PS301/P;
    CLV301=S*PV301/P;
    WEIGHTFA=OLDWTFA+CLS301+CLV301; END;
  ELSE DO; CLV301=0; CLS301=0; END;
  CL301=CLS301+CLV301;
  CLS=CLS+CLS301; CLV=CLV+CLV301; CL=CL+CL301;

/* ---------------------------------------------------------------- */
/*  214C CURTAIN & SIDE AIR BAGS (POLE TEST UPGRADE FOR FMVSS 214)    */
/*  MEDIAN INSTALLATION YEAR: 2006  PHASE-IN STARTED MY 2011         */
/* ---------------------------------------------------------------- */
```

The model will estimate overall lives saved by curtain and/or side air bags (CL214C) and also the lives saved by each specific type of air bag(s): torso only, combination, curtain only, and curtain plus torso.

```
/* IDENTIFIES CARS WITH CURATAIN AND/OR SIDE AIR BAGS: DRIVERS & RF PASSENGERS IN NEARSIDE IMPACTS */
 P_TORSO=0; P_COMBO=0; P_CURTAIN=0; P_CURT_TORS=0;
 IF 1910 LE XMY LE 1995 THEN GOTO BYP214C;
 IF NEW_TORSO=0 AND NEW_COMBO=0 AND NEW_CURTAIN=0 AND CURT_TORS=0 THEN GOTO BYP214C;
 IF 1 LE HARM_EV LE 6 THEN GOTO BYP214C;
```

Special routine for not-in-transport vehicles: cannot assume any air bag is effective unless FARS explicitly said there was a deployment, because if the vehicle had been parked with the ignition off, the air bags would not have deployed.

```
 IF CY GE 2005 AND PER_TYP=3 AND AIR_BAG IN (.,0,20,28:32,97:99) THEN GOTO BYP214C;
 /* OCCUPANT OF A PARKED CAR: ASSUME NO BENEFIT UNLESS FARS SAYS DEPLOYMENT */
```

The evaluations for many of the recent technologies each use slightly different classifications of crash types. In each case, these classifications are preserved here. However, this can on rare occasions lead to one crash fitting into the "effectiveness zone" of two separate technologies that, intuitively, are mutually exclusive. We do not want the model to count lives saved for both technologies. For example, should the FARS case qualify as one where rollover curtains and side-impact curtains might both be effective, we take only the life-saving for the rollover curtain (whose effectiveness is higher) and do not add anything extra for the fact that this rollover curtain also deploys in side impacts.

```
 IF CL226 GT 0 THEN GOTO BYP214C;
 /* IF WE HAVE TREATED THIS CASE AS A ROLLOVER, ABOVE, WE WILL NOT TREAT IT AS A NEARSIDE IMPACT, TOO */
```

Defining near-side impacts (the type of crash where curtain and side air bags save lives):

```
  IF IMPACT1 IN (8,9,10,61:63) AND IMPACT2 IN (2,2.5,3,3,5,4,26,81:83) THEN GOTO BYP214C;
  IF IMPACT1 IN (2,3,4,81:83) AND IMPACT2 IN (8,8.5,9,9.5,10,26,61:63) THEN GOTO BYP214C;
  /* WE WILL NOT COUNT A BENEFIT IN VEHICLES HIT ON BOTH SIDES */
  IF (NEW_TORSO GT 0 OR NEW_COMBO GT 0 OR NEW_CURTAIN GT 0 OR CURT_TORS GT 0) AND
    ((SEAT2=11 AND (IMPACT1 IN (8,9,10,61:63) OR IMPACT2 IN (8,8.5,9,9.5,10,61:63))) OR
    (SEAT2=13 AND (IMPACT1 IN (2,3,4,81:83) OR IMPACT2 IN (2,2.5,3,3.5,4,81:83))))
        THEN DO; P_TORSO=NEW_TORSO; P_COMBO=NEW_COMBO; P_CURTAIN=NEW_CURTAIN; P_CURT_TORS=CURT_TORS; END;
  ELSE GOTO BYP214C;
```

Separate effectiveness estimates and lives saved for each type of curtain or side air bag: torso bag only (7.8% fatality reduction), combination bag (24.8%), curtain only (16.4%), curtain plus torso (31.3%)

```
  /* LIVES SAVED IN NEARSIDE IMPACTS BY CURTAIN AND/OR SIDE AIR BAGS */
  OLDWTFA=WEIGHTFA;
  C_TORSO=OLDWTFA*.078*P_TORSO / (1 - .078*P_TORSO);           /* FATALITY REDUCTION FOR TORSO BAG ONLY: 7.8% */
  C_COMBO=OLDWTFA*.248*P_COMBO / (1 - .248*P_COMBO);           /* FATALITY REDUCTION FOR COMBO BAG: 24.8% */
  C_CURTAIN=OLDWTFA*.164*P_CURTAIN / (1 - .164*P_CURTAIN);     /* FATALITY REDUCTION FOR CURTAIN ONLY: 16.4% */
  C_CURT_TORS=OLDWTFA*.313*P_CURT_TORS / (1 - .313*P_CURT_TORS); /* FATALITY REDUCTION FOR CURTAIN + TORSO:
31.3% */
  IF XMY IN (2011,2012,2013) THEN DO; CLS214C=C_TORSO+C_COMBO+C_CURTAIN+C_CURT_TORS; CLV214C=0; END;
  ELSE IF 1996 LE XMY LE 2010 THEN DO; CLV214C=C_TORSO+C_COMBO+C_CURTAIN+C_CURT_TORS; CLS214C=0; END;
  WEIGHTFA=OLDWTFA+CLS214C+CLV214C; GOTO TALLY214C;

  BYP214C: CLV214C=0; CLS214C=0; C_TORSO=0; C_COMBO=0; C_CURTAIN=0; C_CURT_TORS=0;
  TALLY214C: CL214C=CLS214C+CLV214C;
  CLS=CLS+CLS214C; CLV=CLV+CLV214C; CL=CL+CL214C;

/* ------------------------------------------------------------------ */
/*  208K VOLUNTARY INSTALLATION OF PRETENSIONERS & LOAD LIMITERS      */
/*  MEDIAN INSTALLATION YEAR: 2002                                    */
/* ------------------------------------------------------------------ */

/* IDENTIFIES CARS WITH PRETENSIONERS & LOAD LIMITERS AT THE OUTBOARD FRONT SEATS   */
  PS208K=0; PV208K=0;
  IF SEAT2 IN (11,13) AND REST3=3 THEN DO;
    IF 2007 LE XMY LE 2013 THEN PV208K=1;
    ELSE IF 1995 LE XMY LE 2006 AND PRETENLL=1 THEN PV208K=1; END;
```

NHTSA study showed significant overall (all crash types combined) 12.8-percent fatality reduction for occupant wearing belt with pretensioners and load limiters relative to occupant wearing belt without these devices. However, frontals were the only individual impact type where effect was significant. We will conservatively count the 12.8-percent reduction only in the frontals.

```
/* LIVES SAVED BY PRETENSIONERS & LOAD LIMITERS: BELTED DRIVERS & RF PASSENGERS */
  OLDWTFA=WEIGHTFA;
  IF PS208K GT 0 OR PV208K GT 0 THEN DO;
    IF CRSH=1 THEN E=.128; ELSE E=0;        /* CONSERVATIVELY ASSUME BENEFIT ONLY IN FRONTAL IMPACTS */
    P=PS208K+PV208K;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208K=S*PS208K/P;
    CLV208K=S*PV208K/P;
    WEIGHTFA=OLDWTFA+CLS208K+CLV208K; END;
  ELSE DO; CLS208K=0; CLV208K=0; END;
  CL208K=CLS208K+CLV208K;
  CLS=CLS+CLS208K; CLV=CLV+CLV208K; CL=CL+CL208K;
```

Pretensioners and load limiters differ from the other belt technologies (e.g., the next one, 208J) in that when the pretensioners and load limiters are removed, the occupant is still belted, but with a belt that does not have those devices.

```
/* ------------------------------------------------------------------ */
/*  208J 3-POINT BELTS FOR CENTER REAR SEAT OCCUPANTS (ANTON'S LAW)   */
/*  MEDIAN INSTALLATION YEAR: 2001  PHASE-IN STARTED MY 2006          */
/* ------------------------------------------------------------------ */

/* IDENTIFIES CENTER REAR SEAT OCCUPANTS WEARING 3-POINT BELTS  */
  PS208J=0; PV208J=0;
  IF SEAT2=22 AND REST3=3 THEN DO;
    IF 2006 LE XMY LE 2013 THEN PS208J=1;
    ELSE IF 1994 LE XMY LE 2005 THEN PV208J=1; END;
```

The data in NHTSA's evaluation of 3-point belts in the outboard rear seats indicates fatality reduction of 29 percent in frontals (as defined by the variable CRSH), 42 percent in side impacts, 77 percent in rollovers and 31 percent in rear/other impacts. We will assume the same effectiveness for 3-point belts in the center rear seat. Moreover, when we "remove" the belts from the vehicle, the occupant becomes unrestrained and, in general, 26 percent of unrestrained center rear seat passenger fatalities in frontal crashes were ejected, 33 percent in side impacts, 64 percent in rollovers and 31 percent in rear/other impacts. One of these becomes the new values of EJECT2 as this now-unrestrained occupant fatality case proceeds through the rest of the model.

```
/* LIVES SAVED AND EJECTIONS PREVENTED BY CENTER-REAR-SEAT 3-POINT BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208J GT 0 OR PV208J GT 0 THEN DO;
    IF CRSH=1 THEN DO; E=.29; EJECT2=.26; END;
      ELSE IF CRSH=2 THEN DO; E=.42; EJECT2=.33; END;
      ELSE IF CRSH=3 THEN DO; E=.77; EJECT2=.64; END;
      ELSE IF CRSH=4 THEN DO; E=.31; EJECT2=.31; END;
    P=PS208J+PV208J;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208J=S*PS208J/P;
    CLV208J=S*PV208J/P;
    WEIGHTFA=OLDWTFA+CLS208J+CLV208J; END;
  ELSE DO; CLS208J=0; CLV208J=0; END;
  CL208J=CLS208J+CLV208J;
  CLS=CLS+CLS208J; CLV=CLV+CLV208J; CL=CL+CL208J;
```

By the way, when this model "removes" a 3-point belt system from the vehicle, it removes the entire system, not just the shoulder harness. The occupant from this point onwards is unrestrained, not lap-belted. The lives saved by the 3-point system are the benefits of that system relative to being unrestrained, not the incremental benefit of a 3-point system relative to lap belts only. At most one of the model's first nine belt technologies (208A, 208B, 208C, 208D, 208E, 208F, 208G, 208H and 208J) can apply to any specific occupant case.[624]

```
/* ---------------------------------------------------------------- */
/*  201B INTERIOR IMPACT PROTECTION: HEAD-IMPACT UPGRADE            */
/*  MEDIAN INSTALLATION YEAR: EARLY2001  PHASE-IN STARTED MY 1999   */
/* ---------------------------------------------------------------- */

/* IDENTIFIES ANY OCCUPANT SITTING AT A DESIGNATED SEATING POSITION IN A VEHICLE MEETING THE HEAD-IMPACT UPGRADE
*/
  PS201B=0; PV201B=0;
  IF SEAT2 IN (11,12,13,21,22) THEN DO;
    IF 2003 LE XMY LE 2013 THEN PS201B=1;
    ELSE IF 1999 LE XMY LE 2002 AND FMVSS201=1 THEN PS201B=1; END;
```

4.276-percent fatality reduction for any occupant sitting inside the vehicle in any type of crash

```
/* LIVES SAVED BY UPGRADED UPPER-INTERIOR PADDING */
  OLDWTFA=WEIGHTFA;
  IF PS201B GT 0 OR PV201B GT 0 THEN DO;
    E=.04276;  /* 23.73% REDUCTION OF UPPER-INTERIOR AIS 4-6, UPPER-INTERIOR-HEAD IS MOST SEVERE INJURY IN
18.02% OF FATALS */
    P=PS201B+PV201B;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS201B=S*PS201B/P;
    CLV201B=S*PV201B/P;
    WEIGHTFA=OLDWTFA+CLS201B+CLV201B; END;
  ELSE DO; CLS201B=0; CLV201B=0; END;
  CL201B=CLS201B+CLV201B;
  CLS=CLS+CLS201B; CLV=CLV+CLV201B; CL=CL+CL201B;
```

[624] It would also have been theoretically possible to estimate the effectiveness of 3-point belts relative to lap belts only (rather than relative to being unrestrained), and then have the model subdivide the lives saved by 3-point belts into (1) lives that would have been saved even by just a lap belt (and count them under technology 208A) and (2) lives that were saved only because there was also a shoulder harness (and count only these in technology 208F). This approach would probably be confusing, since it would attribute a large number of saves to lap belts who were, in fact, people that used 3-point belts.

```
/* ------------------------------------------------------------------- */
/*  108 TRAILER CONSPICUITY TAPE (LIVES SAVED IN CARS NOT HITTING THEM) */
/*  54.0% OF TRAILERS ON THE ROAD HAD THEM IN 1996                     */
/*  FMCSA RETROFIT REQUIREMENT ISSUED 3/31/1999, TOOK EFFECT 6/1/2001   */
/* ------------------------------------------------------------------- */

/* IDENTIFIES SIDE/REAR IMPACTS INTO TRAILERS IN THE DARK AND % OF TRAILERS WITH TAPE */
  PS108=0; PV108=0;
```

Identifies cases where the front of a car hit the side or rear of a heavy trailer in the dark.

```
  IF CY GE 1991 AND (TAPECASE=1 OR
    (OVTYP=3 AND ((1991 LE CY LE 1994 AND OVCONFIG=5) OR (CY GE 1995 AND OVCONFIG=6))
       AND 2 LE LGT_COND LE 5 AND
      (OIMPACT2 IN (14,16) AND MAN_COLL IN (1,4,5) AND IMPACT2 IN (11,11.5,12,.5,1))))
    THEN DO;
```

Unlike all the other safety technologies, the tape is not on the case vehicle (the car) but on the other vehicle (the heavy trailer). The MY of the case vehicle is irrelevant. The MY of the trailer is not reported on FARS. It is unknown (before June 1, 2001, the effective date of the FMCSA retrofit requirement) if this specific trailer was equipped with tape, but we can infer, from the CY of the crash, the probability that it was equipped with tape. PS108 is the percentage of trailers on the road that FMVSS No. 108 requires to be equipped with tape when new (if built after December 1, 1993) plus the percentage required by the FMCSA retrofit rule (after 6/1/2001). PV108 is the percentage of trailers on the road that were built before December 1, 1993 and voluntarily fitted or retrofitted with tape, before June 1, 2001.

```
      IF CY=1991 THEN DO; PS108=0; PV108=.09; END;
        ELSE IF CY=1992 THEN DO; PS108=0; PV108=.18; END;
        ELSE IF CY=1993 THEN DO; PS108=0; PV108=.27; END;
        ELSE IF CY=1994 THEN DO; PS108=.09; PV108=.27; END;
        ELSE IF CY=1995 THEN DO; PS108=.18; PV108=.27; END;
        ELSE IF CY=1996 THEN DO; PS108=.27; PV108=.27; END;
        ELSE IF CY=1997 THEN DO; PS108=.36; PV108=.27; END;
        ELSE IF CY=1998 THEN DO; PS108=.45; PV108=.27; END;
        ELSE IF CY=1999 THEN DO; PS108=.54; PV108=.27; END;
        ELSE IF CY=2000 THEN DO; PS108=.63; PV108=.27; END;
        ELSE IF CY=2001 THEN DO; PS108=.8775; PV108=.1125; END;
        ELSE IF CY GE 2002 THEN DO; PS108=1; PV108=0; END; END;
/* CAR OCCUPANT LIVES SAVED BY CONSPICUITY TAPE ON TRUCK TRAILERS */
  OLDWTFA=WEIGHTFA;
  IF PS108 GT 0 OR PV108 GT 0 THEN DO;
```

The tape is estimated to reduce fatal impacts into the side/rear of trailers, in the dark, by 29 percent.

```
    E=.29;
    P=PS108+PV108;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS108=S*PS108/P;
    CLV108=S*PV108/P;
    WEIGHTFA=OLDWTFA+CLS108+CLV108; END;
  ELSE DO; CLS108=0; CLV108=0; END;
  CL108=CLS108+CLV108;
  CLS=CLS+CLS108; CLV=CLV+CLV108; CL=CL+CL108;

/* ------------------------------------------------------------------------ */
/*  214B TTI(d) REDUCTIONS W/O AIR BAGS (DYNAMIC TEST UPGRADE FOR FMVSS 214)  */
/*  64.1% OF CARS CERTIFIED IN MY 1996  PHASE-IN STARTED MY 1994            */
/*  4 SCENARIOS BASED ON N OF DOORS (2,4) & CERTIFICATION (YES,VOLUNTARY RED) */
/* ------------------------------------------------------------------------ */
```

The effect of TTI(d) reductions is different in 2-door and 4-door cars. Furthermore, each analysis (2-door and 4-door) has separate estimation for cars certified to meet the upgraded FMVSS No. 214, where we take a single, overall effectiveness value, and pre-standard or non-certified cars from MY

1986 onwards, where we take a fraction of the overall effect, slightly higher in each successive MY, as explained in the FMVSS No. 214 chapter in Part 1 of this report.

```
IF 1910 LE XMY LE 1985 THEN GOTO BYP214B;
IF SEAT2 NE 11 AND SEAT2 NE 13 THEN GOTO BYP214B;
IF 1 LE HARM_EV LE 6 OR CRSH IN (1,3,4) OR CL226 GT 0 THEN GOTO BYP214B;
/* ASSUME NO BENEFIT IF CRASH IS BASICALLY FRONTAL, ROLLOVER, REAR+OTHER OR IF ROLLOVER CURTAINS SAVE LIVES */
IF SEAT2=11 AND IMPACT1 IN (8,9,10,61:63) THEN NEARSIDE=1;
  ELSE IF SEAT2=13 AND IMPACT1 IN (2,3,4,81:83) THEN NEARSIDE=1;
  ELSE IF SEAT2=11 AND IMPACT2 IN (8,8.5,9,9.5,10,61:63) THEN NEARSIDE=1;
  ELSE IF SEAT2=13 AND IMPACT2 IN (2,2.5,3,3.5,4,81:83) THEN NEARSIDE=1;
  ELSE IF SEAT2=13 AND IMPACT1 IN (8,9,10,61:63) THEN NEARSIDE=2;
  ELSE IF SEAT2=11 AND IMPACT1 IN (2,3,4,81:83) THEN NEARSIDE=2;
  ELSE IF SEAT2=13 AND IMPACT2 IN (8,8.5,9,9.5,10,61:63) THEN NEARSIDE=2;
  ELSE IF SEAT2=11 AND IMPACT2 IN (2,2.5,3,3.5,4,81:83) THEN NEARSIDE=2;
  ELSE GOTO BYP214B;
IF NEWVTYP IN (1,2) THEN GOTO TTI2;
IF FMVSS214 NE 1 AND 1986 LE XMY LE 1996 THEN GOTO VOL4;

/* ------------------------------------------------------------------- */
/*  LIVES SAVED BY FMVSS 214 CERTIFICATION, 4-DOOR CARS                */
/*    17.3% FATALITY REDUCTION IN NEARSIDE, MULTI-VEHICLE IMPACTS ONLY   */
/* ------------------------------------------------------------------- */

/* IDENTIFIES 4-DOOR CARS MEETING FMVSS 214 IN NEARSIDE IMPACTS BY ANOTHER VEHICLE */
  IF FMVSS214=1 AND NEARSIDE=1 AND VE_FORMS GE 2 THEN P214=1; ELSE P214=0;
/* LIVES SAVED BY FMVSS 214 */
  OLDWTFA=WEIGHTFA;
  E=.173;
  CLS214B=OLDWTFA*P214*E / (1 - P214*E);
  CLV214B=0;
  WEIGHTFA=OLDWTFA+CLS214B;
  GOTO TALLY214B;

/* ------------------------------------------------------------------- */
/*  LIVES SAVED BY VOLUNTARY TTI(d) IMPROVEMENTS, 4-DOOR CARS          */
/*    GRADUAL TTI(d) IMPROVEMENT FROM 1986 TO MY BEFORE CERTIFICATION   */
/*    WITH PROPORTIONAL FATALITY REDUCTION IN NEARSIDE, MULTI-VEHICLE   */
/* ------------------------------------------------------------------- */

/* IDENTIFIES EXTENT OF VOLUNTARY TTI(d) IMPROVEMENT IN 4-DOOR CARS BEFORE FMVSS 214 */
VOL4: IF 1986 LE XMY LE 1990 THEN IMPTTI=XMY-1985; ELSE IF XMY=1991 THEN IMPTTI=7;
    ELSE IF XMY=1992 THEN IMPTTI=10; ELSE IF 1993 LE XMY LE 1996 THEN IMPTTI=14;
/* LIVES SAVED BY VOLUNTARY TTI(d) IMPROVEMENTS */
  OLDWTFA=WEIGHTFA;
  IF IMPTTI GT 0 AND NEARSIDE=1 AND VE_FORMS GE 2 THEN E=1 - EXP(-.00863*IMPTTI); ELSE E=0;
  CLS214B=0;
  CLV214B=OLDWTFA*E / (1 - E);
  WEIGHTFA=OLDWTFA+CLV214B;
  GOTO TALLY214B;

/* ------------------------------------------------------------------- */
/*  LIVES SAVED BY FMVSS 214 CERTIFICATION, 2-DOOR CARS                */
/*    33.29% FATALITY REDUCTION IN NEARSIDE, MULTI-VEHICLE IMPACTS      */
/*    20.03% FATALITY REDUCTION IN OTHER TYPES OF SIDE IMPACTS          */
/* ------------------------------------------------------------------- */

/* IDENTIFIES 2-DOOR CARS MEETING FMVSS 214 IN SIDE IMPACTS */
TTI2: IF FMVSS214=1 THEN P214=1;
      ELSE IF FMVSS214 NE 1 AND 1986 LE XMY LE 1996 THEN GOTO VOL2;
      ELSE P214=0;
/* LIVES SAVED BY FMVSS 214 */
  OLDWTFA=WEIGHTFA;
  IF NEARSIDE=1 AND VE_FORMS GE 2 THEN E=.3329; ELSE E=.2003;
  CLS214B=OLDWTFA*P214*E / (1 - P214*E);
  CLV214B=0;
  WEIGHTFA=OLDWTFA+CLS214B;
  GOTO TALLY214B;
```

```
/* ------------------------------------------------------------------ */
/*  LIVES SAVED BY VOLUNTARY TTI(d) IMPROVEMENTS, 2-DOOR CARS          */
/*    GRADUAL TTI(d) IMPROVEMENT FROM 1986 TO MY BEFORE CERTIFICATION   */
/*    WITH PARTIAL FATALITY REDUCTIONS IN ALL TYPES OF SIDE IMPACTS     */
/* ------------------------------------------------------------------ */

/* IDENTIFIES EXTENT OF VOLUNTARY TTI(d) IMPROVEMENT IN 2-DOOR CARS BEFORE FMVSS 214 */
VOL2: IF 1986 LE XMY LE 1991 THEN IMPTTI=2*(XMY-1985);
    ELSE IF XMY=1992 THEN IMPTTI=15; ELSE IF 1993 LE XMY LE 1996 THEN IMPTTI=19;
/* LIVES SAVED BY VOLUNTARY TTI(d) IMPROVEMENTS */
  OLDWTFA=WEIGHTFA;
  IF IMPTTI GT 0 THEN E=1 - (.99073**IMPTTI); ELSE E=0;
  CLS214B=0;
  CLV214B=OLDWTFA*E / (1 - E);
  WEIGHTFA=OLDWTFA+CLV214B;
  GOTO TALLY214B;

  BYP214B: CLV214B=0; CLS214B=0;
  TALLY214B: CL214B=CLS214B+CLV214B;
  CLS=CLS+CLS214B; CLV=CLV+CLV214B; CL=CL+CL214B;

/* ----------------------------------------------------------------- */
/*  208I FRONTAL AIR BAGS FOR DRIVERS AND RF PASSENGERS              */
/*  ASSUMES 18 PERCENT OF ON-OFF SWITCHES ARE TURNED OFF FOR RF 13+   */
/*  MEDIAN INSTALLATION YEAR: 1992  PHASE-IN STARTED MY 1987          */
/* ----------------------------------------------------------------- */
```

Similar to the analysis of curtain and side air bags, this code will estimate an overall effect for frontal air bags and a separate estimate for various types of frontal air bags: barrier-certified, sled-certified, and advanced, also driver and RF passenger. It will estimate the numbers of children fatally injured by barrier-certified and sled-certified air bags – but also the additional, hypothetical numbers of children that survived with sled-certified or advanced air bags but that would have been fatally injured by barrier-certified air bags. It will estimate the number of children saved because the manual on-off switch was turned "off" but also the number not saved because it was "on" – and vice-versa for adult passengers. It will estimate the number of lives saved by advanced air bags because they made it possible to phase out the manual switches.

```
/* IDENTIFIES CARS WITH AIR BAGS      */
PS208I=0; PV208I=0; P_BARRIER=0; P_SLED=0; P_CAC=0; UDAB=0; UPAB=0;
```

"PASSIVE," the variable that indicates the types of occupant protection at the outboard front seats, is only defined if FARS has at least a partial VIN to decode. However, even when there is no VIN at all, we can often infer from the model year and the make if the car had driver and/or passenger air bags. All cars from MY 1997 onwards have had dual air bags. Some makes had driver air bags on all of their cars (UDAB = 1) or passenger air bags (UPAB = 1) before 1997.

```
/* CARS WITH UNKNOWN "PASSIVE" (BAD VINs AND/OR NO MAK_MOD) CLASSIFIED BY MAKE AND MODEL YEAR */

  IF CY GE 1985 AND XMY GE 1986 AND PASSIVE IN (.,9,1099,9999) AND SEAT2 IN (11,12,13,18) THEN DO;
    IF SEAT2=11 THEN DO;
      IF (MAKE=42 AND XMY GE 1986)     /* i.e., ALL MERCEDES-BENZ CARS FROM 1986 ONWARDS HAVE DRIVER AIR BAGS */
      OR (MAKE IN (13,38,45,47,51,59) AND XMY GE 1990)
      OR (MAKE IN (6,32,34) AND XMY GE 1991)
      OR (MAKE=37 AND XMY GE 1992)
      OR (MAKE IN (19,24,39,49) AND XMY GE 1993)
      OR (MAKE IN (18,21,54,58) AND XMY GE 1994)
      OR (MAKE IN (9,10,12,14,20,22,30,35,41,48,52,53) AND XMY GE 1995)
      OR (MAKE IN (55,63) AND XMY GE 1996)
          OR PASSIVE=1099
      OR XMY GE 1997 THEN UDAB=1; END;

    ELSE IF SEAT2 IN (12,13,18) THEN DO;
      IF (MAKE=45 AND XMY GE 1990)
      OR (MAKE=13 AND XMY GE 1993)
      OR (MAKE IN (19,32,37,42,51,54,58,59) AND XMY GE 1994)
```

```
    OR (MAKE IN (6,10,12,14,24,30,34,35,39,41,47,48,52,53) AND XMY GE 1995)
    OR (MAKE IN (9,22,49,55,63) AND XMY GE 1996)
    OR XMY GE 1997 THEN UPAB=1; END; END;
```

These are the codes of PASSIVE, based on VIN analysis, that indicate a car is equipped with frontal air bags and the driver or RF seats, respectively. PS208I includes any installation from MY 1987 onwards, because the phase-in of automatic occupant protection began on September 1, 1986. Sled-certified and advanced air bags are identified by the variables REDES and CAC on LSM2014C.

```
  IF CY GE 1984 AND XMY GE 1985 AND
    (SEAT2=11 AND
        (PASSIVE IN (1,1003,1004,1006,2,3,1090,1099,1303,1313,1404,1505,1606) OR UDAB=1))
    OR (SEAT2 IN (12,13,18) AND (PASSIVE IN (2,3,1313) OR UPAB=1)) THEN DO;
      IF 1985 LE XMY LE 1986 THEN DO; PV208I=1; P_BARRIER=1; END;
      ELSE IF XMY GE 1987 THEN DO; PS208I=1;
        IF XMY LE 1997 THEN P_BARRIER=1;
        ELSE IF 2000 LE XMY LE 2003 THEN P_SLED=1;
        ELSE IF XMY GE 2007 THEN P_CAC=1;
        ELSE IF REDES=0 AND CAC=0 THEN P_BARRIER=1;
        ELSE IF REDES=1 AND CAC=0 THEN P_SLED=1;
        ELSE IF REDES=1 AND CAC=1 THEN P_CAC=1; END; END;

/* ----------------------------------------------------------------- */
/*  SPLITS CASES INTO SCENARIOS DEPENDING ON AIR BAG TYPE, SEAT      */
/*  POSITION, ON-OFF SWITCH PRESENCE, OCCUPANT AGE, RESTRAINT USE    */
/*  COMPUTES LIVES SAVED BY AIR BAGS IN EACH SCENARIO                */
/* ----------------------------------------------------------------- */
```

There are eight different effectiveness scenarios:

- Belted drivers, unbelted drivers;
- Child passengers, belted adult (age 13+) passengers, and unbelted adult passengers – without manual on-off switches;
- Child passengers, belted adult (age 13+) passengers, and unbelted adult passengers – with manual on-off switches.

Plus the default scenario, no air bag. Within each scenario, there are several effectiveness estimates.

```
  IF PS208I=0 AND PV208I=0 THEN GOTO CNOBAG;              /* NO AIR BAG */
    ELSE IF CY GE 2005 AND PER_TYP=3 AND AIR_BAG IN
          (.,0,20,28:32,97:99) THEN GOTO CNOBAG;             /* OCCUPANT OF A PARKED CAR: ASSUME NO BENEFIT
UNLESS FARS SAYS DEPLOYMENT */
    ELSE IF SEAT2=11 AND REST3 GT 0 THEN GOTO CDRVBELT;     /* BELTED DRIVER */
    ELSE IF SEAT2=11 THEN GOTO CDRVUNR;                     /* UNRESTRAINED DRIVER */
    ELSE IF PASSIVE=3 AND 0 LE AGE LE 12 THEN GOTO CKIDSW;  /* CHILD RF WITH SWITCH */
    ELSE IF 0 LE AGE LE 12 THEN GOTO CKID;                  /* CHILD RF NO SWITCH */
        ELSE IF SEAT2 IN (12,18) THEN GOTO CNOBAG;              /* ADULT IN CENTER FRONT OR NON-DESIGNATED
SEAT: AIR BAG HAS NO EFFECT */
    ELSE IF PASSIVE=3 AND REST3 GT 0 THEN GOTO CRFBELSW;    /* BELTED ADULT RF W SWITCH */
    ELSE IF PASSIVE=3 THEN GOTO CRFUNRSW;                   /* UNBELTED ADULT RF W SWITCH */
    ELSE IF REST3 GT 0 THEN GOTO CRFBELT;                   /* BELTED ADULT RF NO SWITCH */
    ELSE GOTO CRFUNR;                                       /* UNBELTED ADULT RF NO SWITCH */
```

In addition to the basic statistics, WEIGHTFA, CLS208I, CLV208I and CL208I, the model compiles more detailed information on air bags:

```
CNOBAG: /* ALL EFFECTS ARE ZERO HERE, BECAUSE NO FRONTAL AIR BAGS - BUT THESE ARE THE VARIABLES WE WILL TALLY IN
EACH SCENARIO */

    CLS208I=0; /* NET LIVES SAVED BY FRONTAL AIR BAGS, MY 1987 & LATER VEHICLES (AFTER 208 AUTOMATIC-PROTECTION
PHASE-IN STARTED) */

    CLV208I=0; /* NET LIVES SAVED BY FRONTAL AIR BAGS, MY 1985 & 1986 (BEFORE 208 PHASE-IN) */
```

```
    CL208I=0; /* NET LIVES SAVED BY ANY FRONTAL AIR BAGS */

    C_BARRIER=0; /* NET LIVES SAVED BY BARRIER-CERTIFIED AIR BAGS */

    C_SLED=0; /* NET LIVES SAVED BY SLED-CERTIFIED AIR BAGS */
    C_CAC=0; /* NET LIVES SAVED BY ADVANCED AIR BAGS. NOTE: CL208I = CLV208I+CLS208I = C_BARRIER+C_SLED+C_CAC */

    CABDRV=0; /* DRIVERS SAVED BY FRONTAL AIR BAGS */

    CABRF=0; /* RF PASSENGERS 13 AND OLDER SAVED BY FRONTAL AIR BAGS IN VEHICLES W/O ON-OFF SWITCHES */

    CABKID_BARRIER=0; /* NET EFFECT OF BARRIER-CERTIFIED BAGS ON RF AGE 0-12 (NEGATIVE NUMBER BECAUSE FATALITY
INCREASE), VEH W/O SWITCHES */

    CABKID_SLED=0; /* NET EFFECT OF SLED-CERTIFIED BAGS ON RF AGE 0-12 (NEGATIVE NUMBER BECAUSE FATALITY IN-
CREASE), VEH W/O SWITCHES */

    CSW0=0; /* ACTUAL RF 13 & OLDER SAVED IN VEH WITH ON-OFF SWITCHES, AND THE SWITCHES WERE LEFT ON */

    CSW1=0; /* THEORETICAL RF 13 & OLDER SAVED IN VEH WITH ON-OFF SWITCHES, IF THESE SWITCHES HAD ALL BEEN LEFT
ON */

    CSW2=0; /* LIVES LOST BECAUSE SWITCHES WERE TURNED OFF FOR RF 13+ (NEGATIVE NUMBER BECAUSE FATALITY IN-
CREASE). NOTE: CSW0=CSW1+CSW2 */

    CSWKID0_BARRIER=0; /* ACTUAL ADD'L CHILD PASSENGER FATALITIES DUE TO BARRIER-CERTIFIED AIR BAGS & SWITCHES
LEFT ON */

    CSWKID1_BARRIER=0; /* THEORETICAL CHILD PASSENGER FATALITIES DUE TO BARRIER-CERTIFIED AIR BAGS IF SWITCHES
HAD NOT EXISTED */

    CSWKID2_BARRIER=0; /* LIVES SAVED BECAUSE SWITCHES WERE TURNED OFF FOR CHILD PASSENGERS WITH BARRIER-
CERTIFIED AIR BAGS */

    CSWKID0_SLED=0; /* ACTUAL ADD'L CHILD PASSENGER FATALITIES DUE TO SLED-CERTIFIED AIR BAGS & SWITCHES LEFT ON
*/

    CSWKID1_SLED=0; /* THEORETICAL CHILD PASSENGER FATALITIES DUE TO SLED-CERTIFIED AIR BAGS IF SWITCHES HAD NOT
EXISTED */

    CSWKID2_SLED=0; /* LIVES SAVED BECAUSE SWITCHES WERE TURNED OFF FOR CHILD PASSENGERS WITH SLED-CERTIFIED AIR
BAGS */

    C_KID_SLED=0; /* CHILDREN'S LIVES SAVED BECAUSE THEY WERE EXPOSED TO SLED-CERTIFIED RATHER THAN BARRIER-
CERTIFIED AIR BAGS */

    C_KID_CAC=0; /* CHILDREN'S LIVES SAVED BECAUSE THEY SAT BEHIND ADVANCED AIR BAGS (NO/LOW-RISK DEPLOYMENT)
RATHER THAN BARRIER-CERT */

    C_ADULT_CAC=0; /* RF 13+ SAVED BECAUSE ADVANCED AIR BAGS ELIMINATED MANUAL SWITCHES THAT WOULD HAVE BEEN
TURNED OFF FOR THESE RF */
    GOTO C208H;
```

Air bag effectiveness: the data from NHTSA’s evaluation indicates that air bags reduce fatalities:

- In all crashes, for all drivers by 12.4 percent, for belted drivers by 10.8 percent, and for unbelted drivers by 14.0 percent.
- In frontal and partially frontal crashes, without a most-harmful-event rollover, fire or immersion, for all drivers, by 29.0 percent if the principal impact is 12 o’clock, by 15.2 percent if it is 11 o’clock or 1 o’clock, and by 5.8 percent if it is 10 o’clock or 2 o’clock
- In 12 o’clock crashes, for all adult RF passengers, by 31.9 percent.

There are not enough data to get precise individual estimates such as, for belted RF passengers in 11 o’clock or 1 o’clock crashes. Instead, ratios of the preceding estimates are used. For example, the effect of air bags for belted drivers in 12 o'clock crashes is estimated to be (.108/.124) x .290 = .25258. For belted RF passengers it would be (.319/.290) x (.108/.124) x .290 = .27784.

```
CDRVBELT:  OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (CL226+CL214C+CLS214B)/OLDWTFA GT .05052 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.25258;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.13239;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.05052;
ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208I=S*PS208I/P;
    CLV208I=S*PV208I/P;
        C_BARRIER=S*P_BARRIER/P;
        C_SLED=S*P_SLED/P;
        C_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+CLS208I+CLV208I;
    CL208I=CLS208I+CLV208I;
    CLS=CLS+CLS208I; CLV=CLV+CLV208I; CL=CL+CL208I;
    CABDRV=CL208I; CABRF=0; CABKID_BARRIER=0; CABKID_SLED=0; CSW0=0; CSW1=0; CSW2=0;
    CSWKID0_BARRIER=0; CSWKID1_BARRIER=0; CSWKID2_BARRIER=0;
    CSWKID0_SLED=0; CSWKID1_SLED=0; CSWKID2_SLED=0;
    C_KID_SLED=0; C_KID_CAC=0; C_ADULT_CAC=0; GOTO C208H;

CDRVUNR:   OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (CL226+CL214C+CLS214B)/OLDWTFA GT .06548 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.32742;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.17161;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.06548;
ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208I=S*PS208I/P;
    CLV208I=S*PV208I/P;
        C_BARRIER=S*P_BARRIER/P;
        C_SLED=S*P_SLED/P;
        C_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+CLS208I+CLV208I;
    CL208I=CLS208I+CLV208I;
    CLS=CLS+CLS208I; CLV=CLV+CLV208I; CL=CL+CL208I;
    CABDRV=CL208I; CABRF=0; CABKID_BARRIER=0; CABKID_SLED=0; CSW0=0; CSW1=0; CSW2=0;
    CSWKID0_BARRIER=0; CSWKID1_BARRIER=0; CSWKID2_BARRIER=0;
    CSWKID0_SLED=0; CSWKID1_SLED=0; CSWKID2_SLED=0;
    C_KID_SLED=0; C_KID_CAC=0; C_ADULT_CAC=0; GOTO C208H;

CRFBELT:   OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (CL226+CL214C+CLS214B)/OLDWTFA GT .05557 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.27784;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.14563;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.05557;
ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208I=S*PS208I/P;
    CLV208I=S*PV208I/P;
        C_BARRIER=S*P_BARRIER/P;
        C_SLED=S*P_SLED/P;
        C_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+CLS208I+CLV208I;
    CL208I=CLS208I+CLV208I;
    CLS=CLS+CLS208I; CLV=CLV+CLV208I; CL=CL+CL208I;
    CABDRV=0; CABRF=CL208I; CABKID_BARRIER=0; CABKID_SLED=0; CSW0=0; CSW1=0; CSW2=0;
```

```
    CSWKID0_BARRIER=0; CSWKID1_BARRIER=0; CSWKID2_BARRIER=0;
    CSWKID0_SLED=0; CSWKID1_SLED=0; CSWKID2_SLED=0;
    C_KID_SLED=0; C_KID_CAC=0;
    IF SWITCH_MM=1 THEN DO;  /* IF CAC VEHICLES, NOW WITHOUT SWITCH, STILL HAD THE SWITCH, AND IT WERE OFF, FEW-
ER LIVES WOULD BE SAVED */
          /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                         */
      IF 13 LE AGE LE 15 THEN U=.22;
        ELSE IF 16 LE AGE LE 19 THEN U=.17;
        ELSE IF 20 LE AGE LE 59 THEN U=.15;
        ELSE IF 60 LE AGE LE 69 THEN U=.19;
        ELSE IF AGE GE 70 THEN U=.56;
          C_ADULT_CAC=U*C_CAC; END;
    ELSE C_ADULT_CAC=0; GOTO C208H;

CRFUNR:    OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (CL226+CL214C+CLS214B)/OLDWTFA GT .07203 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.36016;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.18877;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.07203;
ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208I=S*PS208I/P;
    CLV208I=S*PV208I/P;
        C_BARRIER=S*P_BARRIER/P;
        C_SLED=S*P_SLED/P;
        C_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+CLS208I+CLV208I;
    CL208I=CLS208I+CLV208I;
    CLS=CLS+CLS208I; CLV=CLV+CLV208I; CL=CL+CL208I;
    CABDRV=0; CABRF=CL208I; CABKID_BARRIER=0; CABKID_SLED=0; CSW0=0; CSW1=0; CSW2=0;
    CSWKID0_BARRIER=0; CSWKID1_BARRIER=0; CSWKID2_BARRIER=0;
    CSWKID0_SLED=0; CSWKID1_SLED=0; CSWKID2_SLED=0;
    C_KID_SLED=0; C_KID_CAC=0;
```

Estimation of additional lives saved by advanced air bags because they allowed the phase-out of manual switches that might have been incorrectly turned off for adult passengers.

```
    IF SWITCH_MM=1 THEN DO;  /* IF CAC VEHICLES, NOW WITHOUT SWITCH, STILL HAD THE SWITCH, AND IT WERE OFF, FEW-
ER LIVES WOULD BE SAVED */
          /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                         */
      IF 13 LE AGE LE 15 THEN U=.22;
        ELSE IF 16 LE AGE LE 19 THEN U=.17;
        ELSE IF 20 LE AGE LE 59 THEN U=.15;
        ELSE IF 60 LE AGE LE 69 THEN U=.19;
        ELSE IF AGE GE 70 THEN U=.56;
          C_ADULT_CAC=U*C_CAC; END;
    ELSE C_ADULT_CAC=0; GOTO C208H;
```

Child passengers: as estimated in Part 1 of this report, in 12 o’clock impacts, barrier-certified air bags increased the fatality risk of infants in rear-facing seats by about 450 percent, for unrestrained children < 6 years old by about 100 percent, and for restrained children age 1 to 5 and unrestrained children age 6 to 10 by about 70 percent. In partially frontal crashes (10, 11, 1, or 2 o’clock), the effect of air bags is about 38 percent as large as in 12 o’clock impacts. Sled-certified, redesigned air bags reduced these additional risks by 83 percent.

```
CKID:      OLDWTFA=WEIGHTFA;
      IF KCRSH=1 AND RESTGP=1 THEN E=-4.5;  /* FATALITY INCREASE, BARRIER-CERT REL TO NO BAGS, DIRECT FRONTALS,
3 GPS OF YOUNG CHILDREN */
        ELSE IF KCRSH=1 AND RESTGP IN (2,3) THEN E=-1;
        ELSE IF KCRSH=1 AND RESTGP IN (4,5,6) THEN E=-.70;
        ELSE IF KCRSH IN (2,3) AND RESTGP=1 THEN E=-1.71; /* INCREASE IN OBLIQUE FRONTALS IS 62% LESS THAN IN
DIRECT FRONTALS */
        ELSE IF KCRSH IN (2,3) AND RESTGP IN (2,3) THEN E=-.38;
```

```
        ELSE IF KCRSH IN (2,3) AND RESTGP IN (4,5,6) THEN E=-.27;
        ELSE IF KCRSH=11 AND RESTGP=1 THEN E=-.77;  /* FATALITY INCREASE WITH SLED-CERTIFIED IS 83% LESS THAN
WITH BARRIER-CERTIFIED */
        ELSE IF KCRSH=11 AND RESTGP IN (2,3) THEN E=-.17;
        ELSE IF KCRSH=11 AND RESTGP IN (4,5,6) THEN E=-.12;
        ELSE IF KCRSH IN (12,13) AND RESTGP=1 THEN E=-.29;      /* SLED-CERTIFIED, OBLIQUE FRONTAL */
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (2,3) THEN E=-.06;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (4,5,6) THEN E=-.05;
        ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208I=S*PS208I/P;
    CLV208I=S*PV208I/P;
        C_BARRIER=S*P_BARRIER/P;
        C_SLED=S*P_SLED/P;
        C_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+CLS208I+CLV208I;
    CL208I=CLS208I+CLV208I;
    CLS=CLS+CLS208I; CLV=CLV+CLV208I; CL=CL+CL208I;
    CABDRV=0; CABRF=0;
    IF KCRSH IN (1,2,3) THEN DO; CABKID_BARRIER=CL208I; CABKID_SLED=0; END;
          ELSE IF KCRSH IN (11,12,13) THEN DO; CABKID_BARRIER=0; CABKID_SLED=CL208I; END;
          ELSE DO; CABKID_BARRIER=0; CABKID_SLED=0; END;
    CSW0=0; CSW1=0; CSW2=0;
    CSWKID0_BARRIER=0; CSWKID1_BARRIER=0; CSWKID2_BARRIER=0;
    CSWKID0_SLED=0; CSWKID1_SLED=0; CSWKID2_SLED=0;
    C_KID_SLED=0; C_KID_CAC=0; C_ADULT_CAC=0;
    IF KCRSH IN (11,12,13,21,22,23) THEN DO;   /* ADD'L FATALITIES IF BAGS HAD BEEN 1st GEN RATHER THAN SLED OR
CAC */
        IF KCRSH IN (11) AND RESTGP=1 THEN E_HYP=-3.73;
        ELSE IF KCRSH IN (11) AND RESTGP IN (2,3) THEN E_HYP=-.83;
        ELSE IF KCRSH IN (11) AND RESTGP IN (4,5,6) THEN E_HYP=-.58;
        ELSE IF KCRSH IN (12,13) AND RESTGP=1 THEN E_HYP=-1.42;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (2,3) THEN E_HYP=-.32;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (4,5,6) THEN E_HYP=-.22;
        ELSE IF KCRSH IN (21) AND RESTGP=1 THEN E_HYP=-4.5;
        ELSE IF KCRSH IN (21) AND RESTGP IN (2,3) THEN E_HYP=-1;
        ELSE IF KCRSH IN (21) AND RESTGP IN (4,5,6) THEN E_HYP=-.70;
        ELSE IF KCRSH IN (21,23) AND RESTGP=1 THEN E_HYP=-1.71;
        ELSE IF KCRSH IN (21,23) AND RESTGP IN (2,3) THEN E_HYP=-.38;
        ELSE IF KCRSH IN (21,23) AND RESTGP IN (4,5,6) THEN E_HYP=-.27;
        ELSE E_HYP=0;
                IF KCRSH IN (11,12,13) THEN C_KID_SLED=-1*OLDWTFA*E_HYP;
                ELSE IF KCRSH IN (21,22,23) THEN C_KID_CAC=-1*OLDWTFA*E_HYP; END;
   GOTO C208H;
```

Manual on-off switches for passenger air bags: not many cars had the switches, but some cars with small rear seats or no rear seats had them. In each scenario, it is necessary to compute the lives lost, or not saved, because the switch was set “off” for a child or “on” for an adult. The proportion of switches set incorrectly is based on a 2000 NHTSA survey discussed in Part 1 of this report.

```
CRFBELSW:  OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (CL226+CL214C+CLS214B)/OLDWTFA GT .05557 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.27784;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.14563;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.05557;
ELSE E=0;

  /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                          */
    IF 13 LE AGE LE 15 THEN U=.22;
      ELSE IF 16 LE AGE LE 19 THEN U=.17;
      ELSE IF 20 LE AGE LE 59 THEN U=.15;
      ELSE IF 60 LE AGE LE 69 THEN U=.19;
      ELSE IF AGE GE 70 THEN U=.56;

    P=PS208I+PV208I;
```

```
    X=OLDWTFA/(1 - E*P + U*E*P);
    S=X - OLDWTFA;
    CLS208I=S*PS208I/P;
    CLV208I=S*PV208I/P;
        C_BARRIER=S*P_BARRIER/P;
        C_SLED=S*P_SLED/P;
        C_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+CLS208I+CLV208I;
    Y=X*(1-E);
    CSW1=X-Y;
    CSW2=Y-OLDWTFA;
    CL208I=CLS208I+CLV208I;
    CLS=CLS+CLS208I; CLV=CLV+CLV208I; CL=CL+CL208I;
    CSW0=CL208I;
    CABDRV=0; CABRF=0;
    CABKID_BARRIER=0; CABKID_SLED=0;
    CSWKID0_BARRIER=0; CSWKID1_BARRIER=0; CSWKID2_BARRIER=0;
    CSWKID0_SLED=0; CSWKID1_SLED=0; CSWKID2_SLED=0;
    C_KID_SLED=0; C_KID_CAC=0; C_ADULT_CAC=0; GOTO C208H;

CRFUNRSW:  OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (CL226+CL214C+CLS214B)/OLDWTFA GT .07203 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.36016;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.18877;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.07203;
ELSE E=0;

  /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                         */
    IF 13 LE AGE LE 15 THEN U=.22;
      ELSE IF 16 LE AGE LE 19 THEN U=.17;
      ELSE IF 20 LE AGE LE 59 THEN U=.15;
      ELSE IF 60 LE AGE LE 69 THEN U=.19;
      ELSE IF AGE GE 70 THEN U=.56;

    P=PS208I+PV208I;
    X=OLDWTFA/(1 - E*P + U*E*P);
    S=X - OLDWTFA;
    CLS208I=S*PS208I/P;
    CLV208I=S*PV208I/P;
        C_BARRIER=S*P_BARRIER/P;
        C_SLED=S*P_SLED/P;
        C_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+CLS208I+CLV208I;
    Y=X*(1-E);
    CSW1=X-Y;
    CSW2=Y-OLDWTFA;
    CL208I=CLS208I+CLV208I;
    CLS=CLS+CLS208I; CLV=CLV+CLV208I; CL=CL+CL208I;
    CSW0=CL208I;
    CABDRV=0; CABRF=0;
    CABKID_BARRIER=0; CABKID_SLED=0;
    CSWKID0_BARRIER=0; CSWKID1_BARRIER=0; CSWKID2_BARRIER=0;
    CSWKID0_SLED=0; CSWKID1_SLED=0; CSWKID2_SLED=0;
    C_KID_SLED=0; C_KID_CAC=0; C_ADULT_CAC=0; GOTO C208H;

CKIDSW:    OLDWTFA=WEIGHTFA;
      IF KCRSH=1 AND RESTGP=1 THEN E=-4.5;  /* FATALITY INCREASE, BARRIER-CERT REL TO NO BAGS, DIRECT FRONTALS,
3 GPS OF YOUNG CHILDREN */
        ELSE IF KCRSH=1 AND RESTGP IN (2,3) THEN E=-1;
        ELSE IF KCRSH=1 AND RESTGP IN (4,5,6) THEN E=-.70;
        ELSE IF KCRSH IN (2,3) AND RESTGP=1 THEN E=-1.71; /* INCREASE IN OBLIQUE FRONTALS IS 62% LESS THAN IN
DIRECT FRONTALS */
        ELSE IF KCRSH IN (2,3) AND RESTGP IN (2,3) THEN E=-.38;
        ELSE IF KCRSH IN (2,3) AND RESTGP IN (4,5,6) THEN E=-.27;
        ELSE IF KCRSH=11 AND RESTGP=1 THEN E=-.77;  /* FATALITY INCREASE WITH SLED-CERTIFIED IS 83% LESS THAN
WITH BARRIER-CERTIFIED */
        ELSE IF KCRSH=11 AND RESTGP IN (2,3) THEN E=-.17;
        ELSE IF KCRSH=11 AND RESTGP IN (4,5,6) THEN E=-.12;
        ELSE IF KCRSH IN (12,13) AND RESTGP=1 THEN E=-.29;        /* SLED-CERTIFIED, OBLIQUE FRONTAL */
```

```
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (2,3) THEN E=-.06;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (4,5,6) THEN E=-.05;
        ELSE E=0;

  /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                         */
    IF AGE=0 THEN U=.86;
      ELSE IF 1 LE AGE LE 6 THEN U=.74;
      ELSE IF 7 LE AGE LE 8 THEN U=.59;
      ELSE IF 9 LE AGE LE 10 THEN U=.47;
      ELSE IF 11 LE AGE LE 12 THEN U=.30;

    P=PS208I+PV208I;
    X=OLDWTFA/(1 - E*P + U*E*P);
    S=X - OLDWTFA;
    CLS208I=S*PS208I/P;
    CLV208I=S*PV208I/P;
    CL208I=CLS208I+CLV208I;
    CLS=CLS+CLS208I; CLV=CLV+CLV208I; CL=CL+CL208I;
        C_BARRIER=S*P_BARRIER/P;
        C_SLED=S*P_SLED/P;
        C_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+CLS208I+CLV208I;
    Y=X*(1-E);
        IF KCRSH IN (1,2,3) THEN DO;
      CSWKID1_BARRIER=X-Y; CSWKID1_SLED=0;
      CSWKID2_BARRIER=Y-OLDWTFA; CSWKID2_SLED=0;
      CSWKID0_BARRIER=CL208I; CSWKID0_SLED=0; END;
        ELSE IF KCRSH IN (11,12,13) THEN DO;
      CSWKID1_BARRIER=0; CSWKID1_SLED=X-Y;
      CSWKID2_BARRIER=0; CSWKID2_SLED=Y-OLDWTFA;
      CSWKID0_BARRIER=0; CSWKID0_SLED=CL208I; END;
        ELSE DO;
      CSWKID1_BARRIER=0; CSWKID1_SLED=0;
      CSWKID2_BARRIER=0; CSWKID2_SLED=0;
      CSWKID0_BARRIER=0; CSWKID0_SLED=0; END;
    CSW0=0; CSW1=0; CSW2=0; CABDRV=0; CABRF=0; CABKID_BARRIER=0; CABKID_SLED=0;
    CSWKID0=0; CSWKID1=0; CSWKID2=0;
    C_KID_SLED=0; C_KID_CAC=0; C_ADULT_CAC=0;
    IF KCRSH IN (11,12,13,21,22,23) THEN DO;   /* ADD'L FATALITIES IF BAGS HAD BEEN 1st GEN RATHER THAN SLED OR
CAC */
        IF KCRSH IN (11) AND RESTGP=1 THEN E_HYP=-3.73;
        ELSE IF KCRSH IN (11) AND RESTGP IN (2,3) THEN E_HYP=-.83;
        ELSE IF KCRSH IN (11) AND RESTGP IN (4,5,6) THEN E_HYP=-.58;
        ELSE IF KCRSH IN (12,13) AND RESTGP=1 THEN E_HYP=-1.42;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (2,3) THEN E_HYP=-.32;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (4,5,6) THEN E_HYP=-.22;
        ELSE IF KCRSH IN (21) AND RESTGP=1 THEN E_HYP=-4.5;
        ELSE IF KCRSH IN (21) AND RESTGP IN (2,3) THEN E_HYP=-1;
        ELSE IF KCRSH IN (21) AND RESTGP IN (4,5,6) THEN E_HYP=-.70;
        ELSE IF KCRSH IN (21,23) AND RESTGP=1 THEN E_HYP=-1.71;
        ELSE IF KCRSH IN (21,23) AND RESTGP IN (2,3) THEN E_HYP=-.38;
        ELSE IF KCRSH IN (21,23) AND RESTGP IN (4,5,6) THEN E_HYP=-.27;
        ELSE E_HYP=0;
                IF KCRSH IN (11,12,13) THEN C_KID_SLED=(U-1)*OLDWTFA*E_HYP;
                ELSE IF KCRSH IN (21,22,23) THEN C_KID_CAC=(U-1)*OLDWTFA*E_HYP; END;

/* ---------------------------------------------------------------- */
/*  208H AUTOMATIC 2-POINT BELTS                                    */
/*  PEAK INSTALLATION YEAR: 1991  PHASE-IN STARTED MY 1987          */
/* ---------------------------------------------------------------- */

/* IDENTIFIES OCCUPANTS WEARING AUTOMATIC 2-POINT BELTS  */
C208H: PS208H=0; PV208H=0;
```

"REST3 = 7" indicates use of 2-point automatic belts. PS208H includes any installation from MY 1987 onwards, because the phase-in of automatic occupant protection began on September 1, 1986.

```
 IF REST3=7 THEN DO; IF XMY LE 1986 THEN PV208H=1; ELSE PS208H=1; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY AUTOMATIC 2-POINT BELTS */
 OLDWTFA=WEIGHTFA;
 IF PS208H GT 0 OR PV208H GT 0 THEN DO;
```

Two-point automatic belts reduce fatalities by an estimated 30 percent in frontals, 18 percent in side impacts, 62 percent in rollovers and 68 percent in rear/other impacts. In general, 21 percent of unrestrained outboard front seat occupant fatalities in frontal crashes were ejected, 23 percent in side impacts, 66 percent in rollovers and 35 percent in rear/other impacts.

```
    IF CRSH=1 THEN DO; E=.30; EJECT2=.21; END;
      ELSE IF CRSH=2 THEN DO; E=.18; EJECT2=.23; END;
      ELSE IF CRSH=3 THEN DO; E=.62; EJECT2=.66; END;
      ELSE IF CRSH=4 THEN DO; E=.68; EJECT2=.35; END;
    P=PS208H+PV208H;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208H=S*PS208H/P;
    CLV208H=S*PV208H/P;
    WEIGHTFA=OLDWTFA+CLS208H+CLV208H; END;
  ELSE DO; CLS208H=0; CLV208H=0; END;
  CL208H=CLS208H+CLV208H;
  CLS=CLS+CLS208H; CLV=CLV+CLV208H; CL=CL+CL208H;

/* ---------------------------------------------------------------- */
/*  208G 3-POINT BELTS FOR OUTBOARD REAR SEAT OCCUPANTS             */
/*  MEDIAN INSTALLATION YEAR: 1989  FMVSS EFFECTIVE DATE: 12/11/1989  */
/* ---------------------------------------------------------------- */

/* IDENTIFIES REAR SEAT OCCUPANTS WEARING 3-POINT BELTS  */
  PS208G=0; PV208G=0;
  IF SEAT2=21 AND REST3=3 THEN DO; IF XMY LE 1989 THEN PV208G=1; ELSE PS208G=1; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY REAR-SEAT 3-POINT BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208G GT 0 OR PV208G GT 0 THEN DO;
```

Three-point belts in the outboard rear seats reduce fatalities by 29 percent in frontals, 42 percent in side impacts, 77 percent in rollovers and 31 percent in rear/other impacts. In general, 23 percent of unrestrained outboard rear seat occupant fatalities in frontal crashes were ejected, 28 percent in side impacts, 61 percent in rollovers and 27 percent in rear/other impacts.

```
    IF CRSH=1 THEN DO; E=.29; EJECT2=.23; END;
      ELSE IF CRSH=2 THEN DO; E=.42; EJECT2=.28; END;
      ELSE IF CRSH=3 THEN DO; E=.77; EJECT2=.61; END;
      ELSE IF CRSH=4 THEN DO; E=.31; EJECT2=.27; END;
    P=PS208G+PV208G;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208G=S*PS208G/P;
    CLV208G=S*PV208G/P;
    WEIGHTFA=OLDWTFA+CLS208G+CLV208G; END;
  ELSE DO; CLS208G=0; CLV208G=0; END;
  CL208G=CLS208G+CLV208G;
  CLS=CLS+CLS208G; CLV=CLV+CLV208G; CL=CL+CL208G;

/* ---------------------------------------------------------------- */
/*  213 CHILD SAFETY SEATS                                          */
/*  USE RATE WENT OVER 50% IN: 1985  FMVSS EFFECTIVE DATE: 4/1/1971   */
/* ---------------------------------------------------------------- */

/* IDENTIFIES CHILD PASSENGERS IN SAFETY SEATS  */
  PS213=0; PV213=0;
  IF REST3=4 THEN DO;
```

"REST3 = 4" indicates a child passenger in a safety seat (not necessarily correctly used). FMVSS No. 213 regulates the performance of safety seats but does not mandate their use. Therefore, the distinction between PV213 and PS213 will not be based on the effective date of FMVSS No. 213 (April 1, 1971) but on whether the child was covered by a State law for child passenger protection. That depends on the State and the age of the child. Here is a State-by-State listing of when the laws initially took effect and for what age groups and when the laws were subsequently upgraded to include higher age groups:

```
  IF STATE=1 THEN DO; IF CY=1982 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1; /* STATE LAWS IN EFFECT UP TO WHAT
AGE: ALABAMA */
    ELSE IF 1983 LE CY LE 2004 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2005 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=2 THEN DO; IF CY=1985 AND MONTH GE 6 AND AGE LE 3 THEN PS213=1;     /* ALASKA */
    ELSE IF 1986 LE CY LE 2007 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2008 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=4 THEN DO; IF CY=1983 AND MONTH GE 8 AND AGE LE 4 THEN PS213=1;      /* ARIZONA */
    ELSE IF 1984 LE CY LE 2010 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2011 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=5 THEN DO; IF CY=1983 AND MONTH GE 8 AND AGE LE 2 THEN PS213=1;      /* ARKANSAS */
    ELSE IF 1984 LE CY LE 1993 AND AGE LE 2 THEN PS213=1;
    ELSE IF 1994 LE CY LE 1997 AND AGE LE 3 THEN PS213=1;
    ELSE IF 1998 LE CY LE 2000 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2001 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=6 THEN DO; IF 1983 LE CY LE 2000 AND AGE LE 3 THEN PS213=1;         /* CALIFORNIA */
        ELSE IF CY GE 2001 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=8 THEN DO; IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;         /* COLORADO */
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=9 THEN DO; IF CY=1982 AND MONTH GE 5 AND AGE=0 THEN PS213=1;      /* CONNECTICUT */
    ELSE IF 1983 LE CY LE 1993 AND AGE=0 THEN PS213=1;
    ELSE IF CY=1982 AND MONTH GE 5 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
    ELSE IF 1983 LE CY LE 1993 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
    ELSE IF 1994 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;

  ELSE IF STATE=10 THEN DO; IF CY=1982 AND MONTH GE 6 AND AGE LE 3 THEN PS213=1;      /* DELAWARE */
    ELSE IF 1983 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
    ELSE IF 2002 LE CY LE 2003 AND AGE LE 5 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=11 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;      /* DC */
    ELSE IF 1984 LE CY LE 1997 AND AGE LE 2 THEN PS213=1;
    ELSE IF 1998 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2002 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=12 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1;      /* FLORIDA */
        ELSE IF CY GE 1984 AND AGE LE 3 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=13 THEN DO; IF CY=1984 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;      /* GEORGIA */
    ELSE IF 1985 LE CY LE 2002 AND AGE LE 2 THEN PS213=1;
    ELSE IF CY=2003 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=15 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;      /* HAWAII */
    ELSE IF 1984 LE CY LE 2003 AND AGE LE 2 THEN PS213=1;
    ELSE IF 2004 LE CY LE 2006 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=16 THEN DO; IF 1985 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;         /* IDAHO */
        ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=17 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1;     /* ILLINOIS */
    ELSE IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=18 THEN DO; IF 1984 LE CY LE 1997 AND AGE LE 2 THEN PS213=1;         /* INDIANA */
    ELSE IF 1998 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=19 THEN DO; IF 1985 LE CY LE 2003 AND AGE LE 2 THEN PS213=1;         /* IOWA */
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=20 THEN DO; IF 1982 LE CY LE 2004 AND AGE LE 3 THEN PS213=1;         /* KANSAS */
        ELSE IF CY GE 2005 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=21 THEN DO; IF CY=1982 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;     /* KENTUCKY */
    ELSE IF 1983 LE CY LE 2006 AND AGE LE 2 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=22 THEN DO; IF CY=1984 AND MONTH GE 9 AND AGE LE 2 THEN PS213=1;       /* LOUISIANA */
    ELSE IF 1985 LE CY LE 2003 AND AGE LE 2 THEN PS213=1;
    ELSE IF CY=1984 AND MONTH GE 9 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
    ELSE IF 1985 LE CY LE 2003 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=23 THEN DO; IF CY=1983 AND MONTH GE 9 AND AGE LE 3 THEN PS213=1;      /* MAINE */
    ELSE IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=24 THEN DO; IF 1984 LE CY LE 1992 AND AGE LE 2 THEN PS213=1;          /* MARYLAND */
    ELSE IF 1993 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
    ELSE IF 2002 LE CY LE 2006 AND AGE LE 5 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
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ELSE IF STATE=25 THEN DO; IF 1982 LE CY LE 2006 AND AGE LE 4 THEN PS213=1;        /* MASSACHUSETTS */
      ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=26 THEN DO; IF CY=1982 AND MONTH GE 4 AND AGE=0 THEN PS213=1;         /* MICHIGAN */
  ELSE IF 1983 LE CY LE 1999 AND AGE=0 THEN PS213=1;
  ELSE IF CY=1982 AND MONTH GE 4 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
  ELSE IF 1983 LE CY LE 1999 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
      ELSE IF 2000 LE CY LE 2006 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=27 THEN DO; IF CY=1983 AND MONTH GE 8 AND AGE LE 3 THEN PS213=1;      /* MINNESOTA */
  ELSE IF 1984 LE CY LE 2007 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2008 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=28 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 1 THEN PS213=1;      /* MISSISSIPPI */
  ELSE IF 1984 LE CY LE 1993 AND AGE LE 1 THEN PS213=1;
  ELSE IF 1994 LE CY LE 2006 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2007 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=29 THEN DO; IF 1984 LE CY LE 2004 AND AGE LE 3 THEN PS213=1;         /* MISSOURI */
      ELSE IF CY GE 2005 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=30 THEN DO; IF 1984 LE CY LE 2003 AND AGE LE 1 THEN PS213=1;         /* MONTANA */
      ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=31 THEN DO; IF CY=1983 AND MONTH GE 8 AND AGE LE 3 THEN PS213=1;      /* NEBRASKA */
  ELSE IF 1984 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2002 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=32 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 4 THEN PS213=1;      /* NEVADA */
  ELSE IF 1984 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
  ELSE IF 2004 LE CY LE 2008 AND AGE LE 5 THEN PS213=1;
      ELSE IF CY GE 2009 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=33 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1;    /* NEW HAMPSHIRE */
  ELSE IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=34 THEN DO; IF CY=1983 AND MONTH GE 4 AND AGE=0 THEN PS213=1;         /* NEW JERSEY */
  ELSE IF 1984 LE CY LE 2001 AND AGE=0 THEN PS213=1;
  ELSE IF CY=1983 AND MONTH GE 4 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
  ELSE IF 1984 LE CY LE 2001 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
      ELSE IF CY GE 2002 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=35 THEN DO; IF CY=1983 AND MONTH GE 6 AND AGE=0 THEN PS213=1;         /* NEW MEXICO */
  ELSE IF 1984 LE CY LE 2001 AND AGE=0 THEN PS213=1;
  ELSE IF CY=1983 AND MONTH GE 6 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
  ELSE IF 1984 LE CY LE 2001 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
      ELSE IF 2002 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=36 THEN DO; IF CY=1982 AND MONTH GE 4 AND AGE LE 3 THEN PS213=1;      /* NEW YORK */
  ELSE IF 1983 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
  ELSE IF 2004 LE CY LE 2008 AND AGE LE 6 THEN PS213=1;
      ELSE IF CY GE 2009 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=37 THEN DO; IF CY=1982 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;   /* NORTH CAROLINA */
  ELSE IF 1983 LE CY LE 1992 AND AGE LE 2 THEN PS213=1;
  ELSE IF 1993 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
  ELSE IF 2002 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=38 THEN DO; IF 1984 LE CY LE 1998 AND AGE LE 2 THEN PS213=1;         /* NORTH DAKOTA */
  ELSE IF 1999 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=39 THEN DO; IF CY=1983 AND MONTH GE 3 AND AGE LE 3 THEN PS213=1;      /* OHIO */
  ELSE IF 1984 LE CY LE 2007 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2008 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=40 THEN DO; IF CY=1983 AND MONTH GE 11 AND AGE LE 3 THEN PS213=1;      /* OKLAHOMA */
  ELSE IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=41 THEN DO; IF 1984 LE CY LE 1994 AND AGE=0 THEN PS213=1;              /* OREGON */
  ELSE IF 1995 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
  ELSE IF 2002 LE CY LE 2006 AND AGE LE 5 THEN PS213=1;
      ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=42 THEN DO; IF 1984 LE CY LE 1992 AND AGE=0 THEN PS213=1;            /* PENNSYLVANIA */
  ELSE IF 1984 LE CY LE 1992 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
  ELSE IF 1993 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=44 THEN DO; IF CY=1980 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1;     /* RHODE ISLAND */
  ELSE IF 1981 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
  ELSE IF 2002 LE CY LE 2008 AND AGE LE 6 THEN PS213=1;
      ELSE IF CY GE 2009 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=45 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE=0 THEN PS213=1;      /* SOUTH CAROLINA */
  ELSE IF 1984 LE CY LE 2003 AND AGE=0 THEN PS213=1;
```

```
    ELSE IF CY=1983 AND MONTH GE 7 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
    ELSE IF 1984 LE CY LE 2003 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=46 THEN DO; IF CY=1984 AND MONTH GE 7 AND AGE LE 1 THEN PS213=1;     /* SOUTH DAKOTA */
    ELSE IF 1985 LE CY LE 1997 AND AGE LE 1 THEN PS213=1;
        ELSE IF CY GE 1998 AND AGE LE 4 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=47 THEN DO; IF 1978 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;        /* TENNESSEE */
        ELSE IF CY GE 2004 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=48 THEN DO; IF CY=1984 AND MONTH GE 10 AND AGE LE 1 THEN PS213=1;      /* TEXAS */
    ELSE IF 1985 LE CY LE 2000 AND AGE LE 1 THEN PS213=1;
    ELSE IF 2001 LE CY LE 2007 AND AGE LE 2 THEN PS213=1;
        ELSE IF CY GE 2008 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=49 THEN DO; IF CY=1984 AND MONTH GE 7 AND AGE LE 1 THEN PS213=1;      /* UTAH */
    ELSE IF 1985 LE CY LE 1999 AND AGE LE 1 THEN PS213=1;
    ELSE IF 2000 LE CY LE 2006 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=50 THEN DO; IF CY=1984 AND MONTH GE 7 AND AGE=0 THEN PS213=1;         /* VERMONT */
    ELSE IF 1985 LE CY LE 1992 AND AGE=0 THEN PS213=1;
    ELSE IF CY=1984 AND MONTH GE 7 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
    ELSE IF 1985 LE CY LE 1992 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
    ELSE IF 1993 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
    ELSE IF 2004 LE CY LE 2006 AND AGE LE 6 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=51 THEN DO; IF 1983 LE CY LE 1992 AND AGE LE 2 THEN PS213=1;          /* VIRGINIA */
    ELSE IF 1993 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
    ELSE IF 2002 LE CY LE 2006 AND AGE LE 5 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=53 THEN DO; IF 1984 LE CY LE 1992 AND AGE=0 THEN PS213=1;        /* WASHINGTON STATE */
    ELSE IF 1993 LE CY LE 1995 AND AGE LE 1 THEN PS213=1;
    ELSE IF 1996 LE CY LE 2001 AND AGE LE 2 THEN PS213=1;
    ELSE IF 2002 LE CY LE 2003 AND AGE LE 5 THEN PS213=1;
    ELSE IF 2004 LE CY LE 2008 AND AGE LE 7 THEN PS213=1;
        ELSE IF CY GE 2009 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=54 THEN DO; IF CY=1981 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;    /* WEST VIRGINIA */
    ELSE IF 1982 LE CY LE 2003 AND AGE LE 2 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=55 THEN DO; IF CY=1982 AND MONTH GE 11 AND AGE LE 1 THEN PS213=1;      /* WISCONSIN */
    ELSE IF 1983 LE CY LE 2004 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2005 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=56 THEN DO; IF CY=1985 AND MONTH GE 4 AND AGE LE 2 THEN PS213=1;      /* WYOMING */
    ELSE IF 1986 LE CY LE 1996 AND AGE LE 2 THEN PS213=1;
    ELSE IF 1997 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END; END;

/* LIVES SAVED AND EJECTIONS PREVENTED BY CHILD SAFETY SEATS */
  OLDWTFA=WEIGHTFA;
  IF PS213 GT 0 OR PV213 GT 0 THEN DO;
```

NHTSA’s evaluation estimates that safety seats reduce fatality risk by 71 percent for infants and by 54 percent for toddlers. Effectiveness is not estimated separately by crash mode. In general, 19 percent of unrestrained child passenger fatalities in frontal crashes were ejected, 26 percent in side impacts, 65 percent in rollovers and 34 percent in rear/other impacts.

```
    IF AGE=0 THEN E=.71; ELSE E=.54;
    IF CRSH=1 THEN EJECT2=.19;
      ELSE IF CRSH=2 THEN EJECT2=.26;
      ELSE IF CRSH=3 THEN EJECT2=.65;
      ELSE IF CRSH=4 THEN EJECT2=.34;
    P=PS213+PV213;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS213=S*PS213/P;
    CLV213=S*PV213/P;
    WEIGHTFA=OLDWTFA+CLS213+CLV213; END;
  ELSE DO; CLS213=0; CLV213=0; END;
  CL213=CLS213+CLV213;
  CLS=CLS+CLS213; CLV=CLV+CLV213; CL=CL+CL213;
```

NCAP-related crashworthiness improvement is the only component of the model that is not associated with a specific FMVSS or even a single, specific technology. Nevertheless, cars became safer, saving lives. Starting in 1979 NCAP tested the injury performance of belted dummies in 35-mph frontal impacts, and advised the public about the comparative performance of make-models. Starting about 1982, rapidly at first and more gradually in 1984 to 1987, manufacturers modified or redesigned their cars, resulting in substantial improvements on the NCAP test. Modifications included the belt system, the steering assembly, the instrument panel and the seat structure, taking into account how dummies interacted with those systems in 35 mph tests. NHTSA's evaluation showed a 20-percent reduction of fatality risk, for MY 1983-to-1986 versus MY 1979-to-1982, for belted drivers in head-on collisions with other cars. NHTSA's evaluation did not consider crashes with other types of vehicles or with fixed objects, and it did not study the fatality risk of passengers; the data was limited almost entirely to cars without air bags. We will assume a 20-percent fatality reduction, for belted drivers only (not passengers), when a car frontally impacts another car (but not limited to head-on collisions). Conservatively, we will not assume any benefit for other frontal impacts, such as with an LTV, a heavy truck, or a fixed object; we will limit the benefit to cars without air bags.

```
/* ----------------------------------------------------------------- */
/*  NCAP VOLUNTARY FRONTAL CRASHWORTHINESS IMPROVEMENTS              */
/*  MEDIAN IMPLEMENTATION YEAR: 1984                                 */
/* ----------------------------------------------------------------- */

/* IDENTIFIES NON-AIR-BAG, 3-POINT-BELT CARS WITH IMPROVED NCAP SCORES   */
  PSNCAP=0; PVNCAP=0;
  IF CY GE 1981 AND XMY GE 1982 AND PASSIVE IN (0,505) AND SEAT2=11 THEN DO;
      IF XMY=1982 THEN PVNCAP=.25;
        ELSE IF XMY=1983 THEN PVNCAP=.50;
        ELSE IF XMY=1984 THEN PVNCAP=.67;
        ELSE IF XMY=1985 THEN PVNCAP=.83;
        ELSE IF XMY GE 1986 THEN PVNCAP=1; END;
/* LIVES SAVED BY NCAP-RELATED IMPROVEMENTS: BELTED DRIVERS IN HEAD-ON CRASHES WITH CARS */
  OLDWTFA=WEIGHTFA;
  IF PSNCAP GT 0 OR PVNCAP GT 0 THEN DO;
    IF REST3=3 AND
      (IMPACT2 IN (.5,1,11,11.5,12) OR (CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11,12)))
      AND OVTYP=1 THEN E=.20; ELSE E=0;
    P=PSNCAP+PVNCAP;
    S=OLDWTFA*E*P / (1 - E*P);
    CLSNCAP=S*PSNCAP/P;
    CLVNCAP=S*PVNCAP/P;
    WEIGHTFA=OLDWTFA+CLSNCAP+CLVNCAP; END;
  ELSE DO; CLSNCAP=0; CLVNCAP=0; END;
  CLNCAP=CLSNCAP+CLVNCAP;
  CLS=CLS+CLSNCAP; CLV=CLV+CLVNCAP; CL=CL+CLNCAP;

/* ----------------------------------------------------------------- */
/*  208F 3-POINT BELTS FOR FRONT-SEAT OUTBOARD OCCUPANTS             */
/*  MEDIAN INSTALLATION YEAR: 1974  FMVSS EFFECTIVE DATE: 9/1/1973    */
/* ----------------------------------------------------------------- */

/* IDENTIFIES FRONT SEAT OCCUPANTS WEARING 3-POINT BELTS  */
  PS208F=0; PV208F=0;
```

"REST3 = 3" includes use of manual 3-point belts, use of automatic 3-point belts, and use of both belts at seats with separate lap and shoulder belts (i.e., for the separate belts only, FARS must say REST_USE = 3; for the 3-point systems, REST_USE can be 1, 2, 3, 8, 13 or imputed). The FMVSS No. 208 requirement for integral 3-point belts took effect on September 1, 1973 (model year 1974); all lap/shoulder belt use (integral or separate) before MY 1974 will be credited to PV208F.

```
 IF SEAT2 IN (11,13) AND REST3=3 THEN DO; IF XMY LE 1973 THEN PV208F=1; ELSE PS208F=1; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY OUTBOARD-FRONT-SEAT 3-POINT BELTS */
 OLDWTFA=WEIGHTFA;
 IF PS208F GT 0 OR PV208F GT 0 THEN DO;
```

With the abundant data for evaluating lap/shoulder belt effectiveness, it is possible to fine-tune the estimates more than for other belt systems: 60-percent fatality reduction in single-vehicle frontals, 42 percent in multi-vehicle frontals; 21 percent in single-vehicle near-side; 5 percent in multi-vehicle near-side; 46 percent in single-vehicle far-side; 35 percent in multivehicle far-side; 74 percent in rollovers; 56 percent in rear/other impacts. The proportion of unrestrained fatalities that were ejectees is also computed separately for each of those crash types.

```
    IF CRSH=1 AND VE_FORMS=1 THEN DO; E=.60; EJECT2=.31; END;
      ELSE IF CRSH=1 THEN DO; E=.42; EJECT2=.12; END;
      ELSE IF CRSH=2 THEN DO;
        IF VE_FORMS=1 AND
          ((SEAT2=11 AND IMPACT2 IN (8,8.5,9,9.5,10,26,61:63))
            OR (SEAT2=13 AND IMPACT2 IN (2,2.5,3,3.5,4,26,81:83)) OR
          (SEAT2=11 AND CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (8,9,10,61:63)) OR
          (SEAT2=13 AND CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,3,4,81:83)))
          THEN DO; E=.21; EJECT2=.33; END;
        ELSE IF ((SEAT2=11 AND IMPACT2 IN (8,8.5,9,9.5,10,26,61:63))
            OR (SEAT2=13 AND IMPACT2 IN (2,2.5,3,3.5,4,26,81:83)) OR
          (SEAT2=11 AND CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (8,9,10,61:63)) OR
          (SEAT2=13 AND CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,3,4,81:83)))
          THEN DO; E=.05; EJECT2=.15; END;
        ELSE IF VE_FORMS=1 THEN DO; E=.46; EJECT2=.36; END;
        ELSE DO; E=.35; EJECT2=.20; END; END;
      ELSE IF CRSH=3 THEN DO; E=.74; EJECT2=.66; END;
      ELSE IF CRSH=4 THEN DO; E=.56; EJECT2=.35; END;
    P=PS208F+PV208F;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208F=S*PS208F/P;
    CLV208F=S*PV208F/P;
    WEIGHTFA=OLDWTFA+CLS208F+CLV208F; END;
  ELSE DO; CLS208F=0; CLV208F=0; END;
  CL208F=CLS208F+CLV208F;
  CLS=CLS+CLS208F; CLV=CLV+CLV208F; CL=CL+CL208F;

/* ------------------------------------------------------------------ */
/*  216 B-PILLARS FOR HARDTOP CARS AND OTHER ROOF STRENGTHENING       */
/*  MEDIAN INSTALLATION YEAR: 1973  FMVSS EFFECTIVE DATE: 9/1/1973    */
/* ------------------------------------------------------------------ */

/* ROOF STRENGTH IMPROVED GRADUALLY FROM 1970 TO 1977       */
  IF XMY LE 1969 THEN DO; PS216=0; PV216=0; END;
    ELSE IF 1970 LE XMY LE 1973 THEN DO; PS216=0; PV216=.125*(XMY-1969); END;
    ELSE IF 1974 LE XMY LE 1976 THEN DO; PS216=.125*(XMY-1969); PV216=0; END;
    ELSE IF XMY GE 1977 THEN DO; PS216=1; PV216=0; END;
/* REDUCTION IN NONEJECTION ROLLOVER FATALITY RISK WITH IMPROVED ROOF STRENGTH */
  OLDWTFA=WEIGHTFA;
```

Roof crush resistance can benefit any non-ejected occupant (EJECT2 NE 1) within the vehicle (SEAT2 NE 52) in a rollover crash. NHTSA's evaluation showed an overall 7.4-percent reduction in non-ejection rollover fatalities during the 1970-to-1977 implementation period associated with FMVSS No. 216. This is one of the FMVSS where it was important to track the changes in EJECT2 in previous steps of the model. But EJECT2 also has to be recomputed at the end of this step EJECT2 = EJECT2/(1+REL_S), because "removing" roof crush strength increases non-ejection fatalities, and thus increases the proportion of fatalities that are not ejected

```
  IF (PS216 GT 0 OR PV216 GT 0) AND (CRSH=3 OR M_HARM=1)
      AND SEAT2 NE 52 AND EJECT2 NE 1 THEN DO;
    E=.074;
    P=PS216+PV216;
    REL_S=(1-EJECT2)*E*P / (1 - E*P);
    S=OLDWTFA*REL_S;
    CLS216=S*PS216/P;
    CLV216=S*PV216/P;
    WEIGHTFA=OLDWTFA+CLS216+CLV216;
    EJECT2=EJECT2/(1+ REL_S); END;
  ELSE DO; CLS216=0; CLV216=0; END;
```

```
  CL216=CLS216+CLV216;
  CLS=CLS+CLS216; CLV=CLV+CLV216; CL=CL+CL216;

/* ---------------------------------------------------------------- */
/*  214A SIDE DOOR BEAMS                                            */
/*  MEDIAN INSTALLATION YEAR: EARLY 1973  FMVSS EFFECTIVE: 1/1/1973   */
/* ---------------------------------------------------------------- */

/* IDENTIFIES CARS WITH SIDE DOOR BEAMS                    */
```

We know exactly when each make-model was equipped with side door beams. PS214A and PV214A can be set to 0 or 1 (or possibly to .5 in MY 1973 because FMVSS No. 214 took effect in the middle of the model year). Identification of make-models is based on the VIN, if available, and on the FARS MAK_MOD code, otherwise.

```
  IF XMY GE 1974 THEN DO; PS214A=1; PV214A=0; GOTO SAVE214; END;
  IF XMY LE 1968 THEN DO; PS214A=0; PV214A=0; GOTO SAVE214; END;
  IF 1969 LE XMY LE 1972 THEN PS214A=0;
    ELSE IF XMY=1973 THEN PS214A=.5;
  IF MAKE IN (1,7,9,12,13,14,18,19,20,21,22) THEN GOTO SOMEVOL;
    ELSE GOTO NOVOL;
SOMEVOL: V13=V1||V2||V3;
  IF V13 IN ('999','000','   ') THEN GOTO NOVIN;
  IF XMY=1969 THEN DO;
    IF MAKE IN (1,7,9,12,13,14) THEN PV214A=0;
      ELSE IF MAKE IN (18,20,21,22) AND V2 IN ('5','6','7','8') THEN PV214A=1;
      ELSE IF MAKE=19 AND V1 NE 'H' THEN PV214A=1;
      ELSE PV214A=0; GOTO SAVE214; END;
  IF XMY=1970 THEN DO;
    IF MAKE IN (1,12,13,14) THEN PV214A=0;
      ELSE IF MAKE IN (18,20,21,22) AND V2 IN ('3','4','5','6','7','8') THEN PV214A=1;
      ELSE IF MAKE=19 AND V1 NE 'H' THEN PV214A=1;
      ELSE IF MAKE IN (20,22) AND V2='2' THEN PV214A=.5;
      ELSE IF MAKE=7 AND V1='J' THEN PV214A=1;
      ELSE IF MAKE=9 AND V1='B' THEN PV214A=1;
      ELSE PV214A=0; GOTO SAVE214; END;
  IF XMY=1971 THEN DO;
    IF MAKE IN (18,19,21,22) THEN PV214A=1;
      ELSE IF MAKE=20 AND V2 IN ('2','3','4','5','6') THEN PV214A=1;
      ELSE IF MAKE=12 AND V3 IN ('0','5','6','7') THEN PV214A=1;
      ELSE IF MAKE=13 AND V4 IN ('1','2') THEN PV214A=1;
      ELSE IF MAKE=14 AND V3 IN ('4','5','6','7','9') THEN PV214A=1;
      ELSE IF MAKE=7 AND V1='J' THEN PV214A=1;
      ELSE IF MAKE=9 AND V1='B' THEN PV214A=1;
      ELSE IF MAKE=1 AND V4 IN ('3','7') THEN PV214A=1;
      ELSE PV214A=0; GOTO SAVE214; END;
  IF XMY=1972 THEN DO;
    IF MAKE IN (13,18,19,21) THEN PV214A=1;
      ELSE IF MAKE=20 AND V2 NE 'X' AND V2 NE 'Z' THEN PV214A=1;
      ELSE IF MAKE=22 AND V2 NE 'Y' THEN PV214A=1;
      ELSE IF MAKE=12 AND V3 IN ('0','2','3','4','5','6','7') THEN PV214A=1;
      ELSE IF MAKE=14 AND V3 NE '3' THEN PV214A=1;
      ELSE IF MAKE=7 AND V1='J' THEN PV214A=1;
      ELSE IF MAKE=9 AND V1='B' THEN PV214A=1;
      ELSE IF MAKE=1 AND V4='7' THEN PV214A=1;
      ELSE PV214A=0; GOTO SAVE214; END;
  IF XMY=1973 THEN DO;
    IF MAKE IN (1,13,14,18,19,20,21,22) THEN PV214A=.5;
      ELSE IF MAKE=12 AND V3 NE '8' THEN PV214A=.5;
      ELSE IF MAKE=7 AND V1='J' THEN PV214A=.5;
      ELSE IF MAKE=9 AND V1='B' THEN PV214A=.5;
      ELSE PV214A=0; GOTO SAVE214; END;
NOVIN: IF XMY=1969 THEN DO;
    IF MAKE IN (1,7,9,12,13,14) THEN PV214A=0;
      ELSE IF MAK_MOD IN (1802,18002,1803,18003,1903,19003,2002,20002,
                          2102,21002,2103,21003,2202,22002,2210,22010) THEN PV214A=1;
      ELSE PV214A=0; GOTO SAVE214; END;
  IF XMY=1970 THEN DO;
    IF MAKE IN (1,12,13,14) THEN PV214A=0;
      ELSE IF MAK_MOD IN (1802,18002,1803,18003,1903,19003,2002,20002,
```

```
                          2102,21002,2103,21003,2202,22002,2210,22010,
                          1801,18001,2001,20001,2101,21001,2201,22001,
                          2010,20010,705,7005,905,9005) THEN PV214A=1;
      ELSE IF MAK_MOD IN (2009,20009,2209,22009) THEN PV214A=.5;
      ELSE PV214A=0; GOTO SAVE214; END;
  IF XMY=1971 THEN DO;
    IF MAKE IN (18,19,21,22) THEN PV214A=1;
      ELSE IF MAK_MOD IN (2002,20002,2001,20001,2010,20010,705,7005,905,9005,
                          2009,20009,2011,20011,
                          1203,12003,1206,12006,1301,13001,1404,14004,1406,14006,
                          105,1005,106,1006) THEN PV214A=1;
      ELSE PV214A=0; GOTO SAVE214; END;
  IF XMY=1972 THEN DO;
    IF MAKE IN (13,18,19,21) THEN PV214A=1;
      ELSE IF MAK_MOD IN (2002,20002,2001,20001,2010,20010,705,7005,905,9005,
                          2009,20009,2011,20011,
                          1203,12003,1206,12006,1202,12002,1404,14004,1406,14006,
                          1402,14002,105,1005,106,1006) THEN PV214A=1;
      ELSE IF MAKE=22 AND MAK_MOD NE 2208 AND MAK_MOD NE 22008 THEN PV214A=1;
      ELSE PV214A=0; GOTO SAVE214; END;
  IF XMY=1973 THEN DO;
    IF MAKE IN (1,13,14,18,19,20,21,22) THEN PV214A=.5;
      ELSE IF MAKE=12 AND MAK_MOD NE 1204 AND MAK_MOD NE 12004 THEN PV214A=.5;
      ELSE IF MAK_MOD IN (705,7005,905,9005) THEN PV214A=.5;
      ELSE PV214A=0; GOTO SAVE214; END;
NOVOL: IF 1969 LE XMY LE 1972 THEN DO; PS214A=0; PV214A=0; GOTO SAVE214; END;
   ELSE IF XMY=1973 THEN DO; PS214A=.5; PV214A=0; GOTO SAVE214; END;
/* REDUCTION IN SINGLE-VEHICLE SIDE-IMPACT FATALITIES WITH SIDE DOOR BEAMS     */
SAVE214:  OLDWTFA=WEIGHTFA;
```

Side door beams reduce fatality risk by 14 percent for outboard front-seat and rear-seat occupants in single-vehicle crashes. Whenever possible (CY GE 1979), also exclude collisions with parked vehicles from the “single” vehicle crashes.

```
  IF (PS214A GT 0 OR PV214A GT 0) AND
      (IMPACT2 IN (2,2.5,3,3.5,4,8,8.5,9,9.5,10,26,61:63,81:83) OR
        (CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,3,4,8,9,10,61:63,81:83))) AND
      SEAT2 IN (11,13,21) AND
      (VE_FORMS=1 OR (CY GE 1979 AND M_HARM NE 12 AND M_HARM NE 13 AND M_HARM NE 14))
      THEN DO;
    E=.14;
    P=PS214A+PV214A;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS214A=S*PS214A/P;
    CLV214A=S*PV214A/P;
    WEIGHTFA=OLDWTFA+CLS214A+CLV214A; END;
  ELSE DO; CLS214A=0; CLV214A=0; END;
  CL214A=CLS214A+CLV214A;
  CLS=CLS+CLS214A; CLV=CLV+CLV214A; CL=CL+CL214A;

/* ------------------------------------------------------------------ */
/*  105B FRONT DISC BRAKES                                            */
/*  MEDIAN INSTALLATION YEAR: 1971 (INSTALLATION COMPLETED 1977)      */
/*  FMVSS EFFECTIVE DATE: 1/1/1976                                    */
/* ------------------------------------------------------------------ */
```

As discussed in the analysis of non-occupant fatalities, front disc brakes were gradually introduced into passenger cars during 1965 to 1977 and they reduce fatal crash involvements of all types by an estimated 0.17 percent.

```
/* IMPLEMENTATION OF FRONT DISC BRAKES */
 IF XMY GE 1977 THEN DO; PS105B=1; PV105B=0; END;
 ELSE IF XMY LE 1964 THEN DO; PS105B=0; PV105B=0; END;
 ELSE IF XMY=1965 THEN DO; PS105B=0; PV105B=.02; END;
 ELSE IF XMY=1966 THEN DO; PS105B=0; PV105B=.03; END;
 ELSE IF XMY=1967 THEN DO; PS105B=0; PV105B=.06; END;
 ELSE IF XMY=1968 THEN DO; PS105B=0; PV105B=.13; END;
 ELSE IF XMY=1969 THEN DO; PS105B=0; PV105B=.28; END;
 ELSE IF XMY=1970 THEN DO; PS105B=0; PV105B=.41; END;
```

```
 ELSE IF XMY=1971 THEN DO; PS105B=0; PV105B=.63; END;
 ELSE IF XMY=1972 THEN DO; PS105B=0; PV105B=.74; END;
 ELSE IF XMY=1973 THEN DO; PS105B=0; PV105B=.86; END;
 ELSE IF XMY=1974 THEN DO; PS105B=0; PV105B=.84; END;
 ELSE IF XMY=1975 THEN DO; PS105B=0; PV105B=.93; END;
 ELSE IF XMY=1976 AND CY=1975 THEN DO; PS105B=0; PV105B=.99; END;
 ELSE IF XMY=1976 THEN DO; PS105B=.50; PV105B=.49; END;
/* CAR OCCUPANT LIVES SAVED BY FRONT DISC BRAKES */
 OLDWTFA=WEIGHTFA;
 IF PS105B GT 0 OR PV105B GT 0 THEN DO;
  E=.0017;
  P=PS105B+PV105B;
  S=OLDWTFA*E*P / (1 - E*P);
  CLS105B=S*PS105B/P;
  CLV105B=S*PV105B/P;
  WEIGHTFA=OLDWTFA+CLS105B+CLV105B; END;
 ELSE DO; CLS105B=0; CLV105B=0; END;
 CL105B=CLS105B+CLV105B;
 CLS=CLS+CLS105B; CLV=CLV+CLV105B; CL=CL+CL105B;

/* ---------------------------------------------------------------- */
/* 201A VOLUNTARY INSTRUMENT PANEL IMPROVEMENTS (FMVSS-201 INSPIRED)  */
/* MEDIAN IMPLEMENTATION YEAR: 1968                                 */
/* FMVSS EFFECTIVE: 1/1/1968 (BUT DIDN'T REQUIRE THESE IMPROVEMENTS)  */
/* ---------------------------------------------------------------- */

/* IDENTIFIES CARS WITH VOLUNTARY INSTRUMENT PANEL IMPROVEMENTS */
 PS201A=0; PV201A=0;
```

Part 1 of this report describes how manufacturers significantly modified middle and lower instrument panels in the years before/after FMVSS No. 201 took effect, even though the standard as finally issued only regulated the upper part of the instrument panel. The technology benefits RF passengers (SEAT2 = 13).

```
  IF XMY GE 1967 AND SEAT2=13 THEN DO;
      IF XMY GE 1973 THEN PV201A=1;
        ELSE IF XMY=1967 THEN PV201A=.25; ELSE IF XMY=1968 THEN PV201A=.5;
        ELSE IF XMY=1969 THEN PV201A=.6;  ELSE IF XMY=1970 THEN PV201A=.7;
        ELSE IF XMY=1971 THEN PV201A=.8;  ELSE IF XMY=1972 THEN PV201A=.9; END;
/* LIVES SAVED IN FRONTAL IMPACTS BY INSTRUMENT PANEL IMPROVEMENTS */
  OLDWTFA=WEIGHTFA;
```

The evaluation indicated a 15.9-percent fatality reduction for unrestrained RF passengers in frontal impacts. Since 3-point belts, automatic belts and child safety seats have already been "removed" from the vehicle, REST3 NE 2 (i.e., not lap-belted) identifies unrestrained people.

```
  IF PS201A GT 0 OR PV201A GT 0 THEN DO;
    IF CRSH=1 AND REST3 NE 2 THEN E=.159; ELSE E=0;
    P=PS201A+PV201A;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS201A=S*PS201A/P;
    CLV201A=S*PV201A/P;
    WEIGHTFA=OLDWTFA+CLS201A+CLV201A; END;
  ELSE DO; CLS201A=0; CLV201A=0; END;
  CL201A=CLS201A+CLV201A;
  CLS=CLS+CLS201A; CLV=CLV+CLV201A; CL=CL+CL201A;

/* ---------------------------------------------------------------- */
/*  203 ENERGY-ABSORBING AND TELESCOPING STEERING ASSEMBLIES         */
/*  MEDIAN IMPLEMENTATION YEAR: 1967  FMVSS EFFECTIVE DATE: 1/1/1968  */
/* ---------------------------------------------------------------- */

/* IDENTIFIES CARS WITH ENERGY-ABSORBING STEERING ASSEMBLIES      */
  PS203=0; PV203=0;
```

FMVSS Nos. 203 and 204 took effect on January 1, 1968, but energy-absorbing steering assemblies had already been installed on AMC, Chrysler and GM cars in MY 1967 and all other cars in MY 1968.

```
  IF XMY GE 1967 AND SEAT2=11 THEN DO;
      IF XMY GE 1969 THEN PS203=1;
        ELSE IF XMY=1968 THEN DO; PS203=.5; PV203=.5; END;
        ELSE IF XMY=1967 AND MAKE IN (1,6,7,8,9,18,19,20,21,22) THEN PV203=1;
        ELSE IF XMY=1967 THEN PV203=0; END;
/* LIVES SAVED IN FRONTAL IMPACTS BY INSTRUMENT PANEL IMPROVEMENTS */
  OLDWTFA=WEIGHTFA;
  IF PS203 GT 0 OR PV203 GT 0 THEN DO;
```

Energy-absorbing steering assemblies reduce the fatality risk of drivers by 12.1 percent in frontal impacts.

```
    IF IMPACT2 IN (11,11.5,12,12.5,1) OR (CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11,12))
      THEN E=.121; ELSE E=0;
    P=PS203+PV203;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS203=S*PS203/P;
    CLV203=S*PV203/P;
    WEIGHTFA=OLDWTFA+CLS203+CLV203; END;
  ELSE DO; CLS203=0; CLV203=0; END;
  CL203=CLS203+CLV203;
  CLS=CLS+CLS203; CLV=CLV+CLV203; CL=CL+CL203;

/* ------------------------------------------------------------------ */
/*  208E LAP BELTS FOR CENTER REAR SEAT OCCUPANTS                     */
/*  MEDIAN INSTALLATION YEAR: EARLY 1967  FMVSS EFFECTIVE: 1/1/1968   */
/* ------------------------------------------------------------------ */

/* IDENTIFIES CENTER REAR SEAT PASSENGERS WEARING LAP BELTS  */
  PS208E=0; PV208E=0;
  IF SEAT2=22 AND REST3=2 AND (5 LE AGE LE 99 OR AGE=.) THEN DO;
     IF XMY GE 1969 THEN PS208E=1;
       ELSE IF XMY LE 1967 THEN PV208E=1;
```

Lap belts (as a minimum) were required at all designated seating positions of cars and LTVs effective January 1, 1968, but were already installed in many vehicles well before that date. Since 1/1/1968 is in the middle of the 1968 model year, PV = .5 and PS = .5 for MY 1968 for all of the lap belt technologies in cars and LTVs.

```
       ELSE IF XMY=1968 THEN DO; PS208E=.5; PV208E=.5; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY CENTER-REAR-SEAT LAP BELTS */
 OLDWTFA=WEIGHTFA;
 IF PS208E GT 0 OR PV208E GT 0 THEN DO;
```

The data from NHTSA's evaluation shows lap belts for outboard rear seat passengers reduce fatality risk by 76 percent in rollovers and 39 percent in side impacts, but have little or no net benefit in frontals, rear impacts or other crashes. The same effectiveness estimates are assumed for the center rear seating position.

```
    IF CRSH=1 THEN DO; E=.00; EJECT2=.26; END;
      ELSE IF CRSH=2 THEN DO; E=.39; EJECT2=.33; END;
      ELSE IF CRSH=3 THEN DO; E=.76; EJECT2=.64; END;
      ELSE IF CRSH=4 THEN DO; E=.00; EJECT2=.31; END;
    P=PS208E+PV208E;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208E=S*PS208E/P;
    CLV208E=S*PV208E/P;
    WEIGHTFA=OLDWTFA+CLS208E+CLV208E; END;
  ELSE DO; CLS208E=0; CLV208E=0; END;
  CL208E=CLS208E+CLV208E;
  CLS=CLS+CLS208E; CLV=CLV+CLV208E; CL=CL+CL208E;
```

As stated above, any center rear seat passenger who was originally wearing 3-point belts was "transformed" to an unrestrained passenger back in the 208J step, and will have bypassed the 208E step.

```
/* ----------------------------------------------------------------- */
/*  105A DUAL MASTER CYLINDERS                                       */
/*  MEDIAN INSTALLATION YEAR: LATE 1966  FMVSS EFFECTIVE: 1/1/1968    */
/* ----------------------------------------------------------------- */
```

As discussed in the analysis of non-occupant fatalities, dual master cylinders were gradually introduced into passenger cars during 1962 to 1967 and they reduce fatal crash involvements of all types by an estimated 0.7 percent.

```
/* IMPLEMENTATION OF DUAL MASTER CYLINDERS */
  IF XMY GE 1969 THEN DO; PS105A=1; PV105A=0; END;
    ELSE IF XMY LE 1961 THEN DO; PS105A=0; PV105A=0; END;
    ELSE IF XMY IN (1962,1963) THEN DO; PS105A=0; PV105A=.09; END;
    ELSE IF XMY IN (1964,1965) THEN DO; PS105A=0; PV105A=.07; END;
    ELSE IF XMY=1966 THEN DO; PS105A=0; PV105A=.54; END;
    ELSE IF XMY=1967 THEN DO; PS105A=0; PV105A=1; END;
    ELSE IF XMY=1968 THEN DO; PS105A=.5; PV105A=.5; END;
/* CAR OCCUPANT LIVES SAVED BY DUAL MASTER CYLINDERS */
  OLDWTFA=WEIGHTFA;
  IF PS105A GT 0 OR PV105A GT 0 THEN DO;
    E=.007;
    P=PS105A+PV105A;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS105A=S*PS105A/P;
    CLV105A=S*PV105A/P;
    WEIGHTFA=OLDWTFA+CLS105A+CLV105A; END;
  ELSE DO; CLS105A=0; CLV105A=0; END;
  CL105A=CLS105A+CLV105A;
  CLS=CLS+CLS105A; CLV=CLV+CLV105A; CL=CL+CL105A;

/* ----------------------------------------------------------------- */
/*  208D LAP BELTS FOR FRONT-SEAT CENTER OCCUPANTS                   */
/*  MEDIAN INSTALLATION YEAR: 1966  FMVSS EFFECTIVE DATE: 1/1/1968    */
/* ----------------------------------------------------------------- */
```

A double-pair comparison analysis of lap belt effectiveness for outboard front seat occupants, conducted in support of the 2004 "lives saved" report, found that lap belts reduce fatality risk by 22 percent in frontals, 43 percent in rollovers, and 21 percent in side impacts, rear impacts and other crashes. The same effectiveness is assumed for center front seat passengers. However, the proportion of unrestrained fatalities that were ejected was derived specifically from data on center front seat passengers.

```
/* IDENTIFIES CENTER FRONT SEAT PASSENGERS WEARING LAP BELTS  */
  PS208D=0; PV208D=0;
  IF SEAT2=12 AND REST3=2 AND (5 LE AGE LE 99 OR AGE=.) THEN DO;
     IF XMY GE 1969 THEN PS208D=1;
       ELSE IF XMY LE 1967 THEN PV208D=1;
       ELSE IF XMY=1968 THEN DO; PS208D=.5; PV208D=.5; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY CENTER-FRONT-SEAT LAP BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208D GT 0 OR PV208D GT 0 THEN DO;
    IF CRSH=1 THEN DO; E=.22; EJECT2=.20; END;
      ELSE IF CRSH=2 THEN DO; E=.21; EJECT2=.22; END;
      ELSE IF CRSH=3 THEN DO; E=.43; EJECT2=.58; END;
      ELSE IF CRSH=4 THEN DO; E=.21; EJECT2=.25; END;
    P=PS208D+PV208D;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208D=S*PS208D/P;
    CLV208D=S*PV208D/P;
    WEIGHTFA=OLDWTFA+CLS208D+CLV208D; END;
  ELSE DO; CLS208D=0; CLV208D=0; END;
  CL208D=CLS208D+CLV208D;
  CLS=CLS+CLS208D; CLV=CLV+CLV208D; CL=CL+CL208D;
```

```
/* ------------------------------------------------------------------ */
/*  212 ADHESIVE WINDSHIELD BONDING                                   */
/*  MEDIAN INSTALLATION YEAR: EARLY 1966  FMVSS EFFECTIVE: 1/1/1970   */
/* ------------------------------------------------------------------ */
```

We know exactly when each domestic make-model, and some imported make-models were equipped with adhesive windshield bonding. PS212 and PV212 can be set to 0 or 1 (or possibly to .5 in MY 1970 because FMVSS No. 212 took effect in the middle of the model year). Identification of these make-models is based on the VIN, if available, and on the FARS MAK_MOD code, otherwise. Note that some domestic models continued with rubber gasket installations after 1970 (meeting FMVSS No. 212, but looser than adhesive bonding); for these models, PS212 = 0 as long as the rubber gaskets continued.

For all other make-models, including most Japanese cars, we will conservatively assume that PS212 = 1 only from 1980, even though there is some evidence from NCSS that the rubber gasket installations of the 1970s were about as tight as adhesive bonding in domestic cars.

```
/* IDENTIFIES CARS WITH ADHESIVE WINDSHIELD BONDING         */
  IF XMY GE 1980 THEN DO; PS212=1; PV212=0; GOTO SAVE212; END;
  IF XMY LE 1962 THEN DO; PS212=0; PV212=0; GOTO SAVE212; END;
  IF MAKE IN (41,51) THEN DO;
    IF XMY GE 1971 THEN DO; PS212=1; PV212=0; END;
      ELSE IF XMY=1970 THEN DO; PS212=.5; PV212=.5; END;
      ELSE IF XMY LE 1969 THEN DO; PS212=0; PV212=0; END; GOTO SAVE212; END;
  IF 1963 LE XMY LE 1969 THEN PS212=0;
    ELSE IF 1971 LE XMY LE 1979 THEN PV212=0;
  IF MAKE IN (1,6,7,8,9,12,13,14,18,19,20,21,22,30,32,35,49) THEN GOTO SOMEVOL2;
  PS212=0; PV212=0; GOTO SAVE212;
SOMEVOL2: V13=V1||V2||V3;
  IF V13 IN ('999','000','   ') THEN GOTO NOVIN2;
  IF XMY=1963 THEN DO;
    IF MAKE=18 AND V1 IN ('A','B','C','0','1','3') THEN PV212=.5;
      ELSE IF MAKE=18 AND V1='7' THEN PV212=1;
      ELSE IF MAKE=21 AND V3 IN ('0','1') THEN PV212=.5;
      ELSE PV212=0; GOTO SAVE212; END;
  IF XMY=1964 THEN DO;
    IF MAKE=18 AND V1 IN ('A','B','C','0','1','3','7') THEN PV212=1;
      ELSE IF MAKE=20 AND V2='5' THEN PV212=1;
      ELSE IF MAKE IN (21,22) AND V2 IN ('0','1','2') THEN PV212=1;
      ELSE PV212=0; GOTO SAVE212; END;
  IF XMY=1965 THEN DO;
    IF MAKE IN (18,19,21,22) THEN PV212=1;
      ELSE IF MAKE=20 AND V2 IN ('1','9') THEN PV212=0;
      ELSE IF MAKE=20 THEN PV212=1;
      ELSE IF MAKE=12 AND V3 IN ('5','6','7') THEN PV212=1;
      ELSE IF MAKE=14 AND V3 IN ('4','5','6','7') THEN PV212=1;
      ELSE PV212=0; GOTO SAVE212; END;
  IF XMY=1966 THEN DO;
    IF MAKE IN (13,14,18,19,21,22) THEN PV212=1;
      ELSE IF MAKE=20 AND V2 IN ('1','9') THEN PV212=0;
      ELSE IF MAKE=20 THEN PV212=1;
      ELSE IF MAKE=12 AND (V3='8' OR (V3='0' AND V4 IN ('7','8','9'))) THEN PV212=0;
      ELSE IF MAKE=12 THEN PV212=1;
      ELSE PV212=0; GOTO SAVE212; END;
  IF XMY=1967 THEN DO;
    IF MAKE IN (13,18,19,21,22) THEN PV212=1;
      ELSE IF MAKE=20 AND V2 IN ('1','9') THEN PV212=0;
      ELSE IF MAKE=20 THEN PV212=1;
      ELSE IF MAKE=12 AND V3='0' THEN PV212=0;
      ELSE IF MAKE=12 THEN PV212=1;
      ELSE IF MAKE=14 AND V3='9' THEN PV212=0;
      ELSE IF MAKE=14 THEN PV212=1;
      ELSE IF MAKE=1 THEN GOTO NOVIN2;
      ELSE PV212=0; GOTO SAVE212; END;
  IF XMY=1968 THEN DO;
    IF MAKE IN (13,18,19,20,21,22) THEN PV212=1;
      ELSE IF MAKE=12 AND V3='0' THEN PV212=0;
```

```
      ELSE IF MAKE=12 THEN PV212=1;
      ELSE IF MAKE=14 AND V3='9' THEN PV212=0;
      ELSE IF MAKE=14 THEN PV212=1;
      ELSE IF MAKE=1 AND V4='0' THEN PV212=0;
      ELSE IF MAKE=1 THEN PV212=1;
      ELSE PV212=0; GOTO SAVE212; END;
  IF XMY=1969 THEN DO;
    IF MAKE IN (6,8,12,13,14,18,19,20,21,22) THEN PV212=1;
      ELSE IF MAKE=7 AND V1='D' THEN PV212=1;
      ELSE IF MAKE=9 AND V1='P' THEN PV212=1;
      ELSE IF MAKE=1 AND V4='0' THEN PV212=0;
      ELSE IF MAKE=1 THEN PV212=1;
      ELSE PV212=0; GOTO SAVE212; END;
  IF XMY=1970 THEN DO;
    IF MAKE IN (1,6,8,13,14,18,19,20,21,22) THEN DO; PV212=.5; PS212=.5; END;
      ELSE IF MAKE=12 AND V3='9' THEN DO; PV212=0; PS212=0; END;
      ELSE IF MAKE=12 THEN DO; PV212=.5; PS212=.5; END;
      ELSE IF MAKE=7 AND V1 IN ('D','J') THEN DO; PV212=.5; PS212=.5; END;
      ELSE IF MAKE=9 AND V1 IN ('B','P') THEN DO; PV212=.5; PS212=.5; END;
      ELSE IF MAKE=30 THEN DO; PV212=0; PS212=.5; END;
      ELSE DO; PV212=0; PS212=0; END; GOTO SAVE212; END;
  IF XMY IN (1971,1972,1973) THEN DO;
    IF MAKE IN (1,6,8,13,18,19,20,21,22,30) THEN PS212=1;
      ELSE IF MAKE=12 AND V3 IN ('1','9') THEN PS212=0;
      ELSE IF MAKE=12 THEN PS212=1;
      ELSE IF MAKE=14 AND V3='3' THEN PS212=0;
      ELSE IF MAKE=14 THEN PS212=1;
      ELSE IF MAKE=7 AND V1='L' THEN PS212=0;
      ELSE IF MAKE=7 THEN PS212=1;
      ELSE IF MAKE=9 AND V1='V' THEN PS212=0;
      ELSE IF MAKE=9 THEN PS212=1;
      ELSE PS212=0; GOTO SAVE212; END;
  IF XMY IN (1974,1975,1976) THEN DO;
    IF MAKE IN (1,6,8,13,18,19,20,21,22,30) THEN PS212=1;
      ELSE IF MAKE=12 AND V3 IN ('1','9') THEN PS212=0;
      ELSE IF MAKE=12 THEN PS212=1;
      ELSE IF MAKE=14 AND V3 IN ('2','3') THEN PS212=0;
      ELSE IF MAKE=14 THEN PS212=1;
      ELSE IF MAKE=7 AND V1='L' THEN PS212=0;
      ELSE IF MAKE=7 THEN PS212=1;
      ELSE IF MAKE=9 AND V1='V' THEN PS212=0;
      ELSE IF MAKE=9 THEN PS212=1;
      ELSE IF MAKE=35 THEN GOTO NOVIN2;
      ELSE PS212=0;  GOTO SAVE212; END;
  IF XMY=1977 THEN DO;
    IF MAKE IN (1,6,7,8,9,13,18,19,20,21,22,30) THEN PS212=1;
      ELSE IF MAKE=12 AND V3 IN ('1','9') THEN PS212=0;
      ELSE IF MAKE=12 THEN PS212=1;
      ELSE IF MAKE=14 AND V3 IN ('2','3') THEN PS212=0;
      ELSE IF MAKE=14 THEN PS212=1;
      ELSE IF MAKE=35 THEN GOTO NOVIN2;
      ELSE PS212=0;  GOTO SAVE212; END;
  IF XMY=1978 THEN DO;
    IF MAKE IN (1,6,7,8,9,13,18,19,20,21,22,30,32) THEN PS212=1;
      ELSE IF MAKE=12 AND V3='1' THEN PS212=.5;
      ELSE IF MAKE=12 THEN PS212=1;
      ELSE IF MAKE=14 AND V3='2' THEN PS212=.5;
      ELSE IF MAKE=14 THEN PS212=1;
      ELSE IF MAKE=49 AND V2='A' THEN PS212=1;
      ELSE PS212=0;  GOTO SAVE212; END;
  IF XMY=1979 THEN DO;
    IF MAKE IN (1,6,7,8,9,12,13,14,18,19,20,21,22,30,32) THEN PS212=1;
      ELSE IF MAKE=49 AND V2='A' AND V4 NE '6' THEN PS212=1;
      ELSE PS212=0;  GOTO SAVE212; END;
NOVIN2: IF XMY=1963 THEN DO;
    IF MAK_MOD IN (1801,18001,2101,21001) THEN PV212=.5;
      ELSE IF MAK_MOD IN (1805,18005) THEN PV212=1;
      ELSE PV212=0; GOTO SAVE212; END;
  IF XMY=1964 THEN DO;
    IF MAK_MOD IN (1801,18001,1805,18005,2001,20001,2101,21001,2201,22001) THEN PV212=1;
      ELSE PV212=0; GOTO SAVE212; END;
  IF XMY=1965 THEN DO;
```

```
  IF MAKE IN (18,19,21,22) THEN PV212=1;
    ELSE IF MAK_MOD IN (2004,20004,2008,20008) THEN PV212=0;
    ELSE IF MAKE=20 THEN PV212=1;
    ELSE IF MAK_MOD IN (1206,12006,1406,14006) THEN PV212=1;
    ELSE PV212=0; GOTO SAVE212; END;
IF XMY=1966 THEN DO;
  IF MAKE IN (13,14,18,19,21,22) THEN PV212=1;
    ELSE IF MAK_MOD IN (2004,20004,2008,20008) THEN PV212=0;
    ELSE IF MAKE=20 THEN PV212=1;
    ELSE IF MAK_MOD IN (1203,12003,1204,12004) THEN PV212=0;
    ELSE IF MAKE=12 THEN PV212=1;
    ELSE PV212=0; GOTO SAVE212; END;
IF XMY=1967 THEN DO;
  IF MAKE IN (13,18,19,21,22) THEN PV212=1;
    ELSE IF MAK_MOD IN (2004,20004,2008,20008) THEN PV212=0;
    ELSE IF MAKE=20 THEN PV212=1;
    ELSE IF MAK_MOD IN (1203,12003,1404,14004) THEN PV212=0;
    ELSE IF MAKE IN (12,14) THEN PV212=1;
    ELSE IF MAK_MOD IN (101,1001) THEN PV212=0;
    ELSE IF MAKE=1 THEN PV212=1;
    ELSE PV212=0; GOTO SAVE212; END;
IF XMY=1968 THEN DO;
  IF MAKE IN (13,18,19,20,21,22) THEN PV212=1;
    ELSE IF MAK_MOD IN (1203,12003,1404,14004) THEN PV212=0;
    ELSE IF MAKE IN (12,14) THEN PV212=1;
    ELSE IF MAK_MOD IN (101,1001) THEN PV212=0;
    ELSE IF MAKE=1 THEN PV212=1;
    ELSE PV212=0; GOTO SAVE212; END;
IF XMY=1969 THEN DO;
  IF MAKE IN (6,8,12,13,14,18,19,20,21,22) THEN PV212=1;
    ELSE IF MAK_MOD IN (703,7003,704,7004,903,9003,904,9004) THEN PV212=1;
    ELSE IF MAK_MOD IN (101,1001) THEN PV212=0;
    ELSE IF MAKE=1 THEN PV212=1;
    ELSE PV212=0; GOTO SAVE212; END;
IF XMY=1970 THEN DO;
  IF MAKE IN (1,6,8,13,14,18,19,20,21,22) THEN DO; PV212=.5; PS212=.5; END;
    ELSE IF MAK_MOD IN (1208,12008) THEN DO; PV212=0; PS212=0; END;
    ELSE IF MAKE=12 THEN DO; PV212=.5; PS212=.5; END;
    ELSE IF MAK_MOD IN (703,7003,704,7004,705,7005,903,9003,904,9004,905,9005)
      THEN DO; PV212=.5; PS212=.5; END;
    ELSE IF MAKE=30 THEN DO; PV212=0; PS212=.5; END;
    ELSE DO; PV212=0; PS212=0; END; GOTO SAVE212; END;
IF XMY IN (1971,1972,1973) THEN DO;
  IF MAKE IN (1,6,8,13,18,19,20,21,22,30) THEN PS212=1;
    ELSE IF MAK_MOD IN (1208,12008,1209,12009,1408,14008) THEN PS212=0;
    ELSE IF MAKE IN (12,14) THEN PS212=1;
    ELSE IF MAK_MOD IN (701,7001,901,9001) THEN PS212=0;
    ELSE IF MAKE IN (7,9) THEN PS212=1;
    ELSE PS212=0; GOTO SAVE212; END;
IF XMY IN (1974,1975,1976) THEN DO;
  IF MAKE IN (1,6,8,13,18,19,20,21,22,30) THEN PS212=1;
    ELSE IF MAK_MOD IN (1208,12008,1209,12009,1408,14008,1409,14009) THEN PS212=0;
    ELSE IF MAKE IN (12,14) THEN PS212=1;
    ELSE IF MAK_MOD IN (701,7001,901,9001) THEN PS212=0;
    ELSE IF MAKE IN (7,9) THEN PS212=1;
    ELSE IF MAK_MOD IN (3538,35038,35008) THEN PS212=1;
    ELSE PS212=0; GOTO SAVE212; END;
IF XMY=1977 THEN DO;
  IF MAKE IN (1,6,7,8,9,13,18,19,20,21,22,30) THEN PS212=1;
    ELSE IF MAK_MOD IN (1208,12008,1209,12009,1408,14008,1409,14009) THEN PS212=0;
    ELSE IF MAKE IN (12,14) THEN PS212=1;
    ELSE IF MAK_MOD IN (3538,35038,35008) THEN PS212=1;
    ELSE PS212=0; GOTO SAVE212; END;
IF XMY=1978 THEN DO;
  IF MAKE IN (1,6,7,8,9,13,18,19,20,21,22,30,32) THEN PS212=1;
    ELSE IF MAK_MOD IN (1209,12009,1409,14009) THEN PS212=.5;
    ELSE IF MAKE IN (12,14) THEN PS212=1;
    ELSE IF MAK_MOD IN (4933,49033,49003) THEN PS212=1;
    ELSE PS212=0; GOTO SAVE212; END;
IF XMY=1979 THEN DO;
  IF MAKE IN (1,6,7,8,9,12,13,14,18,19,20,21,22,30,32) THEN PS212=1;
    ELSE IF MAK_MOD IN (4933,49033,49003) THEN PS212=1;
```

```
     ELSE PS212=0; GOTO SAVE212; END;
/* REDUCTION IN EJECTION FATALITY RISK WITH ADHESIVE WINDSHIELD BONDING */
SAVE212:  OLDWTFA=WEIGHTFA;
```

Adhesive windshield bonding is potentially beneficial for any ejected front seat occupant [SEAT2 IN (11,12,13,18) AND EJECT2 NE 0]. In frontal impacts and rollovers of cars without adhesive bonding, 22 percent of ejections were through the windshield portal; in side and rear impacts, 5 percent were through the windshield portal.[625] Adhesive bonding saves 15 percent of the deaths of windshield ejectees.[626] Thus, adhesive bonding saves .22 x .15 = 3.3 percent of all ejection fatalities in frontals and rollovers; .05 x .15 = 0.75 percent of all ejection fatalities in side and rear impacts.

```
  IF (PS212 GT 0 OR PV212 GT 0) AND SEAT2 IN (11,12,13,18) AND EJECT2 NE 0 THEN DO;
    IF CRSH IN (1,3) THEN E=.033;
      ELSE IF CRSH IN (2,4) THEN E=.0075;
    P=PS212+PV212;
    REL_S=EJECT2*E*P / (1 - E*P);
    S=OLDWTFA*REL_S;
    CLS212=S*PS212/P;
    CLV212=S*PV212/P;
    WEIGHTFA=OLDWTFA+CLS212+CLV212;
```

Because adhesive bonding reduces ejection fatalities while leaving non-ejected fatalities unchanged, EJECT2 = (EJECT2 + REL_S)/(1 + REL_S) must be recomputed after this step.

```
    EJECT2=(EJECT2 + REL_S)/(1 + REL_S); END;
  ELSE DO; CLS212=0; CLV212=0; END;
  CL212=CLS212+CLV212;
  CLS=CLS+CLS212; CLV=CLV+CLV212; CL=CL+CL212;

/* ----------------------------------------------------------------- */
/*  208C LAP BELTS FOR OUTBOARD REAR SEAT OCCUPANTS                  */
/*  MEDIAN INSTALLATION YEAR: LATE 1965  FMVSS EFFECTIVE: 1/1/1968    */
/* ----------------------------------------------------------------- */

/* IDENTIFIES OUTBOARD REAR SEAT OCCUPANTS WEARING LAP BELTS  */
  PS208C=0; PV208C=0;
  IF SEAT2=21 AND REST3=2 AND (5 LE AGE LE 99 OR AGE=.) THEN DO;
     IF XMY GE 1969 THEN PS208C=1;
       ELSE IF XMY LE 1967 THEN PV208C=1;
       ELSE IF XMY=1968 THEN DO; PS208C=.5; PV208C=.5; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY OUTBOARD-REAR-SEAT LAP BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208C GT 0 OR PV208C GT 0 THEN DO;
```

The data from NHTSA's evaluation shows lap belts for outboard rear seat passengers reduce fatality risk by 76 percent in rollovers and 39 percent in side impacts, but have little or no net benefit in frontals, rear impacts or other crashes. The same effectiveness estimates are assumed for the center rear seating position.

```
    IF CRSH=1 THEN DO; E=.00; EJECT2=.23; END;
      ELSE IF CRSH=2 THEN DO; E=.39; EJECT2=.28; END;
      ELSE IF CRSH=3 THEN DO; E=.76; EJECT2=.61; END;
      ELSE IF CRSH=4 THEN DO; E=.00; EJECT2=.27; END;
    P=PS208C+PV208C;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208C=S*PS208C/P;
    CLV208C=S*PV208C/P;
    WEIGHTFA=OLDWTFA+CLS208C+CLV208C; END;
  ELSE DO; CLS208C=0; CLV208C=0; END;
  CL208C=CLS208C+CLV208C;
  CLS=CLS+CLS208C; CLV=CLV+CLV208C; CL=CL+CL208C;
```

[625] Kahane (1985, February), p. 167.
[626] *Ibid*., p. xxvii.

```
/* ----------------------------------------------------------------- */
/*  206 DOOR LOCK IMPROVEMENTS                                       */
/*  MEDIAN INSTALLATION YEAR: 1965  FMVSS EFFECTIVE DATE: 1/1/1968    */
/* ----------------------------------------------------------------- */

/* DOOR LOCKS IMPROVED GRADUALLY FROM 1962 TO 1968       */
  IF XMY GE 1969 THEN DO; PS206=1; PV206=0; END;
    ELSE IF XMY=1968 THEN DO; PS206=.5; PV206=.5; END;
    ELSE IF 1962 LE XMY LE 1967 THEN DO; PS206=0; PV206=(XMY-1961)/7; END;
    ELSE IF XMY LE 1961 THEN DO; PS206=0; PV206=0; END;
/* REDUCTION IN EJECTION ROLLOVER FATALITY RISK WITH IMPROVED DOOR LOCKS */
  OLDWTFA=WEIGHTFA;
```

NHTSA's evaluation found that improved door locks would save 15.38 percent (400 of 2,600 in the baseline year for that study) of ejection fatalities (excluding occupants riding outside the passenger compartment).[627]

```
  IF (PS206 GT 0 OR PV206 GT 0) AND (CRSH=3 OR M_HARM=1)
      AND SEAT2 NE 52 AND EJECT2 NE 0 THEN DO;
    E=.1538;
    P=PS206+PV206;
    REL_S=EJECT2*E*P / (1 - E*P);
    S=OLDWTFA*REL_S;
    CLS206=S*PS206/P;
    CLV206=S*PV206/P;
    WEIGHTFA=OLDWTFA+CLS206+CLV206;
    EJECT2=(EJECT2 + REL_S)/(1 + REL_S); END;
  ELSE DO; CLS206=0; CLV206=0; END;
  CL206=CLS206+CLV206;
  CLS=CLS+CLS206; CLV=CLV+CLV206; CL=CL+CL206;

/* ----------------------------------------------------------------- */
/*  208B LAP BELT USE BY CHILDREN AGE 1-4                            */
/*  MEDIAN INSTALLATION YEAR FOR LAP BELTS USED BY CHILDREN: EARLY 65 */
/*  FMVSS EFFECTIVE DATE: 1/1/1968                                   */
/* ----------------------------------------------------------------- */

/* IDENTIFIES CHILD PASSENGERS AGE 1-4 USING LAP BELTS */
  PS208B=0; PV208B=0;
  IF 1 LE AGE LE 4 AND REST3=2 THEN DO;
     IF XMY GE 1969 THEN PS208B=1;
       ELSE IF XMY LE 1967 THEN PV208B=1;
       ELSE IF XMY=1968 THEN DO; PS208B=.5; PV208B=.5; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY LAP BELTS (AGE 1-4) */
  OLDWTFA=WEIGHTFA;
  IF PS208B GT 0 OR PV208B GT 0 THEN DO;
```

NHTSA's evaluation estimates that lap belts reduce fatality risk by 33 percent for toddlers. Effectiveness is not estimated separately by crash mode.[628] In general, 19 percent of unrestrained child passenger fatalities in frontal crashes were ejected, 26 percent in side impacts, 65 percent in rollovers and 34 percent in rear/other impacts.

```
    E=.33;
    IF CRSH=1 THEN EJECT2=.19;
      ELSE IF CRSH=2 THEN EJECT2=.26;
      ELSE IF CRSH=3 THEN EJECT2=.65;
      ELSE IF CRSH=4 THEN EJECT2=.34;
    P=PS208B+PV208B;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208B=S*PS208B/P;
    CLV208B=S*PV208B/P;
    WEIGHTFA=OLDWTFA+CLS208B+CLV208B; END;
  ELSE DO; CLS208B=0; CLV208B=0; END;
```

[627] Kahane (1989, November), pp. 206-209 and 222-225.
[628] This evaluation is discussed in the "Child Safety Seats" section of the FMVSS 213 chapter of Part 1, not the FMVSS 208 chapter.

```
  CL208B=CLS208B+CLV208B;
  CLS=CLS+CLS208B; CLV=CLV+CLV208B; CL=CL+CL208B;

/* ----------------------------------------------------------------- */
/*  208A LAP BELTS FOR FRONT-SEAT OUTBOARD OCCUPANTS                 */
/*  MEDIAN INSTALLATION YEAR: 1962  FMVSS EFFECTIVE DATE: 1/1/1968    */
/* ----------------------------------------------------------------- */
```

A double-pair comparison analysis of lap belt effectiveness for outboard front seat occupants, conducted in support of the 2004 “lives saved” report, found that lap belts reduce fatality risk by 22 percent in frontals, 43 percent in rollovers, and 21 percent in side impacts, rear impacts and other crashes.

```
/* IDENTIFIES OUTBOARD-FRONT-SEAT OCCUPANTS WEARING LAP BELTS  */
  PS208A=0; PV208A=0;
  IF SEAT2 IN (11,13) AND REST3=2 AND (5 LE AGE LE 99 OR AGE=.) THEN DO;
     IF XMY GE 1969 THEN PS208A=1;
       ELSE IF XMY LE 1967 THEN PV208A=1;
       ELSE IF XMY=1968 THEN DO; PS208A=.5; PV208A=.5; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY OUTBOARD-FRONT-SEAT LAP BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208A GT 0 OR PV208A GT 0 THEN DO;
    IF CRSH=1 THEN DO; E=.22; EJECT2=.21; END;
      ELSE IF CRSH=2 THEN DO; E=.21; EJECT2=.23; END;
      ELSE IF CRSH=3 THEN DO; E=.43; EJECT2=.66; END;
      ELSE IF CRSH=4 THEN DO; E=.21; EJECT2=.35; END;
    P=PS208A+PV208A;
    S=OLDWTFA*E*P / (1 - E*P);
    CLS208A=S*PS208A/P;
    CLV208A=S*PV208A/P;
    WEIGHTFA=OLDWTFA+CLS208A+CLV208A; END;
  ELSE DO; CLS208A=0; CLV208A=0; END;
  CL208A=CLS208A+CLV208A;
  CLS=CLS+CLS208A; CLV=CLV+CLV208A; CL=CL+CL208A;
  DROP V13;
RUN;
```

That concludes the model for passenger cars. It has estimated, on a case-by-case basis, by how much fatalities would increase if all the safety technologies were “removed” from vehicles. The next step is to tally up the lives saved over all the cases, by calendar year.

```
PROC MEANS SUM NOPRINT DATA=CAR2; BY CY;
  VAR ORIGWT WEIGHTFA
    CLV226 CLS226 CL226
        CLV126 CLS126 CL126
        CLV301 CLS301 CL301
        CLV214C CLS214C CL214C C_TORSO C_COMBO C_CURTAIN C_CURT_TORS
    CLV208K CLS208K CL208K
    CLV208J CLS208J CL208J
        CLV201B CLS201B CL201B
    CLV108 CLS108 CL108
    CLV214B CLS214B CL214B
    CLV208I CLS208I CL208I C_BARRIER C_SLED C_CAC
    CLV208H CLS208H CL208H
    CLV208G CLS208G CL208G
    CLV213 CLS213 CL213
    CLVNCAP CLSNCAP CLNCAP
    CLV208F CLS208F CL208F
    CLV216 CLS216 CL216
    CLV214A CLS214A CL214A
    CLV105B CLS105B CL105B
    CLV201A CLS201A CL201A
    CLV203 CLS203 CL203
    CLV208E CLS208E CL208E
    CLV105A CLS105A CL105A
    CLV208D CLS208D CL208D
    CLV212 CLS212 CL212
    CLV208C CLS208C CL208C
    CLV206 CLS206 CL206
```

```
    CLV208B CLS208B CL208B
    CLV208A CLS208A CL208A
    CABDRV CABRF CABKID_BARRIER CABKID_SLED CSW0 CSW1 CSW2
    CSWKID0_BARRIER CSWKID1_BARRIER CSWKID2_BARRIER
    CSWKID0_SLED CSWKID1_SLED CSWKID2_SLED
        C_KID_SLED C_KID_CAC C_ADULT_CAC
    CLV CLS CL;
  OUTPUT OUT=CAR3
```

C_ORIGWT = actual car occupant fatalities. C_WTFA = estimated number of fatalities if all safety technologies had been removed.

```
    SUM=C_ORIGWT C_WTFA
    CLV226 CLS226 CL226
        CLV126 CLS126 CL126
        CLV301 CLS301 CL301
        CLV214C CLS214C CL214C C_TORSO C_COMBO C_CURTAIN C_CURT_TORS
    CLV208K CLS208K CL208K
    CLV208J CLS208J CL208J
        CLV201B CLS201B CL201B
    CLV108 CLS108 CL108
    CLV214B CLS214B CL214B
    CLV208I CLS208I CL208I C_BARRIER C_SLED C_CAC
    CLV208H CLS208H CL208H
    CLV208G CLS208G CL208G
    CLV213 CLS213 CL213
    CLVNCAP CLSNCAP CLNCAP
    CLV208F CLS208F CL208F
    CLV216 CLS216 CL216
    CLV214A CLS214A CL214A
    CLV105B CLS105B CL105B
    CLV201A CLS201A CL201A
    CLV203 CLS203 CL203
    CLV208E CLS208E CL208E
    CLV105A CLS105A CL105A
    CLV208D CLS208D CL208D
    CLV212 CLS212 CL212
    CLV208C CLS208C CL208C
    CLV206 CLS206 CL206
    CLV208B CLS208B CL208B
    CLV208A CLS208A CL208A
    CABDRV CABRF CABKID_BARRIER CABKID_SLED CSW0 CSW1 CSW2
    CSWKID0_BARRIER CSWKID1_BARRIER CSWKID2_BARRIER
    CSWKID0_SLED CSWKID1_SLED CSWKID2_SLED
        C_KID_SLED C_KID_CAC C_ADULT_CAC
    CLV CLS CL;
RUN;
```

Prints the number of lives saved by each technology in each CY, and the sum of lives saved from 1975 to 2012.

```
PROC PRINT DATA=CAR3;
  FORMAT CLV226 CLS226 CL226 CLV126 CLS126 CL126 CLV301 CLS301 CL301 9.0;
  ID CY; VAR CLV226 CLS226 CL226 CLV126 CLS126 CL126 CLV301 CLS301 CL301;
  SUM CLV226 CLS226 CL226 CLV126 CLS126 CL126 CLV301 CLS301 CL301;
TITLE1 'CAR OCCUPANT LIVES SAVED BY ROLLOVER CURTAINS, ESC, AND FUEL SYSTEM INTEGRITY - REAR IMPACT UPGRADE, 
1975-2012';
TITLE2 ' ';
TITLE3 '...226 = ROLLOVER CURTAINS (MEDIAN INSTALLATION YEAR AFTER 2011, FMVSS PHASE-IN TO BEGIN MY 2014)';
TITLE4 '...126 = ELECTRONIC STABILITY CONTROL (MEDIAN INSTALLATION YEAR 2010, FMVSS PHASE-IN BEGAN MY 2009)';
TITLE5 '...301 = FUEL SYSTEM INTEGRITY - REAR IMPACT UPGRADE (MEDIAN INSTALLATION YEAR 2008, FMVSS PHASE-IN BE-
GAN MY 2007)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS PHASE-IN';
TITLE7 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS PHASE-IN';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV214C CLS214C CL214C C_TORSO C_COMBO C_CURTAIN C_CURT_TORS 9.0;
  ID CY; VAR CLV214C CLS214C CL214C C_TORSO C_COMBO C_CURTAIN C_CURT_TORS;
  SUM CLV214C CLS214C CL214C C_TORSO C_COMBO C_CURTAIN C_CURT_TORS;
```

```
TITLE1 'CAR OCCUPANT LIVES SAVED BY CURTAIN AND SIDE AIR BAGS IN NEARSIDE IMPACTS, 1975-2012';
TITLE2 ' ';
TITLE3 '...214C = ALL TYPES OF CURTAIN AND SIDE AIR BAGS (MEDIAN INSTALLATION YEAR 2007, FMVSS NO. 214 POLE TEST
PHASE-IN BEGAN MY 2011)';
TITLE4 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS PHASE-IN';
TITLE5 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS PHASE-IN';
TITLE6 '...TORSO = TORSO BAG ONLY                COMBO = COMBINATION HEAD-TORSO BAG';
TITLE7 '...CURTAIN = CURTAIN ONLY                CURT_TORS = CURATAIN PLUS TORSO BAG';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV208K CLS208K CL208K CLV208J CLS208J CL208J CLV201B CLS201B CL201B 9.0;
  ID CY; VAR CLV208K CLS208K CL208K CLV208J CLS208J CL208J CLV201B CLS201B CL201B;
  SUM CLV208K CLS208K CL208K CLV208J CLS208J CL208J CLV201B CLS201B CL201B;
TITLE1 'CAR OCCUPANT LIVES SAVED BY PRETENSIONERS & LOAD LIMITERS, CENTER-REAR-SEAT 3-POINT BELTS, AND HEAD IM-
PACT UPGRADE, 1975-2012';
TITLE2 ' ';
TITLE3 '...208K = PRETENSIONERS & LOAD LIMITERS FOR BELTS (ON 50.5% OF MY 2001 CARS, NOT REQUIRED BY ANY
FMVSS)';
TITLE4 '...208J = 3-POINT BELTS FOR CENTER REAR SEAT PASSENGERS (ON 59.8% OF MY 2001 CARS, FMVSS PHASE-IN BEGAN
MY 2006)';
TITLE5 '...201B = INTERIOR PROTECTION - HEAD IMPACT UPGRADE (ON 64.1% OF MY 2001 CARS, FMVSS PHASE-IN BEGAN MY
1999)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS PHASE-IN';
TITLE7 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS PHASE-IN';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV108 CLS108 CL108 CLV214B CLS214B CL214B 9.0;
  ID CY; VAR CLV108 CLS108 CL108 CLV214B CLS214B CL214B;
  SUM CLV108 CLS108 CL108 CLV214B CLS214B CL214B;
TITLE1 'CAR OCCUPANT LIVES SAVED BY TRAILER CONSPICUITY TAPE AND TTI(d) REDUCTION BY STRUCTURE/PADDING, 1975-
2012';
TITLE2 ' ';
TITLE3 '...108  = TRAILER CONSPICUITY TAPE (ON-ROAD FLEET 54% EQUIPPED IN 1996, FMVSS EFFECTIVE DATE 12/1/93,
RETROFIT REQUIREMENT 6/1/2001)';
TITLE4 '...214B = TTI(d) REDUCTION BY STRUCTURE & PADDING/DYNAMIC SIDE IMPACT TEST (ON 66.5% OF MY 1996 CARS,
FMVSS PHASE-IN BEGAN MY 1994)';
TITLE5 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE OR PHASE-IN';
TITLE6 '...S = STANDARD INSTALLATIONS, AFTER FMVSS EFFECTIVE DATE OR PHASE-IN';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV208I CLS208I CL208I C_BARRIER C_SLED C_CAC 9.0;
  ID CY; VAR CLV208I CLS208I CL208I C_BARRIER C_SLED C_CAC;
  SUM CLV208I CLS208I CL208I C_BARRIER C_SLED C_CAC;
TITLE1 'CAR OCCUPANT LIVES SAVED BY FRONTAL AIR BAGS, 1975-2012';
TITLE2 ' ';
TITLE3 '...208I = FRONTAL AIR BAGS (MEDIAN INSTALLATION YEAR 1994, FMVSS PHASE-IN BEGAN MY 1987)';
TITLE4 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS PHASE-IN';
TITLE5 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS PHASE-IN';
TITLE6 '...BARRIER = FIRST-GENERATION, BARRIER CERTIFIED AIR BAGS';
TITLE7 '...SLED    = REDESIGNED (DEPOWERED), SLED-CERTIFIED AIR BAGS';
TITLE8 '...CAC     = CERTIFIED-ADVANCED COMPLIANT AIR BAGS (WITH SUPPRESSION OR LOW-RISK DEPLOYMENT FOR SMALL
PASSENGERS)';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV208H CLS208H CL208H CLV208G CLS208G CL208G 9.0;
  ID CY; VAR CLV208H CLS208H CL208H CLV208G CLS208G CL208G;
  SUM CLV208H CLS208H CL208H CLV208G CLS208G CL208G;
TITLE1 'CAR OCCUPANT LIVES SAVED BY AUTOMATIC 2-POINT BELTS AND OUTBOARD-REAR-SEAT 3-POINT BELTS, 1975-2012';
TITLE2 ' ';
TITLE3 '...208H = AUTOMATIC 2-POINT BELTS (PEAK INSTALLATION YEAR 1991, FMVSS PHASE-IN BEGAN MY 1987)';
TITLE4 '...208G = 3-POINT BELTS FOR OUTBOARD REAR SEAT OCCUPANTS (MEDIAN INSTALLATION YEAR 1989, FMVSS EFFECTIVE
12/11/89)';
TITLE5 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE6 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV213 CLS213 CL213 CLVNCAP CLSNCAP CLNCAP CLV208F CLS208F CL208F 9.0;
```

```
  ID CY; VAR CLV213 CLS213 CL213 CLVNCAP CLNCAP CLV208F CLS208F CL208F;
  SUM CLV213 CLS213 CL213 CLVNCAP CLNCAP CLV208F CLS208F CL208F;
TITLE1 'CAR OCCUPANT LIVES SAVED BY CHILD SAFETY SEATS, VOLUNTARY NCAP IMPROVEMENTS, AND FRONT-SEAT 3-POINT
BELTS, 1975-2012';
TITLE2 ' ';
TITLE3 '...213  = CHILD SAFETY SEATS (USE EXCEEDED 50% IN 1985, FMVSS EFFECTIVE 4/1/71, STATE LAWS 1978-85)';
TITLE4 '...NCAP = VOLUNTARY NCAP IMPROVEMENTS IN NON-AIR-BAG CARS (MEDIAN IMPLEMENTATION YEAR EARLY 1984)';
TITLE5 '...208F = 3-POINT BELTS FOR FRONT SEAT OCCUPANTS (MEDIAN INSTALLATION YEAR 1974, FMVSS EFFECTIVE
9/1/73)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV216 CLS216 CL216 CLV214A CLS214A CL214A CLV105B CLS105B CL105B 9.0;
  ID CY; VAR CLV216 CLS216 CL216 CLV214A CLS214A CL214A CLV105B CLS105B CL105B;
  SUM CLV216 CLS216 CL216 CLV214A CLS214A CL214A CLV105B CLS105B CL105B;
TITLE1 'CAR OCCUPANT LIVES SAVED BY ROOF CRUSH RESISTANCE, SIDE DOOR BEAMS, AND FRONT DISC BRAKES, 1975-2012';
TITLE2 ' ';
TITLE3 '...216  = ROOF CRUSH RESISTANCE, B-PILLARS, ETC. (MEDIAN INSTALLATION YEAR 1973, FMVSS EFFECTIVE
9/1/73)';
TITLE4 '...214A = SIDE DOOR BEAMS (MEDIAN INSTALLATION YEAR EARLY 1973, FMVSS EFFECTIVE 1/1/73)';
TITLE5 '...105B = FRONT DISC BRAKES (MEDIAN INSTALLATION YEAR 1971, FMVSS EFFECTIVE 1/1/76)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV201A CL201A CLV203 CLS203 CL203 CLV208E CLS208E CL208E 9.0;
  ID CY; VAR CLV201A CL201A CLV203 CLS203 CL203 CLV208E CLS208E CL208E;
  SUM CLV201A CL201A CLV203 CLS203 CL203 CLV208E CLS208E CL208E;
TITLE1 'CAR OCCUPANT LIVES SAVED BY SAFER INSTRUMENT PANELS, EA STEERING ASSEMBLIES, AND CENTER-REAR-SEAT LAP
BELTS,  1975-2012';
TITLE2 ' ';
TITLE3 '...201A = VOLUNTARY INSTRUMENT PANEL IMPROVEMENTS (MEDIAN IMPLEMENTATION YEAR 1968, FMVSS EFFECTIVE
1/1/68)';
TITLE4 '...203  = ENERGY-ABSORBING STEERING ASSEMBLIES (MEDIAN IMPLEMENTATION YEAR 1967, FMVSS EFFECTIVE
1/1/68)';
TITLE5 '...208E = LAP BELTS FOR CENTER REAR SEAT PASSENGERS (MEDIAN INSTALLATION YEAR EARLY 1967, FMVSS EFFEC-
TIVE 1/1/68)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV105A CLS105A CL105A CLV208D CLS208D CL208D CLV212 CLS212 CL212 9.0;
  ID CY; VAR CLV105A CLS105A CL105A CLV208D CLS208D CL208D CLV212 CLS212 CL212;
  SUM CLV105A CLS105A CL105A CLV208D CLS208D CL208D CLV212 CLS212 CL212;
TITLE1 'CAR OCCUPANT LIVES SAVED BY DUAL MASTER CYLINDERS, CENTER-FRONT-SEAT LAP BELTS, AND ADHESIVE WINDSHIELD
BONDING, 1975-2012';
TITLE2 ' ';
TITLE3 '...105A = DUAL MASTER CYLINDERS (MEDIAN INSTALLATION YEAR LATE 1966, FMVSS EFFECTIVE 1/1/68)';
TITLE4 '...208D = LAP BELTS FOR CENTER FRONT SEAT PASSENGERS (MEDIAN INSTALLATION YEAR 1966, FMVSS EFFECTIVE
1/1/68)';
TITLE5 '...212  = ADHESIVE WINDSHIELD BONDING (MEDIAN INSTALLATION YEAR EARLY 1966, FMVSS EFFECTIVE 1/1/70)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV208C CLS208C CL208C CLV206 CLS206 CL206 CLV208B CLS208B CL208B 9.0;
  ID CY; VAR CLV208C CLS208C CL208C CLV206 CLS206 CL206 CLV208B CLS208B CL208B;
  SUM CLV208C CLS208C CL208C CLV206 CLS206 CL206 CLV208B CLS208B CL208B;
TITLE1 'CAR OCCUPANT LIVES SAVED BY OUTBOARD-REAR-SEAT LAP BELTS, IMPROVED DOOR LOCKS, AND LAP BELTS FOR CHIL-
DREN AGE 1-4, 1975-2012';
TITLE2 ' ';
TITLE3 '...208C = LAP BELTS FOR OUTBOARD REAR SEAT OCCUPANTS (MEDIAN INSTALLATION YEAR LATE 1965, FMVSS EFFEC-
TIVE 1/1/68)';
TITLE4 '...206  = IMPROVED DOOR LOCKS (MEDIAN INSTALLATION YEAR 1965, FMVSS EFFECTIVE 1/1/68)';
TITLE5 '...208B = LAP BELT USE BY CHILDREN AGE 1-4 (MEDIAN INSTALLATION YEAR 1964, FMVSS EFFECTIVE 1/1/68)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
```

```
RUN;

PROC PRINT DATA=CAR3;
  FORMAT CLV208A CLS208A CL208A 9.0;
  ID CY; VAR CLV208A CLS208A CL208A;
  SUM CLV208A CLS208A CL208A;
TITLE1 'CAR OCCUPANT LIVES SAVED BY OUTBOARD-FRONT-SEAT LAP BELTS, 1975-2012';
TITLE2 ' ';
TITLE3 '...208A = LAP BELTS FOR OUTBOARD FRONT SEAT OCCUPANTS (MEDIAN INSTALLATION YEAR 1963, FMVSS EFFECTIVE
1/1/68)';
TITLE4 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE5 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;
```

Summary results for cars. CL = total lives saved. PCT_SAVE = percentage of potential fatalities that were saved by the technologies.

```
DATA CAR4; SET CAR3;
PCT_SAVE=100*CL/C_WTFA;
PROC PRINT DATA=CAR4;
  FORMAT C_ORIGWT C_WTFA CLV CLS CL 9.0 PCT_SAVE 6.2;
  ID CY; VAR C_ORIGWT C_WTFA CLV CLS CL PCT_SAVE;
  SUM C_ORIGWT C_WTFA CLV CLS CL;
TITLE1 'OVERALL CAR OCCUPANT LIVES SAVED BY VEHICLE SAFETY STANDARDS AND TECHNOLOGIES, 1975-2012';
TITLE2 ' ';
TITLE3 'C_ORIGWT = ACTUAL CAR OCCUPANT FATALITIES';
TITLE4 'C_WTFA = FATALITIES THAT WOULD HAVE OCCURRED WITHOUT ANY VEHICLE SAFETY IMPROVEMENTS';
TITLE5 'CLV = OVERALL LIVES SAVED BY VOLUNTARY IMPROVEMENTS, BEFORE FMVSS EFFECTIVE DATE';
TITLE6 'CLS = OVERALL LIVES SAVED IN CARS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
TITLE7 'CL = OVERALL LIVES SAVED BY VEHICLE SAFETY IMPROVEMENTS (CLV + CLS)';
TITLE8 'PCT_SAVE = PERCENT OF WOULD-HAVE-BEEN FATALITIES SAVED BY SAFETY STANDARDS AND TECHNOLOGIES';
RUN;


/* ----------------------------------------------------------------- */
/* ----------------------------------------------------------------- */
/*  LIVES SAVED BY FMVSS IN LTVs                                     */
/* ----------------------------------------------------------------- */
/* ----------------------------------------------------------------- */
```

The main model for LTVs begins here. The basic approach is the same as for cars, but the implementation dates and effectiveness of the various technologies may be different. In general, the notes on this section will be limited to the spots where LTVs differ from cars.

```
DATA TRK2; SET TRK1;
IF EJECTION IN (1,2) OR (CY GE 2008 AND EJECTION=3) THEN EJECT2=1; ELSE EJECT2=0;  /* NEW VALUE FOR EJECTION */

/* ----------------------------------------------------------------- */
/*  226 ROLLOVER CURTAINS                                            */
/*  MEDIAN INSTALLATION YEAR: 2009        PHASE-IN STARTS MY 2014    */
/* ----------------------------------------------------------------- */
```

Same effectiveness as in cars; curtains identified by the same variable, ROLLCURT, as in cars.

```
/* IDENTIFIES LTVs WITH ROLLOVER CURTAINS: DRIVERS & RF PASSENGERS IN FIRST-EVENT ROLLOVERS  */
  PV226=0; PS226=0;
  IF ROLLCURT GT 0 AND SEAT2 IN (11,13) AND
    ((HARM_EV=1 AND VE_FORMS=1) OR (VE_FORMS=1 AND M_HARM=1 AND HARM_EV IN (33,34,38,41,44,48,53,54,59,60,72)))
        THEN PV226=ROLLCURT;
/* LIVES SAVED IN FIRST-EVENT ROLLOVERS BY ROLLOVER CURTAINS */
  OLDWTFA=WEIGHTFA;
  IF PV226 OR PS226 GT 0 THEN DO;
    IF CY GE 2005 AND PER_TYP=3 AND AIR_BAG IN (.,0,20,28:32,97:99) THEN E=0;
   /* OCCUPANT OF A PARKED OR NON-TRANSPORT LTV: ASSUME NO BENEFIT UNLESS FARS SAYS DEPLOYMENT */
    ELSE E=.413;
    P=PV226+PS226;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS226=S*PS226/P;
```

```
    TLV226=S*PV226/P;
    WEIGHTFA=OLDWTFA+TLS226+TLV226; END;
  ELSE DO; TLV226=0; TLS226=0; END;
  TL226=TLS226+TLV226;
  TLS=TLS226; TLV=TLV226; TL=TL226;
```

TLV226: “T” = LTV, “L” = lives saved, “V” = voluntary, “226” = rollover curtain

```
/* ------------------------------------------------------------------ */
/*  214C CURTAIN & SIDE AIR BAGS (POLE TEST UPGRADE FOR FMVSS 214)    */
/*  MEDIAN INSTALLATION YEAR: 2008  PHASE-IN STARTED MY 2011          */
/* ------------------------------------------------------------------ */

/* IDENTIFIES LTVs WITH CURATAIN AND/OR SIDE AIR BAGS: DRIVERS & RF PASSENGERS IN NEARSIDE IMPACTS  */
  P_TORSO=0; P_COMBO=0; P_CURTAIN=0; P_CURT_TORS=0;
  IF 1910 LE XMY LE 1995 THEN GOTO BYP214C;
  IF NEW_TORSO=0 AND NEW_COMBO=0 AND NEW_CURTAIN=0 AND CURT_TORS=0 THEN GOTO BYP214C;
  IF 1 LE HARM_EV LE 6 THEN GOTO BYP214C;
  IF CY GE 2005 AND PER_TYP=3 AND AIR_BAG IN (.,0,20,28:32,97:99) THEN GOTO BYP214C;
  /* OCCUPANT OF A PARKED LTV: ASSUME NO BENEFIT UNLESS FARS SAYS DEPLOYMENT */
  IF TL226 GT 0 THEN GOTO BYP214C;
  /* IF WE HAVE TREATED THIS CASE AS A ROLLOVER, ABOVE, WE WILL NOT TREAT IT AS A NEARSIDE IMPACT, TOO */
  IF IMPACT1 IN (8,9,10,61:63) AND IMPACT2 IN (2,2.5,3,3,5,4,26,81:83) THEN GOTO BYP214C;
  IF IMPACT1 IN (2,3,4,81:83) AND IMPACT2 IN (8,8.5,9,9.5,10,26,61:63) THEN GOTO BYP214C;
  /* WE WILL NOT COUNT A BENEFIT IN VEHICLES HIT ON BOTH SIDES */
  IF (NEW_TORSO GT 0 OR NEW_COMBO GT 0 OR NEW_CURTAIN GT 0 OR CURT_TORS GT 0) AND
    ((SEAT2=11 AND (IMPACT1 IN (8,9,10,61:63) OR IMPACT2 IN (8,8.5,9,9.5,10,61:63))) OR
    (SEAT2=13 AND (IMPACT1 IN (2,3,4,81:83) OR IMPACT2 IN (2,2.5,3,3.5,4,81:83))))
        THEN DO; P_TORSO=NEW_TORSO; P_COMBO=NEW_COMBO; P_CURTAIN=NEW_CURTAIN; P_CURT_TORS=CURT_TORS; END;
  ELSE GOTO BYP214C;
  /* LIVES SAVED IN NEARSIDE IMPACTS BY CURTAIN AND/OR SIDE AIR BAGS */
  OLDWTFA=WEIGHTFA;
  T_TORSO=OLDWTFA*.078*P_TORSO / (1 - .078*P_TORSO);           /* FATALITY REDUCTION FOR TORSO BAG ONLY: 7.8% */
  T_COMBO=OLDWTFA*.248*P_COMBO / (1 - .248*P_COMBO);           /* FATALITY REDUCTION FOR COMBO BAG: 24.8% */
  T_CURTAIN=OLDWTFA*.164*P_CURTAIN / (1 - .164*P_CURTAIN);     /* FATALITY REDUCTION FOR CURTAIN ONLY: 16.4% */
  T_CURT_TORS=OLDWTFA*.313*P_CURT_TORS / (1 - .313*P_CURT_TORS); /* FATALITY REDUCTION FOR CURTAIN + TORSO:
31.3% */
  IF XMY IN (2011,2012,2013) THEN DO; TLS214C=T_TORSO+T_COMBO+T_CURTAIN+T_CURT_TORS; TLV214C=0; END;
  ELSE IF 1996 LE XMY LE 2010 THEN DO; TLV214C=T_TORSO+T_COMBO+T_CURTAIN+T_CURT_TORS; TLS214C=0; END;
  WEIGHTFA=OLDWTFA+TLS214C+TLV214C; GOTO TALLY214C;

  BYP214C: TLV214C=0; TLS214C=0; T_TORSO=0; T_COMBO=0; T_CURTAIN=0; T_CURT_TORS=0;
  TALLY214C: TL214C=TLS214C+TLV214C;
  TLS=TLS+TLS214C; TLV=TLV+TLV214C; TL=TL+TL214C;

/* ------------------------------------------------------------------ */
/*  126 ELECTRONIC STABILITY CONTROL                                  */
/*  MEDIAN INSTALLATION YEAR: EARLY 2008  PHASE-IN STARTED MY 2009    */
/* ------------------------------------------------------------------ */

/* IDENTIFIES LTVs WITH ESC  */
  PV126=0; PS126=0;
  IF ESC GT 0 THEN DO; IF 1998 LE XMY LE 2008 THEN PV126=ESC; ELSE IF 2009 LE XMY LE 2013 THEN PS126=ESC; END;
/* LIVES SAVED BY ESC IN CRASHES WHERE ESC IS BENEFICIAL */
  OLDWTFA=WEIGHTFA;
  IF PV126 OR PS126 GT 0 THEN DO;
/* IDENTIFY FIRST-EVENT ROLLOVERS, OTHER RUN-OFF-ROAD CRASHES, AND CULPABLE MULTI-VEHICLE INVOLVEMENTS */
    DRCF=0;         /* IN MULTI-VEHICLE CRASHES, DRCF=0 MEANS NOT CULPABLE, DRCF=1 MEANS CULPABLE */
    IF CY LE 2009 AND (DR_CF1 IN (3,6,8,26,27,28,30,31,33,35,36,38,39,44,46,47,48,50,51,57,58,79,87)
      OR DR_CF2 IN (3,6,8,26,27,28,30,31,33,35,36,38,39,44,46,47,48,50,51,57,58,79,87)
      OR DR_CF3 IN (3,6,8,26,27,28,30,31,33,35,36,38,39,44,46,47,48,50,51,57,58,79,87)
      OR DR_CF4 IN (3,6,8,26,27,28,30,31,33,35,36,38,39,44,46,47,48,50,51,57,58,79,87))
      THEN DRCF=1;
    ELSE IF CY GE 2010 AND (DR_SF1 IN (6,8,18,26:30,33:36,38,39,41,47,48,50,51,57,58)
      OR DR_SF2 IN (6,8,18,26:30,33:36,38,39,41,47,48,50,51,57,58)
      OR DR_SF3 IN (6,8,18,26:30,33:36,38,39,41,47,48,50,51,57,58)
      OR DR_SF4 IN (6,8,18,26:30,33:36,38,39,41,47,48,50,51,57,58))
      THEN DRCF=1;

    IF HARM_EV=1 AND VE_FORMS=1 THEN ESC_CRSH=1; /* FIRST-EVENT ROLLOVER */
        ELSE IF VE_FORMS=1 AND M_HARM=1 AND HARM_EV IN (33,34,38,41,44,48,53,54,58,59,60,72) THEN ESC_CRSH=1;
```

```
       /* ALSO "1st EVENT ROLLOVER": CURB, DITCH, FENCE, SHRUBBERY, PAVEMENT IRREGULARITY, SNOWBANK, MAILBOX, */
       /* FALLING CARGO, GROUND, CARGO SHIFT IS 1st EVENT AND ROLLOVER IS MOST HARMFUL EVENT */
      ELSE IF HARM_EV IN (8,9,11,49) THEN ESC_CRSH=0;           /* PED/BIKE/ANIMAL (ESC NOT EFFECTIVE) */
      ELSE IF VE_FORMS=1 AND HARM_EV IN
(14,17,19,20,21,22,23,25,26,27,28,29,30,31,32,35,36,37,39,40,42,43,46,50,52,57,59)
         THEN ESC_CRSH=2;  /* RUN-OFF ROAD CRASH THAT IS NOT A 1st EVENT ROLLOVER */
      /* FIXED-OBJECT COLLISIONS: 1st IMPACT WITH PARKED VEH, BOULDER, BUILDING, IMPACT ATTENUATOR, BRIDGE */
      /* (ANY PART), BARRIER (ANY TYPE), HIGHWAY SIGN POST, OVERHEAD SIGN, LIGHT SUPPORT, UTILITY POLE, OTHER */
      /* POST/POLE, CULVERT, EMBANKMENT (ANY MATERIAL), WALL, FIRE HYDRANT, TREE, OTHER FIXED OBJECT, TRAFFIC */
      /* SIGNAL SUPPORT, BRIDGE OVERHEAD STRUCTURE - REGARDLESS OF SUBSEQUENT EVENTS */
       ELSE IF VE_FORMS=1 AND HARM_EV IN (24,33,34,38,41,44,48,53,57,58) AND
         M_HARM IN (24,33,34,38,41,48,52,53,57,14,17,19:23,25:32,35:37,39,40,42,43,46,50) THEN ESC_CRSH=2;
      /* ALSO FIXED-OBJECT COLLISION: GUARDRAIL FACE, CURB, DITCH, FENCE, SHRUBBERY, PAVEMENT IRREGULARITY, */
      /* SNOWBANK, GUARDRAIL END, MAILBOX, CABLE BARRIER IS 1st EVENT AND MOST HARMFUL EVENT IS ONE OF THESE */
      /* (EXCEPT PAVEMENT IRREGULARITY) OR ONE OF THE FIXED OBJECTS LISTED ABOVE */
       ELSE IF VE_FORMS=1 AND HARM_EV IN (3,24,52,33,34,38,41,53) THEN ESC_CRSH=2;
     /* RAN-OFF-ROAD, NOT NECESSARILY FIXED OBJECT OR 1st EVENT ROLLOVER: IMMERSION, VARIOUS OFF-ROAD OBJECTS */
      ELSE IF CY LE 2009 AND (VEH_MAN IN (4,7) OR TRAV_SP=0) THEN ESC_CRSH=0;      /* STOPPED/PARKED (ESC NOT
EFFECTIVE) */
      ELSE IF CY GE 2010 AND (P_CRASH1 IN (5,7) OR TRAV_SP=0) THEN ESC_CRSH=0;      /* STOPPED/PARKED (ESC NOT
EFFECTIVE) */
          ELSE IF CY GE 2005 AND PER_TYP=3 THEN ESC_CRSH=0;                           /* OCCS OF PARKED VEHS
(ESC NOT EFFECTIVE) */
     ELSE IF CY LE 2009 AND (VEH_MAN IN (3,6,8,15) OR 1 LE TRAV_SP LE 10)
        THEN ESC_CRSH=0;                                      /* BACKING/PARKING/LO-SPEED (ESC NOT EFFECTIVE) */
      ELSE IF CY GE 2010 AND (P_CRASH1 IN (4,8,9,13) OR 1 LE TRAV_SP LE 10)
        THEN ESC_CRSH=0;                                      /* BACKING/PARKING/LO-SPEED (ESC NOT EFFECTIVE) */
      ELSE IF IMPACT1 IN (5,6,7) THEN ESC_CRSH=0;             /* REAR-END STRUCK (ESC NOT EFFECTIVE) */
      ELSE IF DRCF=1 THEN ESC_CRSH=3;                         /* CULPABLE VEHICLE IN A MULTI-VEHICLE CRASH */
```

Fatal-crash reduction estimates for LTVs are higher than for cars: (1) first-event rollovers (74.00%); (2) all other single-vehicle crashes without non-occupants involved (45.47%); and (3) culpable involvements in multivehicle crashes (16.15%).

```
    IF ESC_CRSH=1 THEN E=.7400;                /* LTVs: NEW ESTIMATE OF ESC EFFECTIVENESS IN FIRST-EVENT ROLLO-
VERS */
      ELSE IF ESC_CRSH=2 THEN E=.4547;         /* LTVs: NEW ESTIMATE OF ESC EFFECTIVENESS IN OTHER RUN-OFF-ROAD
CRASHES */
      ELSE IF ESC_CRSH=3 THEN E=.1615;         /* LTVs: NEW ESTIMATE OF ESC EFFECTIVENESS IN CULPABLE MULTI-
VEHICLE INVOLVEMENTS */
      ELSE E=0;

    P=PV126+PS126;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS126=S*PS126/P;
    TLV126=S*PV126/P;
    WEIGHTFA=OLDWTFA+TLS126+TLV126; END;
  ELSE DO; TLV126=0; TLS126=0; END;
  TL126=TLS126+TLV126;
  TLS=TLS+TLS126; TLV=TLV+TLV126; TL=TL+TL126;

/* ------------------------------------------------------------------ */
/*  301 FUEL SYSTEM INTEGRITY - REAR IMPACT UPGRADE                   */
/*  MEDIAN INSTALLATION YEAR: 2007  PHASE-IN STARTED MY 2007          */
/* ------------------------------------------------------------------ */

/* IDENTIFIES LTVs CERTIFIED TO FMVSS 301 REAR-IMPACT UPGRADE: REAR IMPACTS WITH FIRE  */
  PV301=0; PS301=0;
  IF (5 LE IMPACT2 LE 7 OR (CRSH=4 AND IMPACT1 IN (5,6,7))) AND FIRE_EXP=1 AND FMVSS301=1 THEN DO;
    IF XMY=2006 THEN PV301=1; ELSE IF 2007 LE XMY LE 2013 THEN PS301=1; END;
/* LIVES SAVED IN REAR-IMPACT FIRES BY FMVSS 301 REAR-IMPACT UPGRADE */
  OLDWTFA=WEIGHTFA;
  IF PV301 OR PS301 GT 0 THEN DO;
    E=.3519;
    P=PV301+PS301;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS301=S*PS301/P;
    TLV301=S*PV301/P;
    WEIGHTFA=OLDWTFA+TLS301+TLV301; END;
  ELSE DO; TLV301=0; TLS301=0; END;
```

```
  TL301=TLS301+TLV301;
  TLS=TLS+TLS301; TLV=TLV+TLV301; TL=TL+TL301;

/* ----------------------------------------------------------------- */
/*  208J 3-POINT BELTS FOR CENTER REAR SEAT OCCUPANTS (ANTON'S LAW)   */
/*  MEDIAN INSTALLATION YEAR: 2003  PHASE-IN STARTED MY 2006         */
/* ----------------------------------------------------------------- */

/* IDENTIFIES CENTER REAR SEAT OCCUPANTS WEARING 3-POINT BELTS  */
  PS208J=0; PV208J=0;
  IF SEAT2=22 AND REST3=3 THEN DO;
    IF 2006 LE XMY LE 2013 THEN PS208J=1;
    ELSE IF 1994 LE XMY LE 2005 THEN PV208J=1; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY CENTER-REAR-SEAT 3-POINT BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208J GT 0 OR PV208J GT 0 THEN DO;
```

In general, belts are more effective in LTVs than in cars; also, a higher percentage of unrestrained fatalities were ejected. The data in NHTSA's evaluation of 3-point belts in the outboard rear seats indicate fatality reduction of 50 percent in frontals, 84 percent in rollovers and 70 percent in side, rear and other impacts. We will assume the same effectiveness for 3-point belts in the center rear seat. In frontal crashes, 49 percent of unrestrained center rear seat passenger fatalities were ejected, 59 percent in side impacts, 85 percent in rollovers and 58 percent in rear/other impacts.

```
    IF CRSH=1 THEN DO; E=.50; EJECT2=.49; END;
      ELSE IF CRSH=2 THEN DO; E=.70; EJECT2=.59; END;
      ELSE IF CRSH=3 THEN DO; E=.84; EJECT2=.85; END;
      ELSE IF CRSH=4 THEN DO; E=.70; EJECT2=.58; END;
    P=PS208J+PV208J;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208J=S*PS208J/P;
    TLV208J=S*PV208J/P;
    WEIGHTFA=OLDWTFA+TLS208J+TLV208J; END;
  ELSE DO; TLS208J=0; TLV208J=0; END;
  TL208J=TLS208J+TLV208J;
  TLS=TLS+TLS208J; TLV=TLV+TLV208J; TL=TL+TL208J;

/* ----------------------------------------------------------------- */
/*  208K VOLUNTARY INSTALLATION OF PRETENSIONERS & LOAD LIMITERS      */
/*  MEDIAN INSTALLATION YEAR: 2002                                    */
/* ----------------------------------------------------------------- */
```

NHTSA study showed significant 12.8-percent fatality reduction for occupant wearing belt with pretensioners and load limiters relative to occupant wearing belt without these devices: in passenger cars, CUVs, and minivans. No significant effect in pickup trucks, full-size vans, or truck-based SUVs. First step is identifying the make-models of LTVs that are CUVs or minivans.

```
/* IDENTIFIES CUVs AND MINIVANS WITH PRETENSIONERS & LOAD LIMITERS AT THE OUTBOARD FRONT SEATS   */
/* NHTSA DOES NOT CLAIM AN EFFECTIVENESS IN PICKUP TRUCKS, TRUCK-BASED SUVs, OR FULL-SIZE VANS   */
  PS208K=0; PV208K=0;
  IF SEAT2 IN (11,13) AND REST3=3
  AND (XMM2 IN (2001,2352,2353,6052,6054,7021,7027,12017,12022,12014,13014,12025,13016,          /* CUVs */
              12342:12347,14342:14347,41342:41347,18024,18356,18357,19020,47038,20023,20024,
              23008,22352,22353,24010,24362:24366,30302,30303,30313,32047,32303,32313,
              33035,34044,34303,34313,35049,35051,35052,35332,35333,37032,37302,37303,37332,37333,
              41053,41054,42323,42333,42336,42337,45313,48044,48045,48303,48313,
              49053,49320:49323,49342:49347,51043,51047,51312,51313,52047,52312,52313,
              20338,20339,22338,22339,23338,23339,55302:55309,55322,55323,55332,55333,
              54040,54302,54303,54323,58039,58040,59332,59333,59342,59343,63241,63243) OR
       XMM2 IN (6400:6409,7400:7409,7600:7609,9400:9409,30406,12400,12402,12460,12462,          /* MINIVANS */
              14402,14450,14452,35450,35452,18450:18459,18650:18659,20440:20459,20640:20659,
              21450:21459,22440:22459,22640:22659,24450:24459,30412,30612,37402,38402,
              41400:41403,49400:49403,49422,49423,55402,63402) OR
       (XMM2 IN (37322,37323) AND XMY GE 2003) OR        /* STARTED AS TRUCK-BASED SUVs BUT LATER REDESIGNED AS
CUVs */
       (XMM2 IN (42302,42303) AND XMY GE 2006) OR
       (XMM2 IN (53338,53339) AND XMY GE 2007) OR
```

```
       (XMM2 IN (63302,63303) AND XMY GE 2005) OR
       (XMM2 IN (63312,63313) AND XMY GE 2011)) THEN DO;
    IF 2008 LE XMY LE 2013 THEN PV208K=1;
    ELSE IF 1995 LE XMY LE 2007 AND PRETENLL=1 THEN PV208K=1; END;
/* LIVES SAVED BY PRETENSIONERS & LOAD LIMITERS: BELTED DRIVERS & RF PASSENGERS */
  OLDWTFA=WEIGHTFA;
  IF PS208K GT 0 OR PV208K GT 0 THEN DO;
    IF CRSH=1 THEN E=.128; ELSE E=0;        /* CONSERVATIVELY ASSUME BENEFIT ONLY IN FRONTAL IMPACTS */
    P=PS208K+PV208K;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208K=S*PS208K/P;
    TLV208K=S*PV208K/P;
    WEIGHTFA=OLDWTFA+TLS208K+TLV208K; END;
  ELSE DO; TLS208K=0; TLV208K=0; END;
  TL208K=TLS208K+TLV208K;
  TLS=TLS+TLS208K; TLV=TLV+TLV208K; TL=TL+TL208K;

/* ---------------------------------------------------------------- */
/*  201B INTERIOR IMPACT PROTECTION: HEAD-IMPACT UPGRADE            */
/*  MEDIAN INSTALLATION YEAR: EARLY 2002  PHASE-IN STARTED MY 1999  */
/* ---------------------------------------------------------------- */

/* IDENTIFIES ANY OCCUPANT SITTING AT A DESIGNATED SEATING POSITION IN A VEHICLE MEETING THE HEAD-IMPACT UPGRADE
*/
  PS201B=0; PV201B=0;
  IF SEAT2 IN (11,12,13,21,22) THEN DO;
    IF 2003 LE XMY LE 2013 THEN PS201B=1;
    ELSE IF 1999 LE XMY LE 2002 AND FMVSS201=1 THEN PS201B=1; END;
/* LIVES SAVED BY UPGRADED UPPER-INTERIOR PADDING */
  OLDWTFA=WEIGHTFA;
  IF PS201B GT 0 OR PV201B GT 0 THEN DO;
    E=.04276;  /* 23.73% REDUCTION OF UPPER-INTERIOR AIS 4-6, UPPER-INTERIOR-HEAD IS MOST SEVERE INJURY IN
18.02% OF FATALS */
    P=PS201B+PV201B;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS201B=S*PS201B/P;
    TLV201B=S*PV201B/P;
    WEIGHTFA=OLDWTFA+TLS201B+TLV201B; END;
  ELSE DO; TLS201B=0; TLV201B=0; END;
  TL201B=TLS201B+TLV201B;
  TLS=TLS+TLS201B; TLV=TLV+TLV201B; TL=TL+TL201B;

/* ------------------------------------------------------------------- */
/*  108 TRAILER CONSPICUITY TAPE - LIVES SAVED, LTVs NOT HITTING THEM   */
/*  54% OF TRAILERS ON THE ROAD HAD THEM IN: 1996                       */
/*  FMCSA RETROFIT REQUIREMENT ISSUED 3/31/1999, TOOK EFFECT 6/1/2001   */
/* ------------------------------------------------------------------- */

/* IDENTIFIES SIDE/REAR IMPACTS INTO TRAILERS IN THE DARK AND % OF TRAILERS WITH TAPE */
  PS108=0; PV108=0;
  IF CY GE 1991 AND (TAPECASE=1 OR
    (OVTYP=3 AND ((1991 LE CY LE 1994 AND OVCONFIG=5) OR (CY GE 1995 AND OVCONFIG=6))
       AND 2 LE LGT_COND LE 5 AND
      (OIMPACT2 IN (14,16) AND MAN_COLL IN (1,4,5) AND IMPACT2 IN (11,11.5,12,.5,1))))
    THEN DO;
      IF CY=1991 THEN DO; PS108=0; PV108=.09; END;
        ELSE IF CY=1992 THEN DO; PS108=0; PV108=.18; END;
        ELSE IF CY=1993 THEN DO; PS108=0; PV108=.27; END;
        ELSE IF CY=1994 THEN DO; PS108=.09; PV108=.27; END;
        ELSE IF CY=1995 THEN DO; PS108=.18; PV108=.27; END;
        ELSE IF CY=1996 THEN DO; PS108=.27; PV108=.27; END;
        ELSE IF CY=1997 THEN DO; PS108=.36; PV108=.27; END;
        ELSE IF CY=1998 THEN DO; PS108=.45; PV108=.27; END;
        ELSE IF CY=1999 THEN DO; PS108=.54; PV108=.27; END;
        ELSE IF CY=2000 THEN DO; PS108=.63; PV108=.27; END;
        ELSE IF CY=2001 THEN DO; PS108=.8775; PV108=.1125; END;
        ELSE IF CY GE 2002 THEN DO; PS108=1; PV108=0; END; END;
/* LTV OCCUPANT LIVES SAVED BY CONSPICUITY TAPE ON TRUCK TRAILERS */
  OLDWTFA=WEIGHTFA;
  IF PS108 GT 0 OR PV108 GT 0 THEN DO;
    E=.29;
    P=PS108+PV108;
```

```
    S=OLDWTFA*E*P / (1 - E*P);
    TLS108=S*PS108/P;
    TLV108=S*PV108/P;
    WEIGHTFA=OLDWTFA+TLS108+TLV108; END;
  ELSE DO; TLS108=0; TLV108=0; END;
  TL108=TLS108+TLV108;
  TLS=TLS+TLS108; TLV=TLV+TLV108; TL=TL+TL108;

/* ---------------------------------------------------------------------- */
/*  208I FRONTAL AIR BAGS FOR DRIVERS AND RF PASSENGERS                   */
/*  ASSUMES 18 PERCENT OF ON-OFF SWITCHES ARE TURNED OFF FOR RF 13+       */
/*  MEDIAN INSTALLATION YEAR: 1995  PHASE-IN STARTED MY 1995              */
/* ---------------------------------------------------------------------- */

/* IDENTIFIES LTVs WITH AIR BAGS                                              */
PS208I=0; PV208I=0; P_BARRIER=0; P_SLED=0; P_CAC=0; UDAB=0; UPAB=0;
```

"PASSIVE," the variable that indicates the types of occupant protection at the outboard front seats, is only defined if FARS has at least a partial VIN to decode. However, even when there is no VIN at all, we can often infer from the body type, the model year and the make if the LTV had driver and/or passenger air bags. All SUVs and minivans from MY 1998 onwards have had dual air bags; all compact pickups have had driver air bags from MY 1998 onwards. Some makes had driver air bags (UDAB = 1) or passenger air bags (UPAB = 1) on all LTVs of a certain body type before 1998. Because the FARS body types "large van" and "standard pickup" include vehicles with GVWR over 8,500 pounds, they may be without air bags even after 1998.

```
/* LTVs WITH UNKNOWN "PASSIVE" (BAD VINs AND/OR NO MAK_MOD) CLASSIFIED BY MAKE AND MODEL YEAR */

  IF CY GE 1991 AND XMY GE 1992 AND PASSIVE IN (.,9,1099,9999) AND SEAT2 IN (11,12,13,18) THEN DO;
    IF SEAT2=11 THEN DO;
      IF (MAKE IN (6,9) AND XMY GE 1992)
      OR (MAKE IN (7,12,49) AND BODY_TYP=20 AND XMY GE 1992)
      OR (MAKE=41 AND BODY_TYP=20 AND XMY GE 1993)
      OR (MAKE IN (14,21,22) AND XMY GE 1994)
      OR (MAKE=7 AND BODY_TYP=30 AND XMY GE 1994)
      OR (MAKE=12 AND BODY_TYP IN (15,16) AND XMY GE 1994)
      OR (MAKE IN (20,23,35) AND BODY_TYP=20 AND XMY GE 1994)
      OR (MAKE=49 AND BODY_TYP=31 AND XMY GE 1994)
      OR (MAKE=30 AND XMY GE 1995)
      OR (MAKE=7 AND BODY_TYP=21 AND XMY GE 1995)
      OR (MAKE IN (12,20,23) AND BODY_TYP=30 AND XMY GE 1995)
      OR (MAKE IN (12,23) AND BODY_TYP=14 AND XMY GE 1995)
      OR (MAKE IN (20,23,49) AND BODY_TYP IN (15,16) AND XMY GE 1995)
      OR (MAKE=12 AND BODY_TYP=21 AND XMY GE 1995)
      OR (MAKE IN (2,37,53,54,59,62) AND XMY GE 1996)
      OR (MAKE IN (20,38,49) AND BODY_TYP=14 AND XMY GE 1996)
      OR (MAKE IN (35,38,41,49) AND BODY_TYP=30 AND XMY GE 1996)
      OR (MAKE=38 AND BODY_TYP=20 AND XMY GE 1996)
      OR (MAKE IN (52,58,63) AND XMY GE 1997)
      OR (MAKE=35 AND BODY_TYP=14 AND XMY GE 1997)
      OR (MAKE IN (13,18,19,34,42,48,55) AND XMY GE 1998)
      OR (MAKE=7 AND BODY_TYP IN (15,16) AND XMY GE 1998)
      OR (MAKE=41 AND BODY_TYP=14 AND XMY GE 1998)
      OR (MAKE=12 AND BODY_TYP=31 AND XMY GE 1999)
      OR (MAKE IN (20,23) AND BODY_TYP=31 AND XMY GE 2001)
     THEN UDAB=1; END;

    ELSE IF SEAT2 IN (12,13,18) THEN DO;
      IF (MAKE IN (6,9) AND XMY GE 1994)
      OR (MAKE IN (7,49) AND BODY_TYP=20 AND XMY GE 1994)
      OR (MAKE=12 AND BODY_TYP=14 AND XMY GE 1995)
      OR (MAKE=49 AND BODY_TYP IN (15,16) AND XMY GE 1995)
      OR (MAKE IN (14,37,53,54,59,62) AND XMY GE 1996)
      OR (MAKE IN (23,35,38,41) AND BODY_TYP=20 AND XMY GE 1996)
      OR (MAKE IN (38,49) AND BODY_TYP=14 AND XMY GE 1996)
      OR (MAKE IN (2,22,30,52,58) AND XMY GE 1997)
      OR (MAKE IN (12,20,23) AND BODY_TYP IN (15,16) AND XMY GE 1997)
      OR (MAKE=12 AND BODY_TYP=21 AND XMY GE 1997)
```

```
    OR (MAKE=20 AND BODY_TYP=20 AND XMY GE 1997)
    OR (MAKE=35 AND BODY_TYP=14 AND XMY GE 1997)
    OR (MAKE IN (13,18,19,21,34,42,48,55,63) AND XMY GE 1998)
    OR (MAKE=7 AND BODY_TYP IN (15,16) AND XMY GE 1998)
    OR (MAKE=7 AND BODY_TYP=21 AND XMY GE 1998)
    OR (MAKE=12 AND BODY_TYP=20 AND XMY GE 1998)
    OR (MAKE IN (20,23,41) AND BODY_TYP=14 AND XMY GE 1998)
  THEN UPAB=1; END; END;
```

These are the codes of PASSIVE, based on VIN analysis, that indicate a car is equipped with frontal air bags and the driver or RF seats, respectively – and whether they are barrier-certified, sled-certified, or advanced. PS208I includes any installation from MY 1995 onwards, because the phase-in of automatic occupant protection began on September 1, 1994.

```
  IF CY GE 1990 AND XMY GE 1991 AND
    (SEAT2=11 AND (PASSIVE IN (1,2,3,1090) OR UDAB=1))
    OR (SEAT2 IN (12,13,18) AND (PASSIVE IN (2,3) OR UPAB=2)) THEN DO;
      IF 1991 LE XMY LE 1994 THEN DO; PV208I=1; P_BARRIER=1; END;
      ELSE IF XMY GE 1995 THEN DO; PS208I=1;
        IF XMY LE 1997 THEN P_BARRIER=1;
        ELSE IF 2000 LE XMY LE 2002 THEN P_SLED=1;
        ELSE IF XMY GE 2007 THEN P_CAC=1;
        ELSE IF REDES=0 AND CAC=0 THEN P_BARRIER=1;
        ELSE IF REDES=1 AND CAC=0 THEN P_SLED=1;
        ELSE IF REDES=1 AND CAC=1 THEN P_CAC=1; END; END;

/* ------------------------------------------------------------------ */
/*  SPLITS CASES INTO SCENARIOS DEPENDING ON AIR BAG TYPE, SEAT       */
/*  POSITION, ON-OFF SWITCH PRESENCE, OCCUPANT AGE, RESTRAINT USE     */
/*  COMPUTES LIVES SAVED BY AIR BAGS IN EACH SCENARIO                 */
/* ------------------------------------------------------------------ */
```

Same eight scenarios (plus default scenario of no air bag), same effectiveness, and same lives-saved computations as for passenger cars:

```
  IF PS208I=0 AND PV208I=0 THEN GOTO TNOBAG;                /* NO AIR BAG */
    ELSE IF CY GE 2005 AND PER_TYP=3 AND AIR_BAG IN
          (.,0,20,28:32,97:99) THEN GOTO TNOBAG;               /* OCCUPANT OF A PARKED CAR: ASSUME NO BENEFIT
UNLESS FARS SAYS DEPLOYMENT */
    ELSE IF SEAT2=11 AND REST3 GT 0 THEN GOTO TDRVBELT;      /* BELTED DRIVER */
    ELSE IF SEAT2=11 THEN GOTO TDRVUNR;                      /* UNRESTRAINED DRIVER */
    ELSE IF PASSIVE=3 AND 0 LE AGE LE 12 THEN GOTO TKIDSW;   /* CHILD RF WITH SWITCH */
    ELSE IF 0 LE AGE LE 12 THEN GOTO TKID;                   /* CHILD RF NO SWITCH */
        ELSE IF SEAT2 IN (12,18) THEN GOTO TNOBAG;               /* ADULT IN CENTER FRONT OR NON-DESIGNATED
SEAT: AIR BAG HAS NO EFFECT */
    ELSE IF PASSIVE=3 AND REST3 GT 0 THEN GOTO TRFBELSW;     /* BELTED ADULT RF W SWITCH */
    ELSE IF PASSIVE=3 THEN GOTO TRFUNRSW;                    /* UNBELTED ADULT RF W SWITCH */
    ELSE IF REST3 GT 0 THEN GOTO TRFBELT;                    /* BELTED ADULT RF NO SWITCH */
    ELSE GOTO TRFUNR;                                        /* UNBELTED ADULT RF NO SWITCH */

TNOBAG: /* ALL EFFECTS ARE ZERO HERE, BECAUSE NO FRONTAL AIR BAGS - BUT THESE ARE THE VARIABLES WE WILL TALLY IN
EACH SCENARIO */
    TLS208I=0; /* NET LIVES SAVED BY FRONTAL AIR BAGS, MY 1987 & LATER VEHICLES (AFTER 208 AUTOMATIC-PROTECTION
PHASE-IN STARTED) */

    TLV208I=0; /* NET LIVES SAVED BY FRONTAL AIR BAGS, MY 1985 & 1986 (BEFORE 208 PHASE-IN) */

    TL208I=0; /* NET LIVES SAVED BY ANY FRONTAL AIR BAGS */

    T_BARRIER=0; /* NET LIVES SAVED BY BARRIER-CERTIFIED AIR BAGS */

    T_SLED=0; /* NET LIVES SAVED BY SLED-CERTIFIED AIR BAGS */

    T_CAC=0; /* NET LIVES SAVED BY ADVANCED AIR BAGS. NOTE: TL208I = TLV208I+TLS208I = T_BARRIER+T_SLED+T_CAC */

    TABDRV=0; /* DRIVERS SAVED BY FRONTAL AIR BAGS */

    TABRF=0; /* RF PASSENGERS 13 AND OLDER SAVED BY FRONTAL AIR BAGS IN VEHICLES W/O ON-OFF SWITCHES */
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    TABKID_BARRIER=0; /* NET EFFECT OF BARRIER-CERTIFIED BAGS ON RF AGE 0-12 (NEGATIVE NUMBER BECAUSE FATALITY
INCREASE), VEH W/O SWITCHES */

    TABKID_SLED=0; /* NET EFFECT OF SLED-CERTIFIED BAGS ON RF AGE 0-12 (NEGATIVE NUMBER BECAUSE FATALITY IN-
CREASE), VEH W/O SWITCHES */

    TSW0=0; /* ACTUAL RF 13 & OLDER SAVED IN VEH WITH ON-OFF SWITCHES, AND THE SWITCHES WERE LEFT ON */

    TSW1=0; /* THEORETICAL RF 13 & OLDER SAVED IN VEH WITH ON-OFF SWITCHES, IF THESE SWITCHES HAD ALL BEEN LEFT
ON */

    TSW2=0; /* LIVES LOST BECAUSE SWITCHES WERE TURNED OFF FOR RF 13+ (NEGATIVE NUMBER BECAUSE FATALITY IN-
CREASE). NOTE: TSW0=TSW1+TSW2 */

    TSWKID0_BARRIER=0; /* ACTUAL ADD'L CHILD PASSENGER FATALITIES DUE TO BARRIER-CERTIFIED AIR BAGS & SWITCHES
LEFT ON */

    TSWKID1_BARRIER=0; /* THEORETICAL CHILD PASSENGER FATALITIES DUE TO BARRIER-CERTIFIED AIR BAGS IF SWITCHES
HAD NOT EXISTED */

    TSWKID2_BARRIER=0; /* LIVES SAVED BECAUSE SWITCHES WERE TURNED OFF FOR CHILD PASSENGERS WITH BARRIER-
CERTIFIED AIR BAGS */

    TSWKID0_SLED=0; /* ACTUAL ADD'L CHILD PASSENGER FATALITIES DUE TO SLED-CERTIFIED AIR BAGS & SWITCHES LEFT ON
*/

    TSWKID1_SLED=0; /* THEORETICAL CHILD PASSENGER FATALITIES DUE TO SLED-CERTIFIED AIR BAGS IF SWITCHES HAD NOT
EXISTED */

    TSWKID2_SLED=0; /* LIVES SAVED BECAUSE SWITCHES WERE TURNED OFF FOR CHILD PASSENGERS WITH SLED-CERTIFIED AIR
BAGS */

    T_KID_SLED=0; /* CHILDREN'S LIVES SAVED BECAUSE THEY WERE EXPOSED TO SLED-CERTIFIED RATHER THAN BARRIER-
CERTIFIED AIR BAGS */

    T_KID_CAC=0; /* CHILDREN'S LIVES SAVED BECAUSE THEY SAT BEHIND ADVANCED AIR BAGS (NO/LOW-RISK DEPLOYMENT)
RATHER THAN BARRIER-CERT */

    T_ADULT_CAC=0; /* RF 13+ SAVED BECAUSE ADVANCED AIR BAGS ELIMINATED MANUAL SWITCHES THAT WOULD HAVE BEEN
TURNED OFF FOR THESE RF */
    GOTO T214A;

TDRVBELT:  OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (TL226+TL214C)/OLDWTFA GT .05052 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.25258;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.13239;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.05052;
ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208I=S*PS208I/P;
    TLV208I=S*PV208I/P;
        T_BARRIER=S*P_BARRIER/P;
        T_SLED=S*P_SLED/P;
        T_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+TLS208I+TLV208I;
    TL208I=TLS208I+TLV208I;
    TLS=TLS+TLS208I; TLV=TLV+TLV208I; TL=TL+TL208I;
    TABDRV=TL208I; TABRF=0; TABKID_BARRIER=0; TABKID_SLED=0; TSW0=0; TSW1=0; TSW2=0;
    TSWKID0_BARRIER=0; TSWKID1_BARRIER=0; TSWKID2_BARRIER=0;
    TSWKID0_SLED=0; TSWKID1_SLED=0; TSWKID2_SLED=0;
    T_KID_SLED=0; T_KID_CAC=0; T_ADULT_CAC=0; GOTO T214A;

TDRVUNR:   OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (TL226+TL214C)/OLDWTFA GT .06548 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
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      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.32742;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.17161;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.06548;
ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208I=S*PS208I/P;
    TLV208I=S*PV208I/P;
        T_BARRIER=S*P_BARRIER/P;
        T_SLED=S*P_SLED/P;
        T_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+TLS208I+TLV208I;
    TL208I=TLS208I+TLV208I;
    TLS=TLS+TLS208I; TLV=TLV+TLV208I; TL=TL+TL208I;
    TABDRV=TL208I; TABRF=0; TABKID_BARRIER=0; TABKID_SLED=0; TSW0=0; TSW1=0; TSW2=0;
    TSWKID0_BARRIER=0; TSWKID1_BARRIER=0; TSWKID2_BARRIER=0;
    TSWKID0_SLED=0; TSWKID1_SLED=0; TSWKID2_SLED=0;
    T_KID_SLED=0; T_KID_CAC=0; T_ADULT_CAC=0; GOTO T214A;

TRFBELT:   OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (TL226+TL214C)/OLDWTFA GT .05557 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.27784;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.14563;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.05557;
ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208I=S*PS208I/P;
    TLV208I=S*PV208I/P;
        T_BARRIER=S*P_BARRIER/P;
        T_SLED=S*P_SLED/P;
        T_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+TLS208I+TLV208I;
    TL208I=TLS208I+TLV208I;
    TLS=TLS+TLS208I; TLV=TLV+TLV208I; TL=TL+TL208I;
    TABDRV=0; TABRF=TL208I; TABKID_BARRIER=0; TABKID_SLED=0; TSW0=0; TSW1=0; TSW2=0;
    TSWKID0_BARRIER=0; TSWKID1_BARRIER=0; TSWKID2_BARRIER=0;
    TSWKID0_SLED=0; TSWKID1_SLED=0; TSWKID2_SLED=0;
    T_KID_SLED=0; T_KID_CAC=0;
    IF SWITCH_MM=1 THEN DO;  /* IF CAC VEHICLES, NOW WITHOUT SWITCH, STILL HAD THE SWITCH, AND IT WERE OFF, FEW-
ER LIVES WOULD BE SAVED */
          /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                          */
      IF 13 LE AGE LE 15 THEN U=.22;
        ELSE IF 16 LE AGE LE 19 THEN U=.17;
        ELSE IF 20 LE AGE LE 59 THEN U=.15;
        ELSE IF 60 LE AGE LE 69 THEN U=.19;
        ELSE IF AGE GE 70 THEN U=.56;
          T_ADULT_CAC=U*T_CAC; END;
    ELSE T_ADULT_CAC=0; GOTO T214A;

TRFUNR:    OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (TL226+TL214C)/OLDWTFA GT .07203 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.36016;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.18877;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.07203;
ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208I=S*PS208I/P;
    TLV208I=S*PV208I/P;
        T_BARRIER=S*P_BARRIER/P;
        T_SLED=S*P_SLED/P;
        T_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+TLS208I+TLV208I;
    TL208I=TLS208I+TLV208I;
    TLS=TLS+TLS208I; TLV=TLV+TLV208I; TL=TL+TL208I;
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    TABDRV=0; TABRF=TL208I; TABKID_BARRIER=0; TABKID_SLED=0; TSW0=0; TSW1=0; TSW2=0;
    TSWKID0_BARRIER=0; TSWKID1_BARRIER=0; TSWKID2_BARRIER=0;
    TSWKID0_SLED=0; TSWKID1_SLED=0; TSWKID2_SLED=0;
    T_KID_SLED=0; T_KID_CAC=0;
    IF SWITCH_MM=1 THEN DO;  /* IF CAC VEHICLES, NOW WITHOUT SWITCH, STILL HAD THE SWITCH, AND IT WERE OFF, FEW-
ER LIVES WOULD BE SAVED */
          /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                          */
      IF 13 LE AGE LE 15 THEN U=.22;
        ELSE IF 16 LE AGE LE 19 THEN U=.17;
        ELSE IF 20 LE AGE LE 59 THEN U=.15;
        ELSE IF 60 LE AGE LE 69 THEN U=.19;
        ELSE IF AGE GE 70 THEN U=.56;
          T_ADULT_CAC=U*T_CAC; END;
    ELSE T_ADULT_CAC=0; GOTO T214A;

TKID:      OLDWTFA=WEIGHTFA;
      IF KCRSH=1 AND RESTGP=1 THEN E=-4.5;  /* FATALITY INCREASE, BARRIER-CERT REL TO NO BAGS, DIRECT FRONTALS,
3 GPS OF YOUNG CHILDREN */
        ELSE IF KCRSH=1 AND RESTGP IN (2,3) THEN E=-1;
        ELSE IF KCRSH=1 AND RESTGP IN (4,5,6) THEN E=-.70;
        ELSE IF KCRSH IN (2,3) AND RESTGP=1 THEN E=-1.71; /* INCREASE IN OBLIQUE FRONTALS IS 62% LESS THAN IN
DIRECT FRONTALS */
        ELSE IF KCRSH IN (2,3) AND RESTGP IN (2,3) THEN E=-.38;
        ELSE IF KCRSH IN (2,3) AND RESTGP IN (4,5,6) THEN E=-.27;
        ELSE IF KCRSH=11 AND RESTGP=1 THEN E=-.77;  /* FATALITY INCREASE WITH SLED-CERTIFIED IS 83% LESS THAN
WITH BARRIER-CERTIFIED */
        ELSE IF KCRSH=11 AND RESTGP IN (2,3) THEN E=-.17;
        ELSE IF KCRSH=11 AND RESTGP IN (4,5,6) THEN E=-.12;
        ELSE IF KCRSH IN (12,13) AND RESTGP=1 THEN E=-.29;       /* SLED-CERTIFIED, OBLIQUE FRONTAL */
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (2,3) THEN E=-.06;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (4,5,6) THEN E=-.05;
        ELSE E=0;
    P=PS208I+PV208I;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208I=S*PS208I/P;
    TLV208I=S*PV208I/P;
        T_BARRIER=S*P_BARRIER/P;
        T_SLED=S*P_SLED/P;
        T_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+TLS208I+TLV208I;
    TL208I=TLS208I+TLV208I;
    TLS=TLS+TLS208I; TLV=TLV+TLV208I; TL=TL+TL208I;
    TABDRV=0; TABRF=0;
    IF KCRSH IN (1,2,3) THEN DO; TABKID_BARRIER=TL208I; TABKID_SLED=0; END;
          ELSE IF KCRSH IN (11,12,13) THEN DO; TABKID_BARRIER=0; TABKID_SLED=TL208I; END;
          ELSE DO; TABKID_BARRIER=0; TABKID_SLED=0; END;
    TSW0=0; TSW1=0; TSW2=0;
    TSWKID0_BARRIER=0; TSWKID1_BARRIER=0; TSWKID2_BARRIER=0;
    TSWKID0_SLED=0; TSWKID1_SLED=0; TSWKID2_SLED=0;
    T_KID_SLED=0; T_KID_CAC=0; T_ADULT_CAC=0;
    IF KCRSH IN (11,12,13,21,22,23) THEN DO;   /* ADD'L FATALITIES IF BAGS HAD BEEN 1st GEN RATHER THAN SLED OR
CAC */
        IF KCRSH IN (11) AND RESTGP=1 THEN E_HYP=-3.73;
        ELSE IF KCRSH IN (11) AND RESTGP IN (2,3) THEN E_HYP=-.83;
        ELSE IF KCRSH IN (11) AND RESTGP IN (4,5,6) THEN E_HYP=-.58;
        ELSE IF KCRSH IN (12,13) AND RESTGP=1 THEN E_HYP=-1.42;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (2,3) THEN E_HYP=-.32;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (4,5,6) THEN E_HYP=-.22;
        ELSE IF KCRSH IN (21) AND RESTGP=1 THEN E_HYP=-4.5;
        ELSE IF KCRSH IN (21) AND RESTGP IN (2,3) THEN E_HYP=-1;
        ELSE IF KCRSH IN (21) AND RESTGP IN (4,5,6) THEN E_HYP=-.70;
        ELSE IF KCRSH IN (21,23) AND RESTGP=1 THEN E_HYP=-1.71;
        ELSE IF KCRSH IN (21,23) AND RESTGP IN (2,3) THEN E_HYP=-.38;
        ELSE IF KCRSH IN (21,23) AND RESTGP IN (4,5,6) THEN E_HYP=-.27;
        ELSE E_HYP=0;
                IF KCRSH IN (11,12,13) THEN T_KID_SLED=-1*OLDWTFA*E_HYP;
                ELSE IF KCRSH IN (21,22,23) THEN T_KID_CAC=-1*OLDWTFA*E_HYP; END;
   GOTO T214A;

TRFBELSW:  OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (TL226+TL214C)/OLDWTFA GT .05557 THEN E=0;
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     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.27784;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.14563;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.05557;
ELSE E=0;

  /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                         */
    IF 13 LE AGE LE 15 THEN U=.22;
      ELSE IF 16 LE AGE LE 19 THEN U=.17;
      ELSE IF 20 LE AGE LE 59 THEN U=.15;
      ELSE IF 60 LE AGE LE 69 THEN U=.19;
      ELSE IF AGE GE 70 THEN U=.56;

    P=PS208I+PV208I;
    X=OLDWTFA/(1 - E*P + U*E*P);
    S=X - OLDWTFA;
    TLS208I=S*PS208I/P;
    TLV208I=S*PV208I/P;
        T_BARRIER=S*P_BARRIER/P;
        T_SLED=S*P_SLED/P;
        T_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+TLS208I+TLV208I;
    Y=X*(1-E);
    TSW1=X-Y;
    TSW2=Y-OLDWTFA;
    TL208I=TLS208I+TLV208I;
    TLS=TLS+TLS208I; TLV=TLV+TLV208I; TL=TL+TL208I;
    TSW0=TL208I;
    TABDRV=0; TABRF=0;
    TABKID_BARRIER=0; TABKID_SLED=0;
    TSWKID0_BARRIER=0; TSWKID1_BARRIER=0; TSWKID2_BARRIER=0;
    TSWKID0_SLED=0; TSWKID1_SLED=0; TSWKID2_SLED=0;
    T_KID_SLED=0; T_KID_CAC=0; T_ADULT_CAC=0; GOTO T214A;

TRFUNRSW:  OLDWTFA=WEIGHTFA;
    IF 1 LE M_HARM LE 6 OR CRSH IN (3,4) OR (TL226+TL214C)/OLDWTFA GT .07203 THEN E=0;
     /* ASSUME NO BENEFIT IF THE CRASH IS BASICALLY ROLLOVER/REAR/OTHER OR IF ROLLOVER CURTAINS/SIDE AIR
BAGS/SIDE STRUCTURE+PADDING SAVE LIVES. EXCEPTION: FRONTAL AIR BAG CAN HAVE BENEFIT (E.G. IN 2:00 OR 10:00) IF
THESE OTHERS HAVE LITTLE EFFECT  */
      ELSE IF IMPACT2=12 OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1=12) THEN E=.36016;
      ELSE IF IMPACT2 IN (.5,1,11,11.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11)) THEN E=.18877;
      ELSE IF IMPACT2 IN (1.5,2,10,10.5) OR (IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,10)) THEN E=.07203;
ELSE E=0;

  /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                         */
    IF 13 LE AGE LE 15 THEN U=.22;
      ELSE IF 16 LE AGE LE 19 THEN U=.17;
      ELSE IF 20 LE AGE LE 59 THEN U=.15;
      ELSE IF 60 LE AGE LE 69 THEN U=.19;
      ELSE IF AGE GE 70 THEN U=.56;

    P=PS208I+PV208I;
    X=OLDWTFA/(1 - E*P + U*E*P);
    S=X - OLDWTFA;
    TLS208I=S*PS208I/P;
    TLV208I=S*PV208I/P;
        T_BARRIER=S*P_BARRIER/P;
        T_SLED=S*P_SLED/P;
        T_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+TLS208I+TLV208I;
    Y=X*(1-E);
    TSW1=X-Y;
    TSW2=Y-OLDWTFA;
    TL208I=TLS208I+TLV208I;
    TLS=TLS+TLS208I; TLV=TLV+TLV208I; TL=TL+TL208I;
    TSW0=TL208I;
    TABDRV=0; TABRF=0;
    TABKID_BARRIER=0; TABKID_SLED=0;
    TSWKID0_BARRIER=0; TSWKID1_BARRIER=0; TSWKID2_BARRIER=0;
    TSWKID0_SLED=0; TSWKID1_SLED=0; TSWKID2_SLED=0;
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    T_KID_SLED=0; T_KID_CAC=0; T_ADULT_CAC=0; GOTO T214A;

TKIDSW:    OLDWTFA=WEIGHTFA;
      IF KCRSH=1 AND RESTGP=1 THEN E=-4.5;  /* FATALITY INCREASE, BARRIER-CERT REL TO NO BAGS, DIRECT FRONTALS,
3 GPS OF YOUNG CHILDREN */
        ELSE IF KCRSH=1 AND RESTGP IN (2,3) THEN E=-1;
        ELSE IF KCRSH=1 AND RESTGP IN (4,5,6) THEN E=-.70;
        ELSE IF KCRSH IN (2,3) AND RESTGP=1 THEN E=-1.71; /* INCREASE IN OBLIQUE FRONTALS IS 62% LESS THAN IN
DIRECT FRONTALS */
        ELSE IF KCRSH IN (2,3) AND RESTGP IN (2,3) THEN E=-.38;
        ELSE IF KCRSH IN (2,3) AND RESTGP IN (4,5,6) THEN E=-.27;
        ELSE IF KCRSH=11 AND RESTGP=1 THEN E=-.77;  /* FATALITY INCREASE WITH SLED-CERTIFIED IS 83% LESS THAN
WITH BARRIER-CERTIFIED */
        ELSE IF KCRSH=11 AND RESTGP IN (2,3) THEN E=-.17;
        ELSE IF KCRSH=11 AND RESTGP IN (4,5,6) THEN E=-.12;
        ELSE IF KCRSH IN (12,13) AND RESTGP=1 THEN E=-.29;        /* SLED-CERTIFIED, OBLIQUE FRONTAL */
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (2,3) THEN E=-.06;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (4,5,6) THEN E=-.05;
        ELSE E=0;

  /* USE RATES FOR ON-OFF SWITCHES BY PASSENGER AGE                         */
    IF AGE=0 THEN U=.86;
      ELSE IF 1 LE AGE LE 6 THEN U=.74;
      ELSE IF 7 LE AGE LE 8 THEN U=.59;
      ELSE IF 9 LE AGE LE 10 THEN U=.47;
      ELSE IF 11 LE AGE LE 12 THEN U=.30;

    P=PS208I+PV208I;
    X=OLDWTFA/(1 - E*P + U*E*P);
    S=X - OLDWTFA;
    TLS208I=S*PS208I/P;
    TLV208I=S*PV208I/P;
    TL208I=TLS208I+TLV208I;
    TLS=TLS+TLS208I; TLV=TLV+TLV208I; TL=TL+TL208I;
        T_BARRIER=S*P_BARRIER/P;
        T_SLED=S*P_SLED/P;
        T_CAC=S*P_CAC/P;
    WEIGHTFA=OLDWTFA+TLS208I+TLV208I;
    Y=X*(1-E);
        IF KCRSH IN (1,2,3) THEN DO;
      TSWKID1_BARRIER=X-Y; TSWKID1_SLED=0;
      TSWKID2_BARRIER=Y-OLDWTFA; TSWKID2_SLED=0;
      TSWKID0_BARRIER=TL208I; TSWKID0_SLED=0; END;
        ELSE IF KCRSH IN (11,12,13) THEN DO;
      TSWKID1_BARRIER=0; TSWKID1_SLED=X-Y;
      TSWKID2_BARRIER=0; TSWKID2_SLED=Y-OLDWTFA;
      TSWKID0_BARRIER=0; TSWKID0_SLED=TL208I; END;
        ELSE DO;
      TSWKID1_BARRIER=0; TSWKID1_SLED=0;
      TSWKID2_BARRIER=0; TSWKID2_SLED=0;
      TSWKID0_BARRIER=0; TSWKID0_SLED=0; END;
    TSW0=0; TSW1=0; TSW2=0; TABDRV=0; TABRF=0; TABKID_BARRIER=0; TABKID_SLED=0;
    TSWKID0=0; TSWKID1=0; TSWKID2=0;
    T_KID_SLED=0; T_KID_CAC=0; T_ADULT_CAC=0;
    IF KCRSH IN (11,12,13,21,22,23) THEN DO;   /* ADD'L FATALITIES IF BAGS HAD BEEN 1st GEN RATHER THAN SLED OR
CAC */
        IF KCRSH IN (11) AND RESTGP=1 THEN E_HYP=-3.73;
        ELSE IF KCRSH IN (11) AND RESTGP IN (2,3) THEN E_HYP=-.83;
        ELSE IF KCRSH IN (11) AND RESTGP IN (4,5,6) THEN E_HYP=-.58;
        ELSE IF KCRSH IN (12,13) AND RESTGP=1 THEN E_HYP=-1.42;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (2,3) THEN E_HYP=-.32;
        ELSE IF KCRSH IN (12,13) AND RESTGP IN (4,5,6) THEN E_HYP=-.22;
        ELSE IF KCRSH IN (21) AND RESTGP=1 THEN E_HYP=-4.5;
        ELSE IF KCRSH IN (21) AND RESTGP IN (2,3) THEN E_HYP=-1;
        ELSE IF KCRSH IN (21) AND RESTGP IN (4,5,6) THEN E_HYP=-.70;
        ELSE IF KCRSH IN (21,23) AND RESTGP=1 THEN E_HYP=-1.71;
        ELSE IF KCRSH IN (21,23) AND RESTGP IN (2,3) THEN E_HYP=-.38;
        ELSE IF KCRSH IN (21,23) AND RESTGP IN (4,5,6) THEN E_HYP=-.27;
        ELSE E_HYP=0;
                IF KCRSH IN (11,12,13) THEN T_KID_SLED=(U-1)*OLDWTFA*E_HYP;
                ELSE IF KCRSH IN (21,22,23) THEN T_KID_CAC=(U-1)*OLDWTFA*E_HYP; END;
```

```
/* ---------------------------------------------------------------- */
/*  214A SIDE DOOR BEAMS                                            */
/*  MEDIAN INSTALLATION YEAR: 1994  FMVSS EFFECTIVE DATE: 9/1/1993    */
/* ---------------------------------------------------------------- */
```

Side door beams were introduced in a few LTV models in 1991-93. All MY 1994 LTVs were equipped with them.

```
/* IDENTIFIES LTVs WITH SIDE DOOR BEAMS                       */
T214A: PS214A=0; PV214A=0;
  IF XMY LE 1990 THEN GOTO SAVE214T;
  IF XMY GE 1994 THEN DO; PS214A=1; GOTO SAVE214T; END;
  IF (XMM2 IN (12300:12303,41300,41301,20440,20442,21452,22442,49422,49423) OR CG IN (12303,12304,18405,49402))
      AND 1991 LE XMY LE 1993 THEN DO; PV214A=1; GOTO SAVE214T; END;
  IF (XMM2 IN (12410:12439,12610:12639) OR CG=12404)
      AND 1992 LE XMY LE 1993 THEN DO; PV214A=1; GOTO SAVE214T; END;
  IF (XMM2 IN (14450,14452,35450,35452,35240:35249,35300:35303,49313) OR CG IN (12405,35203,35204,35301,49303))
      AND XMY=1993 THEN DO; PV214A=1; GOTO SAVE214T; END;
  IF 1 LE XMM2 LE 65999 OR 1201 LE CG LE 63401 THEN GOTO SAVE214T;
  IF MAKE IN (12,14,20,21,22,35,41,49) THEN GOTO SOMEVOLT; GOTO SAVE214T;

SOMEVOLT: IF MAK_MOD IN (12401,41401,20442,21441,22441,49441)
    AND 1991 LE XMY LE 1993 THEN DO; PV214A=1; GOTO SAVE214T; END;
IF MAK_MOD=12461 AND 1992 LE XMY LE 1993 THEN DO; PV214A=1; GOTO SAVE214T; END;
IF MAK_MOD IN (14443,35443,35471,35401,49421) AND XMY=1993 THEN DO;
    PV214A=1; GOTO SAVE214T; END;

/* REDUCTION IN SINGLE-VEHICLE SIDE-IMPACT FATALITIES WITH SIDE DOOR BEAMS     */
SAVE214T: OLDWTFA=WEIGHTFA;
```

NHTSA’s evaluation showed side door beams are effective for outboard occupants in single-vehicle side-impact crashes. Fatality reduction is 26 percent for near-side occupants and 11 percent for far-side occupants.

```
  IF (PS214A GT 0 OR PV214A GT 0) AND CRSH=2 AND
      SEAT2 IN (11,13,21) AND VE_FORMS=1 THEN DO;
  IF (SEAT_POS IN (11,21) AND (IMPACT2 IN (8,8.5,9,9.5,10,61:63)
          OR (CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (8,9,10,61:63))) OR
        (SEAT_POS IN (13,23) AND IMPACT2 IN (2,2.5,3,3.5,4,81:83)
          OR (CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,3,4,81:83))))
      THEN E=.25; ELSE E=.11;
    P=PS214A+PV214A;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS214A=S*PS214A/P;
    TLV214A=S*PV214A/P;
    WEIGHTFA=OLDWTFA+TLS214A+TLV214A; END;
  ELSE DO; TLS214A=0; TLV214A=0; END;
  TL214A=TLS214A+TLV214A;
  TLS=TLS+TLS214A; TLV=TLV+TLV214A; TL=TL+TL214A;

/* ---------------------------------------------------------------- */
/*  208G 3-POINT BELTS FOR OUTBOARD REAR SEAT OCCUPANTS             */
/*  MEDIAN INSTALLATION YEAR: 1992  FMVSS EFFECTIVE DATE: 9/1/1991    */
/* ---------------------------------------------------------------- */

/* IDENTIFIES OUTBOARD REAR SEAT OCCUPANTS WEARING 3-POINT BELTS  */
  PS208G=0; PV208G=0;
  IF SEAT2=21 AND REST3=3 THEN DO; IF XMY LE 1991 THEN PV208G=1; ELSE PS208G=1; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY OUTBOARD-REAR-SEAT 3-POINT BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208G GT 0 OR PV208G GT 0 THEN DO;
```

Three-point belts in the outboard rear seats reduce fatality risk by 50 percent in frontals, 84 percent in rollovers and 70 percent in side, rear and other impacts.

```
    IF CRSH=1 THEN DO; E=.50; EJECT2=.48; END;
      ELSE IF CRSH=2 THEN DO; E=.70; EJECT2=.59; END;
      ELSE IF CRSH=3 THEN DO; E=.84; EJECT2=.85; END;
```

```
      ELSE IF CRSH=4 THEN DO; E=.70; EJECT2=.58; END;
    P=PS208G+PV208G;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208G=S*PS208G/P;
    TLV208G=S*PV208G/P;
    WEIGHTFA=OLDWTFA+TLS208G+TLV208G; END;
  ELSE DO; TLS208G=0; TLV208G=0; END;
  TL208G=TLS208G+TLV208G;
  TLS=TLS+TLS208G; TLV=TLV+TLV208G; TL=TL+TL208G;

/* ---------------------------------------------------------------- */
/*  213 CHILD SAFETY SEATS                                          */
/*  USE RATE WENT OVER 50% IN: 1985  FMVSS EFFECTIVE DATE: 4/1/1971   */
/* ---------------------------------------------------------------- */

/* IDENTIFIES CHILD PASSENGERS IN SAFETY SEATS  */
  PS213=0; PV213=0;
  IF REST3=4 THEN DO;
  IF STATE=1 THEN DO; IF CY=1982 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1; /* STATE LAWS IN EFFECT UP TO WHAT
AGE: ALABAMA */
    ELSE IF 1983 LE CY LE 2004 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2005 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=2 THEN DO; IF CY=1985 AND MONTH GE 6 AND AGE LE 3 THEN PS213=1;     /* ALASKA */
    ELSE IF 1986 LE CY LE 2007 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2008 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=4 THEN DO; IF CY=1983 AND MONTH GE 8 AND AGE LE 4 THEN PS213=1;      /* ARIZONA */
    ELSE IF 1984 LE CY LE 2010 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2011 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=5 THEN DO; IF CY=1983 AND MONTH GE 8 AND AGE LE 2 THEN PS213=1;      /* ARKANSAS */
    ELSE IF 1984 LE CY LE 1993 AND AGE LE 2 THEN PS213=1;
    ELSE IF 1994 LE CY LE 1997 AND AGE LE 3 THEN PS213=1;
    ELSE IF 1998 LE CY LE 2000 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2001 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=6 THEN DO; IF 1983 LE CY LE 2000 AND AGE LE 3 THEN PS213=1;         /* CALIFORNIA */
        ELSE IF CY GE 2001 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=8 THEN DO; IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;         /* COLORADO */
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=9 THEN DO; IF CY=1982 AND MONTH GE 5 AND AGE=0 THEN PS213=1;      /* CONNECTICUT */
    ELSE IF 1983 LE CY LE 1993 AND AGE=0 THEN PS213=1;
    ELSE IF CY=1982 AND MONTH GE 5 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
    ELSE IF 1983 LE CY LE 1993 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
    ELSE IF 1994 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=10 THEN DO; IF CY=1982 AND MONTH GE 6 AND AGE LE 3 THEN PS213=1;      /* DELAWARE */
    ELSE IF 1983 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
    ELSE IF 2002 LE CY LE 2003 AND AGE LE 5 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=11 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;      /* DC */
    ELSE IF 1984 LE CY LE 1997 AND AGE LE 2 THEN PS213=1;
    ELSE IF 1998 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2002 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=12 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1;      /* FLORIDA */
        ELSE IF CY GE 1984 AND AGE LE 3 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=13 THEN DO; IF CY=1984 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;      /* GEORGIA */
    ELSE IF 1985 LE CY LE 2002 AND AGE LE 2 THEN PS213=1;
    ELSE IF CY=2003 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=15 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;      /* HAWAII */
    ELSE IF 1984 LE CY LE 2003 AND AGE LE 2 THEN PS213=1;
    ELSE IF 2004 LE CY LE 2006 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=16 THEN DO; IF 1985 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;         /* IDAHO */
        ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=17 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1;     /* ILLINOIS */
    ELSE IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=18 THEN DO; IF 1984 LE CY LE 1997 AND AGE LE 2 THEN PS213=1;         /* INDIANA */
    ELSE IF 1998 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=19 THEN DO; IF 1985 LE CY LE 2003 AND AGE LE 2 THEN PS213=1;         /* IOWA */
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=20 THEN DO; IF 1982 LE CY LE 2004 AND AGE LE 3 THEN PS213=1;         /* KANSAS */
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      ELSE IF CY GE 2005 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=21 THEN DO; IF CY=1982 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;     /* KENTUCKY */
  ELSE IF 1983 LE CY LE 2006 AND AGE LE 2 THEN PS213=1;
      ELSE IF CY GE 2007 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=22 THEN DO; IF CY=1984 AND MONTH GE 9 AND AGE LE 2 THEN PS213=1;       /* LOUISIANA */
  ELSE IF 1985 LE CY LE 2003 AND AGE LE 2 THEN PS213=1;
  ELSE IF CY=1984 AND MONTH GE 9 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
  ELSE IF 1985 LE CY LE 2003 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=23 THEN DO; IF CY=1983 AND MONTH GE 9 AND AGE LE 3 THEN PS213=1;      /* MAINE */
  ELSE IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=24 THEN DO; IF 1984 LE CY LE 1992 AND AGE LE 2 THEN PS213=1;          /* MARYLAND */
  ELSE IF 1993 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
  ELSE IF 2002 LE CY LE 2006 AND AGE LE 5 THEN PS213=1;
      ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=25 THEN DO; IF 1982 LE CY LE 2006 AND AGE LE 4 THEN PS213=1;        /* MASSACHUSETTS */
      ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=26 THEN DO; IF CY=1982 AND MONTH GE 4 AND AGE=0 THEN PS213=1;         /* MICHIGAN */
  ELSE IF 1983 LE CY LE 1999 AND AGE=0 THEN PS213=1;
  ELSE IF CY=1982 AND MONTH GE 4 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
  ELSE IF 1983 LE CY LE 1999 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
      ELSE IF 2000 LE CY LE 2006 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=27 THEN DO; IF CY=1983 AND MONTH GE 8 AND AGE LE 3 THEN PS213=1;      /* MINNESOTA */
  ELSE IF 1984 LE CY LE 2007 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2008 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=28 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 1 THEN PS213=1;      /* MISSISSIPPI */
  ELSE IF 1984 LE CY LE 1993 AND AGE LE 1 THEN PS213=1;
  ELSE IF 1994 LE CY LE 2006 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2007 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=29 THEN DO; IF 1984 LE CY LE 2004 AND AGE LE 3 THEN PS213=1;         /* MISSOURI */
      ELSE IF CY GE 2005 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=30 THEN DO; IF 1984 LE CY LE 2003 AND AGE LE 1 THEN PS213=1;         /* MONTANA */
      ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=31 THEN DO; IF CY=1983 AND MONTH GE 8 AND AGE LE 3 THEN PS213=1;      /* NEBRASKA */
  ELSE IF 1984 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2002 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=32 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 4 THEN PS213=1;      /* NEVADA */
  ELSE IF 1984 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
  ELSE IF 2004 LE CY LE 2008 AND AGE LE 5 THEN PS213=1;
      ELSE IF CY GE 2009 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=33 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1;    /* NEW HAMPSHIRE */
  ELSE IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=34 THEN DO; IF CY=1983 AND MONTH GE 4 AND AGE=0 THEN PS213=1;         /* NEW JERSEY */
  ELSE IF 1984 LE CY LE 2001 AND AGE=0 THEN PS213=1;
  ELSE IF CY=1983 AND MONTH GE 4 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
  ELSE IF 1984 LE CY LE 2001 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
      ELSE IF CY GE 2002 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=35 THEN DO; IF CY=1983 AND MONTH GE 6 AND AGE=0 THEN PS213=1;         /* NEW MEXICO */
  ELSE IF 1984 LE CY LE 2001 AND AGE=0 THEN PS213=1;
  ELSE IF CY=1983 AND MONTH GE 6 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
  ELSE IF 1984 LE CY LE 2001 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
      ELSE IF 2002 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=36 THEN DO; IF CY=1982 AND MONTH GE 4 AND AGE LE 3 THEN PS213=1;      /* NEW YORK */
  ELSE IF 1983 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
  ELSE IF 2004 LE CY LE 2008 AND AGE LE 6 THEN PS213=1;
      ELSE IF CY GE 2009 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=37 THEN DO; IF CY=1982 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;   /* NORTH CAROLINA */
  ELSE IF 1983 LE CY LE 1992 AND AGE LE 2 THEN PS213=1;
  ELSE IF 1993 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
  ELSE IF 2002 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=38 THEN DO; IF 1984 LE CY LE 1998 AND AGE LE 2 THEN PS213=1;         /* NORTH DAKOTA */
  ELSE IF 1999 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2004 AND AGE LE 6 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=39 THEN DO; IF CY=1983 AND MONTH GE 3 AND AGE LE 3 THEN PS213=1;      /* OHIO */
  ELSE IF 1984 LE CY LE 2007 AND AGE LE 3 THEN PS213=1;
      ELSE IF CY GE 2008 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
ELSE IF STATE=40 THEN DO; IF CY=1983 AND MONTH GE 11 AND AGE LE 3 THEN PS213=1;      /* OKLAHOMA */
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    ELSE IF 1984 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=41 THEN DO; IF 1984 LE CY LE 1994 AND AGE=0 THEN PS213=1;              /* OREGON */
    ELSE IF 1995 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
    ELSE IF 2002 LE CY LE 2006 AND AGE LE 5 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=42 THEN DO; IF 1984 LE CY LE 1992 AND AGE=0 THEN PS213=1;           /* PENNSYLVANIA */
    ELSE IF 1984 LE CY LE 1992 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
    ELSE IF 1993 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=44 THEN DO; IF CY=1980 AND MONTH GE 7 AND AGE LE 3 THEN PS213=1;     /* RHODE ISLAND */
    ELSE IF 1981 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
    ELSE IF 2002 LE CY LE 2008 AND AGE LE 6 THEN PS213=1;
        ELSE IF CY GE 2009 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=45 THEN DO; IF CY=1983 AND MONTH GE 7 AND AGE=0 THEN PS213=1;      /* SOUTH CAROLINA */
    ELSE IF 1984 LE CY LE 2003 AND AGE=0 THEN PS213=1;
    ELSE IF CY=1983 AND MONTH GE 7 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
    ELSE IF 1984 LE CY LE 2003 AND SEAT2 IN (12,13,18) AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 5 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=46 THEN DO; IF CY=1984 AND MONTH GE 7 AND AGE LE 1 THEN PS213=1;     /* SOUTH DAKOTA */
    ELSE IF 1985 LE CY LE 1997 AND AGE LE 1 THEN PS213=1;
        ELSE IF CY GE 1998 AND AGE LE 4 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=47 THEN DO; IF 1978 LE CY LE 2003 AND AGE LE 3 THEN PS213=1;         /* TENNESSEE */
        ELSE IF CY GE 2004 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=48 THEN DO; IF CY=1984 AND MONTH GE 10 AND AGE LE 1 THEN PS213=1;      /* TEXAS */
    ELSE IF 1985 LE CY LE 2000 AND AGE LE 1 THEN PS213=1;
    ELSE IF 2001 LE CY LE 2007 AND AGE LE 2 THEN PS213=1;
        ELSE IF CY GE 2008 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=49 THEN DO; IF CY=1984 AND MONTH GE 7 AND AGE LE 1 THEN PS213=1;      /* UTAH */
    ELSE IF 1985 LE CY LE 1999 AND AGE LE 1 THEN PS213=1;
    ELSE IF 2000 LE CY LE 2006 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=50 THEN DO; IF CY=1984 AND MONTH GE 7 AND AGE=0 THEN PS213=1;         /* VERMONT */
    ELSE IF 1985 LE CY LE 1992 AND AGE=0 THEN PS213=1;
    ELSE IF CY=1984 AND MONTH GE 7 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
    ELSE IF 1985 LE CY LE 1992 AND SEAT2 IN (12,13,18) AND AGE LE 4 THEN PS213=1;
    ELSE IF 1993 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
    ELSE IF 2004 LE CY LE 2006 AND AGE LE 6 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=51 THEN DO; IF 1983 LE CY LE 1992 AND AGE LE 2 THEN PS213=1;          /* VIRGINIA */
    ELSE IF 1993 LE CY LE 2001 AND AGE LE 3 THEN PS213=1;
    ELSE IF 2002 LE CY LE 2006 AND AGE LE 5 THEN PS213=1;
        ELSE IF CY GE 2007 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=53 THEN DO; IF 1984 LE CY LE 1992 AND AGE=0 THEN PS213=1;       /* WASHINGTON STATE */
    ELSE IF 1993 LE CY LE 1995 AND AGE LE 1 THEN PS213=1;
    ELSE IF 1996 LE CY LE 2001 AND AGE LE 2 THEN PS213=1;
    ELSE IF 2002 LE CY LE 2003 AND AGE LE 5 THEN PS213=1;
    ELSE IF 2004 LE CY LE 2008 AND AGE LE 7 THEN PS213=1;
        ELSE IF CY GE 2009 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=54 THEN DO; IF CY=1981 AND MONTH GE 7 AND AGE LE 2 THEN PS213=1;    /* WEST VIRGINIA */
    ELSE IF 1982 LE CY LE 2003 AND AGE LE 2 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=55 THEN DO; IF CY=1982 AND MONTH GE 11 AND AGE LE 1 THEN PS213=1;      /* WISCONSIN */
    ELSE IF 1983 LE CY LE 2004 AND AGE LE 3 THEN PS213=1;
        ELSE IF CY GE 2005 AND AGE LE 7 THEN PS213=1; ELSE PV213=1; END;
  ELSE IF STATE=56 THEN DO; IF CY=1985 AND MONTH GE 4 AND AGE LE 2 THEN PS213=1;      /* WYOMING */
    ELSE IF 1986 LE CY LE 1996 AND AGE LE 2 THEN PS213=1;
    ELSE IF 1997 LE CY LE 2003 AND AGE LE 4 THEN PS213=1;
        ELSE IF CY GE 2004 AND AGE LE 8 THEN PS213=1; ELSE PV213=1; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY CHILD SAFETY SEATS */
  OLDWTFA=WEIGHTFA;
  IF PS213 GT 0 OR PV213 GT 0 THEN DO;
```

NHTSA’s evaluation estimates that safety seats reduce fatality risk by 58 percent for infants and by 59 percent for toddlers. Effectiveness is not estimated separately by crash mode. In general, 34 percent of unrestrained child passenger fatalities in frontal crashes were ejected, 48 percent in side impacts, 79 percent in rollovers and 42 percent in rear/other impacts.

```
    IF AGE=0 THEN E=.58; ELSE E=.59;
    IF CRSH=1 THEN EJECT2=.34;
      ELSE IF CRSH=2 THEN EJECT2=.48;
```

```
      ELSE IF CRSH=3 THEN EJECT2=.79;
      ELSE IF CRSH=4 THEN EJECT2=.42;
    P=PS213+PV213;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS213=S*PS213/P;
    TLV213=S*PV213/P;
    WEIGHTFA=OLDWTFA+TLS213+TLV213; END;
  ELSE DO; TLS213=0; TLV213=0; END;
  TL213=TLS213+TLV213;
  TLS=TLS+TLS213; TLV=TLV+TLV213; TL=TL+TL213;

/* ------------------------------------------------------------------ */
/*  212 ADHESIVE WINDSHIELD BONDING                                   */
/*  MEDIAN INSTALLATION YEAR: 1980  FMVSS EFFECTIVE DATE: 9/1/1978    */
/* ------------------------------------------------------------------ */

/* IDENTIFIES LTVs WITH ADHESIVE WINDSHIELD BONDING        */
```

FMVSS No. 212 took effect in LTVs on September 1, 1978. However, many LTVs had rubber gasket installations that complied with the standard. The transition to adhesive bonding began shortly before the standard and continued for several years afterward.

```
  IF XMY LE 1977 THEN DO; PS212=0; PV212=0; END;
    ELSE IF XMY GE 1985 THEN DO; PS212=1; PV212=0; END;
    ELSE IF XMY=1978 THEN DO; PS212=0; PV212=.2; END;
    ELSE IF XMY=1979 THEN DO; PS212=.4; PV212=0; END;
    ELSE IF XMY=1980 THEN DO; PS212=.5; PV212=0; END;
    ELSE IF XMY=1981 THEN DO; PS212=.6; PV212=0; END;
    ELSE IF XMY=1982 THEN DO; PS212=.7; PV212=0; END;
    ELSE IF XMY=1983 THEN DO; PS212=.8; PV212=0; END;
    ELSE IF XMY=1984 THEN DO; PS212=.9; PV212=0; END;
/* REDUCTION IN EJECTION FATALITY RISK WITH ADHESIVE WINDSHIELD BONDING */
  OLDWTFA=WEIGHTFA;
```

NCSS data show that the proportion of ejections that are via the windshield portal is about the same in LTVs with rubber gaskets as in cars with rubber gaskets. We will assume that adhesive bonding has the same percentage effect on ejection fatalities in LTVs as in cars.

```
  IF (PS212 GT 0 OR PV212 GT 0) AND SEAT2 IN (11,12,13,18) AND EJECT2 NE 0 THEN DO;
    IF CRSH IN (1,3) THEN E=.033;
      ELSE IF CRSH IN (2,4) THEN E=.0075;
    P=PS212+PV212;
    REL_S=EJECT2*E*P / (1 - E*P);
    S=OLDWTFA*REL_S;
    TLS212=S*PS212/P;
    TLV212=S*PV212/P;
    WEIGHTFA=OLDWTFA+TLS212+TLV212;
    EJECT2=(EJECT2 + REL_S)/(1 + REL_S); END;
  ELSE DO; TLS212=0; TLV212=0; END;
  TL212=TLS212+TLV212;
  TLS=TLS+TLS212; TLV=TLV+TLV212; TL=TL+TL212;

/* ------------------------------------------------------------------ */
/*  208F 3-POINT BELTS FOR FRONT-SEAT OUTBOARD OCCUPANTS              */
/*  MEDIAN INSTALLATION YEAR: 1977  FMVSS EFFECTIVE DATE: 9/1/1976    */
/* ------------------------------------------------------------------ */

/* IDENTIFIES FRONT SEAT OCCUPANTS WEARING 3-POINT BELTS  */
  PS208F=0; PV208F=0;
  IF SEAT2 IN (11,13) AND REST3=3 THEN DO; IF XMY LE 1976 THEN PV208F=1;
    ELSE IF 1977 LE XMY LE 1981 AND NEWVTYP IN (12,13) THEN PV208F=1;
    ELSE PS208F=1; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY OUTBOARD FRONT SEAT 3-POINT BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208F GT 0 OR PV208F GT 0 THEN DO;
```

In LTVs, 3-point belts reduce fatality risk by 64 percent in single-vehicle frontals, 40 percent in multi-vehicle frontals; 47 percent in single-vehicle near-side; 36 percent in multivehicle near-side; 61 percent in single-vehicle far-side; 54 percent in multivehicle far-side; 80 percent in rollovers; and 81 percent in rear/other impacts.

```
    IF CRSH=1 AND VE_FORMS=1 THEN DO; E=.64; EJECT2=.42; END;
      ELSE IF CRSH=1 THEN DO; E=.40; EJECT2=.24; END;
      ELSE IF CRSH=2 THEN DO;
        IF VE_FORMS=1 AND
          ((SEAT2=11 AND IMPACT2 IN (8,8.5,9,9.5,10,26,61:63))
            OR (SEAT2=13 AND IMPACT2 IN (2,2.5,3,3.5,4,26,81:83)) OR
          (SEAT2=11 AND CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (8,9,10,61:63)) OR
          (SEAT2=13 AND CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,3,4,81:83)))
          THEN DO; E=.47; EJECT2=.44; END;
        ELSE IF ((SEAT2=11 AND IMPACT2 IN (8,8.5,9,9.5,10,26,61:63))
            OR (SEAT2=13 AND IMPACT2 IN (2,2.5,3,3.5,4,26,81:83)) OR
          (SEAT2=11 AND CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (8,9,10,61:63)) OR
          (SEAT2=13 AND CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (2,3,4,81:83)))
          THEN DO; E=.36; EJECT2=.37; END;
        ELSE IF VE_FORMS=1 THEN DO; E=.61; EJECT2=.49; END;
        ELSE DO; E=.54; EJECT2=.41; END; END;
      ELSE IF CRSH=3 THEN DO; E=.80; EJECT2=.77; END;
      ELSE IF CRSH=4 THEN DO; E=.81; EJECT2=.51; END;
    P=PS208F+PV208F;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208F=S*PS208F/P;
    TLV208F=S*PV208F/P;
    WEIGHTFA=OLDWTFA+TLS208F+TLV208F; END;
  ELSE DO; TLS208F=0; TLV208F=0; END;
  TL208F=TLS208F+TLV208F;
  TLS=TLS+TLS208F; TLV=TLV+TLV208F; TL=TL+TL208F;

/* ----------------------------------------------------------------- */
/*  203 ENERGY-ABSORBING AND TELESCOPING STEERING ASSEMBLIES          */
/*  MEDIAN IMPLEMENTATION YEAR: 1975  FMVSS EFFECTIVE: 9/1/1981       */
/* ----------------------------------------------------------------- */

/* IDENTIFIES LTVs WITH ENERGY-ABSORBING STEERING ASSEMBLIES      */
  PS203=0; PV203=0;
  IF XMY GE 1970 AND SEAT2=11 THEN DO;
```

The introduction date for energy-absorbing steering assemblies in LTVs depends on the manufacturer and the truck type (pickup, SUV or van).

```
      IF XMY GE 1982 THEN PS203=1;
        ELSE IF MAKE=30 THEN PV203=1;
        ELSE IF MAKE IN (2,20,23) AND XMY GE 1973 THEN PV203=1;
        ELSE IF MAKE IN (7,9) AND NEWVTYP IN (11,12) AND XMY GE 1977 THEN PV203=1;
        ELSE IF MAKE IN (7,9) AND XMY GE 1979 THEN PV203=1;
        ELSE IF MAKE=12 AND NEWVTYP IN (11,12) AND XMY GE 1980 THEN PV203=1; END;
/* LIVES SAVED IN FRONTAL IMPACTS BY INSTRUMENT PANEL IMPROVEMENTS */
  OLDWTFA=WEIGHTFA;
  IF PS203 GT 0 OR PV203 GT 0 THEN DO;
```

NHTSA’s evaluations suggest that energy-absorbing steering assemblies are about equally effective in LTVs and cars.

```
    IF IMPACT2 IN (11,11.5,12,12.5,1) OR (CY GE 2010 AND IMPACT2 IN (.,14:18,98,99) AND IMPACT1 IN (1,11,12))
      THEN E=.121; ELSE E=0;
    P=PS203+PV203;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS203=S*PS203/P;
    TLV203=S*PV203/P;
    WEIGHTFA=OLDWTFA+TLS203+TLV203; END;
  ELSE DO; TLS203=0; TLV203=0; END;
  TL203=TLS203+TLV203;
  TLS=TLS+TLS203; TLV=TLV+TLV203; TL=TL+TL203;

/* ----------------------------------------------------------------- */
/*  201A VOLUNTARY INSTRUMENT PANEL IMPROVEMENTS (FMVSS-201 INSPIRED) */
/*  MEDIAN IMPLEMENTATION YEAR: 1972                                  */
```

```
/*  FMVSS EFFECTIVE: 9/1/1981 (BUT DIDN'T REQUIRE THESE IMPROVEMENTS) */
/* ------------------------------------------------------------------ */

/* INSTRUMENT PANELS WERE GRADUALLY IMPROVED FROM 1969 TO 1977    */
  PS201A=0; PV201A=0;
```

NHTSA's evaluation suggests that LTVs received the same types of instrument panel modifications as cars, and that they were gradually introduced, perhaps over a 1969-77 timeframe. NHTSA has no details about specific make-models.

```
  IF XMY GE 1969 AND SEAT2=13 THEN DO;
      IF XMY GE 1977 THEN PV201A=1;
        ELSE PV201A=.125*(XMY-1968); END;
/* LIVES SAVED IN FRONTAL IMPACTS BY INSTRUMENT PANEL IMPROVEMENTS */
  OLDWTFA=WEIGHTFA;
  IF PS201A GT 0 OR PV201A GT 0 THEN DO;
```

NHTSA's evaluation found the instrument panel improvements to be about equally effective in LTVs and cars.

```
    IF CRSH=1 AND REST3 NE 2 THEN E=.159; ELSE E=0;
    P=PS201A+PV201A;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS201A=S*PS201A/P;
    TLV201A=S*PV201A/P;
    WEIGHTFA=OLDWTFA+TLS201A+TLV201A; END;
  ELSE DO; TLS201A=0; TLV201A=0; END;
  TL201A=TLS201A+TLV201A;
  TLS=TLS+TLS201A; TLV=TLV+TLV201A; TL=TL+TL201A;

/* ------------------------------------------------------------------ */
/*  105B FRONT DISC BRAKES                                            */
/*  MEDIAN INSTALLATION YEAR: 1971 (INSTALLATION COMPLETED 1977)      */
/*  FMVSS EFFECTIVE DATE: 9/1/1983                                    */
/* ------------------------------------------------------------------ */

/* IMPLEMENTATION OF FRONT DISC BRAKES */
```

We believe the timeframe for introducing front disc brakes was approximately the same for LTVs as cars; we are using the same implementation schedule as for cars. (However, FMVSS No. 105 was not extended to LTVs until September 1, 1983.)

```
  IF XMY GE 1984 THEN DO; PS105B=1; PV105B=0; END;
    ELSE IF XMY LE 1964 THEN DO; PS105B=0; PV105B=0; END;
    ELSE IF XMY=1965 THEN DO; PS105B=0; PV105B=.02; END;
    ELSE IF XMY=1966 THEN DO; PS105B=0; PV105B=.03; END;
    ELSE IF XMY=1967 THEN DO; PS105B=0; PV105B=.06; END;
    ELSE IF XMY=1968 THEN DO; PS105B=0; PV105B=.13; END;
    ELSE IF XMY=1969 THEN DO; PS105B=0; PV105B=.28; END;
    ELSE IF XMY=1970 THEN DO; PS105B=0; PV105B=.41; END;
    ELSE IF XMY=1971 THEN DO; PS105B=0; PV105B=.63; END;
    ELSE IF XMY=1972 THEN DO; PS105B=0; PV105B=.74; END;
    ELSE IF XMY=1973 THEN DO; PS105B=0; PV105B=.86; END;
    ELSE IF XMY=1974 THEN DO; PS105B=0; PV105B=.84; END;
    ELSE IF XMY=1975 THEN DO; PS105B=0; PV105B=.93; END;
    ELSE IF XMY=1976 THEN DO; PS105B=0; PV105B=.99; END;
    ELSE IF 1977 LE XMY LE 1983 THEN DO; PS105B=0; PV105B=1; END;
/* LTV OCCUPANT LIVES SAVED BY FRONT DISC BRAKES */
  OLDWTFA=WEIGHTFA;
  IF PS105B GT 0 OR PV105B GT 0 THEN DO;
    E=.0017;
    P=PS105B+PV105B;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS105B=S*PS105B/P;
    TLV105B=S*PV105B/P;
    WEIGHTFA=OLDWTFA+TLS105B+TLV105B; END;
  ELSE DO; TLS105B=0; TLV105B=0; END;
  TL105B=TLS105B+TLV105B;
```

```
  TLS=TLS+TLS105B; TLV=TLV+TLV105B; TL=TL+TL105B;

/* ------------------------------------------------------------------ */
/*  208E LAP BELTS FOR CENTER REAR SEAT OCCUPANTS                     */
/*  MEDIAN INSTALLATION YEAR: 1968  FMVSS EFFECTIVE DATE: 7/1/1971    */
/* ------------------------------------------------------------------ */

/* IDENTIFIES CENTER REAR SEAT OCCUPANTS WEARING LAP BELTS  */
  PS208E=0; PV208E=0;
  IF SEAT2=22 AND REST3=2 AND (5 LE AGE LE 99 OR AGE=.) THEN DO;
```

The original FMVSS No. 208 requirement for lap belts at all designated seating positions was extended to LTVs effective July 1, 1971.

```
     IF XMY GE 1972 THEN PS208E=1;
       ELSE IF XMY LE 1970 THEN PV208E=1;
       ELSE IF XMY=1971 THEN DO; PS208E=.17; PV208E=.83; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY CENTER-REAR-SEAT LAP BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208E GT 0 OR PV208E GT 0 THEN DO;
```

Lap belts in the outboard rear seats reduce fatality risk by 44 percent in frontals, 80 percent in rollovers and 64 percent in side, rear and other impacts. The same effectiveness is assumed for the center rear seat.

```
    IF CRSH=1 THEN DO; E=.44; EJECT2=.49; END;
      ELSE IF CRSH=2 THEN DO; E=.64; EJECT2=.59; END;
      ELSE IF CRSH=3 THEN DO; E=.80; EJECT2=.85; END;
      ELSE IF CRSH=4 THEN DO; E=.64; EJECT2=.58; END;
    P=PS208E+PV208E;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208E=S*PS208E/P;
    TLV208E=S*PV208E/P;
    WEIGHTFA=OLDWTFA+TLS208E+TLV208E; END;
  ELSE DO; TLS208E=0; TLV208E=0; END;
  TL208E=TLS208E+TLV208E;
  TLS=TLS+TLS208E; TLV=TLV+TLV208E; TL=TL+TL208E;
```

Even though lap belts for center rear seat passengers and the next two technologies, lap belts for center front seat passengers and lap belts for outboard rear seat passengers have approximately the same median installation year in LTVs, 1968, it makes no difference what their sequential order is in the model. Only one of these technologies can apply to any occupant: a properly seated, belted person cannot be in two different seating positions at the same time.

```
/* ------------------------------------------------------------------ */
/*  208D LAP BELTS FOR CENTER FRONT SEAT PASSENGERS                   */
/*  MEDIAN INSTALLATION YEAR: 1968  FMVSS EFFECTIVE DATE: 7/1/1971    */
/* ------------------------------------------------------------------ */

/* IDENTIFIES CENTER FRONT SEAT PASSENGERS WEARING LAP BELTS  */
  PS208D=0; PV208D=0;
  IF SEAT2=12 AND REST3=2 AND (5 LE AGE LE 99 OR AGE=.) THEN DO;
     IF XMY GE 1972 THEN PS208D=1;
       ELSE IF XMY LE 1970 THEN PV208D=1;
       ELSE IF XMY=1971 THEN DO; PS208D=.17; PV208D=.83; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY CENTER-FRONT-SEAT LAP BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208D GT 0 OR PV208D GT 0 THEN DO;
```

A double-pair comparison analysis of lap belt effectiveness for outboard front seat occupants, conducted in support of the 2004 “lives saved” report, found that lap belts reduce fatality risk by 48 percent in LTVs. There were not enough data for separate effectiveness estimates by crash mode. This effectiveness will also be assumed for the center front seat passenger.

```
    E=.48;
```

```
    IF CRSH=1 THEN EJECT2=.33; ELSE IF CRSH=2 THEN EJECT2=.38;
      ELSE IF CRSH=3 THEN EJECT2=.72; ELSE IF CRSH=4 THEN EJECT2=.53;
    P=PS208D+PV208D;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208D=S*PS208D/P;
    TLV208D=S*PV208D/P;
    WEIGHTFA=OLDWTFA+TLS208D+TLV208D; END;
  ELSE DO; TLS208D=0; TLV208D=0; END;
  TL208D=TLS208D+TLV208D;
  TLS=TLS+TLS208D; TLV=TLV+TLV208D; TL=TL+TL208D;

/* ---------------------------------------------------------------- */
/*  208C LAP BELTS FOR OUTBOARD REAR SEAT OCCUPANTS                  */
/*  MEDIAN INSTALLATION YEAR: LATE 67  FMVSS EFFECTIVE DATE: 7/1/1971 */
/* ---------------------------------------------------------------- */

/* IDENTIFIES OUTBOARD REAR SEAT OCCUPANTS WEARING LAP BELTS  */
  PS208C=0; PV208C=0;
  IF SEAT2=21 AND REST3=2 AND (5 LE AGE LE 99 OR AGE=.) THEN DO;
     IF XMY GE 1972 THEN PS208C=1;
       ELSE IF XMY LE 1970 THEN PV208C=1;
       ELSE IF XMY=1971 THEN DO; PS208C=.17; PV208C=.83; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY OUTBOARD-REAR-SEAT LAP BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208C GT 0 OR PV208C GT 0 THEN DO;
```

Lap belts in the outboard rear seats reduce fatality risk by 44 percent in frontals, 80 percent in rollovers and 64 percent in side, rear and other impacts.

```
    IF CRSH=1 THEN DO; E=.44; EJECT2=.48; END;
      ELSE IF CRSH=2 THEN DO; E=.64; EJECT2=.59; END;
      ELSE IF CRSH=3 THEN DO; E=.80; EJECT2=.85; END;
      ELSE IF CRSH=4 THEN DO; E=.64; EJECT2=.58; END;
    P=PS208C+PV208C;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208C=S*PS208C/P;
    TLV208C=S*PV208C/P;
    WEIGHTFA=OLDWTFA+TLS208C+TLV208C; END;
  ELSE DO; TLS208C=0; TLV208C=0; END;
  TL208C=TLS208C+TLV208C;
  TLS=TLS+TLS208C; TLV=TLV+TLV208C; TL=TL+TL208C;

/* ---------------------------------------------------------------- */
/*  206 DOOR LOCK IMPROVEMENTS                                       */
/*  MEDIAN INSTALLATION YEAR: 1967  FMVSS EFFECTIVE DATE: 1/1/1972   */
/* ---------------------------------------------------------------- */

/* DOOR LOCKS IMPROVED GRADUALLY FROM 1962 TO 1972       */
```

FMVSS No. 206 took effect on January 1, 1972 in LTVs (and on January 1, 1968, in cars). Door lock improvements were gradually introduced in cars from MY 1962 until MY 1968, the year the standard took effect. We will assume that LTV door locks received comparable improvements, also starting about 1962 but extending until the 1972 effective date.

```
  IF XMY GE 1973 THEN DO; PS206=1; PV206=0; END;
    ELSE IF XMY=1972 THEN DO; PS206=.5; PV206=.5; END;
    ELSE IF 1962 LE XMY LE 1971 THEN DO; PS206=0; PV206=(XMY-1961)/11; END;
    ELSE IF XMY LE 1961 THEN DO; PS206=0; PV206=0; END;
/* REDUCTION IN EJECTION ROLLOVER FATALITY RISK WITH IMPROVED DOOR LOCKS */
  OLDWTFA=WEIGHTFA;
  IF (PS206 GT 0 OR PV206 GT 0) AND (CRSH=3 OR M_HARM=1)
      AND SEAT2 NE 52 AND EJECT2 NE 0 THEN DO;
```

In passenger cars, the reduction of ejection fatalities in rollovers was 15.38 percent. However, in NCSS, 32.11 percent of ejection fatalities in rollovers in cars were through doors, but only 20.45 percent in LTVs. Thus, the effectiveness in LTVs is estimated to be (.2045/.3211) x .1538 = 9.8 percent (excluding occupants riding in the beds of pickups or elsewhere outside the passenger compartment).

```
    E=.098;
    P=PS206+PV206;
    REL_S=EJECT2*E*P / (1 - E*P);
    S=OLDWTFA*REL_S;
    TLS206=S*PS206/P;
    TLV206=S*PV206/P;
    WEIGHTFA=OLDWTFA+TLS206+TLV206;
    EJECT2=(EJECT2 + REL_S)/(1 + REL_S); END;
  ELSE DO; TLS206=0; TLV206=0; END;
  TL206=TLS206+TLV206;
  TLS=TLS+TLS206; TLV=TLV+TLV206; TL=TL+TL206;

/* ----------------------------------------------------------------- */
/*  105A DUAL MASTER CYLINDERS                                       */
/*  MEDIAN INSTALLATION YEAR: LATE 1966  FMVSS EFFECTIVE: 9/1/1983    */
/* ----------------------------------------------------------------- */

/* IMPLEMENTATION OF DUAL MASTER CYLINDERS */
```

We believe the timeframe for introducing dual master cylinders was approximately the same for LTVs as cars; we are using the same implementation schedule as for cars. (However, FMVSS No. 105 was not extended to LTVs until September 1, 1983.)

```
  IF XMY GE 1984 THEN DO; PS105A=1; PV105A=0; END;
    ELSE IF XMY LE 1961 THEN DO; PS105A=0; PV105A=0; END;
    ELSE IF XMY IN (1962,1963) THEN DO; PS105A=0; PV105A=.09; END;
    ELSE IF XMY IN (1964,1965) THEN DO; PS105A=0; PV105A=.07; END;
    ELSE IF XMY=1966 THEN DO; PS105A=0; PV105A=.54; END;
    ELSE IF 1967 LE XMY LE 1983 THEN DO; PS105A=0; PV105A=1; END;
/* LTV OCCUPANT LIVES SAVED BY DUAL MASTER CYLINDERS */
  OLDWTFA=WEIGHTFA;
  IF PS105A GT 0 OR PV105A GT 0 THEN DO;
    E=.007;
    P=PS105A+PV105A;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS105A=S*PS105A/P;
    TLV105A=S*PV105A/P;
    WEIGHTFA=OLDWTFA+TLS105A+TLV105A; END;
  ELSE DO; TLS105A=0; TLV105A=0; END;
  TL105A=TLS105A+TLV105A;
  TLS=TLS+TLS105A; TLV=TLV+TLV105A; TL=TL+TL105A;

/* ----------------------------------------------------------------- */
/*  208B LAP BELT USE BY CHILDREN AGE 1-4                            */
/*  MEDIAN INSTALLATION YEAR FOR LAP BELTS USED BY CHILDREN: 1966     */
/*  FMVSS EFFECTIVE DATE: 7/1/1971                                   */
/* ----------------------------------------------------------------- */

/* IDENTIFIES CHILD PASSENGERS AGE 1-4 USING LAP BELTS */
  PS208B=0; PV208B=0;
  IF 1 LE AGE LE 4 AND REST3=2 THEN DO;
     IF XMY GE 1972 THEN PS208B=1;
       ELSE IF XMY LE 1970 THEN PV208B=1;
       ELSE IF XMY=1971 THEN DO; PS208B=.17; PV208B=.83; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY LAP BELTS (AGE 1-4) */
  OLDWTFA=WEIGHTFA;
  IF PS208B GT 0 OR PV208B GT 0 THEN DO;
```

NHTSA's evaluation estimates that lap belts reduce fatality risk by 48 percent for toddlers in LTVs. Effectiveness is not estimated separately by crash mode.[629]

```
    E=.48;
    IF CRSH=1 THEN EJECT2=.34; ELSE IF CRSH=2 THEN EJECT2=.48;
      ELSE IF CRSH=3 THEN EJECT2=.79; ELSE IF CRSH=4 THEN EJECT2=.42;
```

[629] This evaluation is discussed in the "Child Safety Seats" section of the FMVSS 213 chapter of Part 1, not the FMVSS 208 chapter.

```
    P=PS208B+PV208B;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208B=S*PS208B/P;
    TLV208B=S*PV208B/P;
    WEIGHTFA=OLDWTFA+TLS208B+TLV208B; END;
  ELSE DO; TLS208B=0; TLV208B=0; END;
  TL208B=TLS208B+TLV208B;
  TLS=TLS+TLS208B; TLV=TLV+TLV208B; TL=TL+TL208B;

/* ----------------------------------------------------------------- */
/*  208A LAP BELTS FOR FRONT-SEAT OUTBOARD OCCUPANTS                 */
/*  MEDIAN INSTALLATION YEAR: 1964  FMVSS EFFECTIVE DATE: 7/1/1971    */
/* ----------------------------------------------------------------- */

/* IDENTIFIES OUTBOARD FRONT SEAT OCCUPANTS WEARING LAP BELTS  */
  PS208A=0; PV208A=0;
  IF SEAT2 IN (11,13) AND REST3=2 AND (5 LE AGE LE 99 OR AGE=.) THEN DO;
     IF XMY GE 1972 THEN PS208A=1;
       ELSE IF XMY LE 1970 THEN PV208A=1;
       ELSE IF XMY=1971 THEN DO; PS208A=.17; PV208A=.83; END; END;
/* LIVES SAVED AND EJECTIONS PREVENTED BY OUTBOARD-FRONT-SEAT LAP BELTS */
  OLDWTFA=WEIGHTFA;
  IF PS208A GT 0 OR PV208A GT 0 THEN DO;
```

A double-pair comparison analysis of lap belt effectiveness for outboard front seat occupants, conducted in support of the 2004 "lives saved" report, found that lap belts reduce fatality risk by 48 percent in LTVs. There were not enough data for separate effectiveness estimates by crash mode.

```
    E=.48;
    IF CRSH=1 THEN EJECT2=.34; ELSE IF CRSH=2 THEN EJECT2=.42;
      ELSE IF CRSH=3 THEN EJECT2=.77; ELSE IF CRSH=4 THEN EJECT2=.51;
    P=PS208A+PV208A;
    S=OLDWTFA*E*P / (1 - E*P);
    TLS208A=S*PS208A/P;
    TLV208A=S*PV208A/P;
    WEIGHTFA=OLDWTFA+TLS208A+TLV208A; END;
  ELSE DO; TLS208A=0; TLV208A=0; END;
  TL208A=TLS208A+TLV208A;
  TLS=TLS+TLS208A; TLV=TLV+TLV208A; TL=TL+TL208A;
RUN;
```

That concludes the model for LTVs. It has estimated, on a case-by-case basis, by how much fatalities would increase if all the safety technologies were "removed" from vehicles. The next step is to tally up the lives saved over all the cases, by CY.

```
PROC MEANS SUM NOPRINT DATA=TRK2; BY CY;
  VAR ORIGWT WEIGHTFA
    TLV226 TLS226 TL226
        TLV214C TLS214C TL214C T_TORSO T_COMBO T_CURTAIN T_CURT_TORS
        TLV126 TLS126 TL126
        TLV301 TLS301 TL301
    TLV208J TLS208J TL208J
    TLV208K TLS208K TL208K
        TLV201B TLS201B TL201B
    TLV108 TLS108 TL108
    TLV208I TLS208I TL208I T_BARRIER T_SLED T_CAC
    TLV214A TLS214A TL214A
    TLV208G TLS208G TL208G
    TLV213 TLS213 TL213
    TLV212 TLS212 TL212
    TLV208F TLS208F TL208F
    TLV203 TLS203 TL203
    TLV201A TLS201A TL201A
    TLV105B TLS105B TL105B
    TLV208E TLS208E TL208E
    TLV208D TLS208D TL208D
    TLV208C TLS208C TL208C
    TLV206 TLS206 TL206
    TLV105A TLS105A TL105A
```

```
    TLV208B TLS208B TL208B
    TLV208A TLS208A TL208A
    TABDRV TABRF TABKID_BARRIER TABKID_SLED TSW0 TSW1 TSW2
    TSWKID0_BARRIER TSWKID1_BARRIER TSWKID2_BARRIER
    TSWKID0_SLED TSWKID1_SLED TSWKID2_SLED
        T_KID_SLED T_KID_CAC T_ADULT_CAC
    TLV TLS TL;
  OUTPUT OUT=TRK3
    SUM=T_ORIGWT T_WTFA
    TLV226 TLS226 TL226
        TLV214C TLS214C TL214C T_TORSO T_COMBO T_CURTAIN T_CURT_TORS
        TLV126 TLS126 TL126
        TLV301 TLS301 TL301
    TLV208J TLS208J TL208J
    TLV208K TLS208K TL208K
        TLV201B TLS201B TL201B
    TLV108 TLS108 TL108
    TLV208I TLS208I TL208I T_BARRIER T_SLED T_CAC
    TLV214A TLS214A TL214A
    TLV208G TLS208G TL208G
    TLV213 TLS213 TL213
    TLV212 TLS212 TL212
    TLV208F TLS208F TL208F
    TLV203 TLS203 TL203
    TLV201A TLS201A TL201A
    TLV105B TLS105B TL105B
    TLV208E TLS208E TL208E
    TLV208D TLS208D TL208D
    TLV208C TLS208C TL208C
    TLV206 TLS206 TL206
    TLV105A TLS105A TL105A
    TLV208B TLS208B TL208B
    TLV208A TLS208A TL208A
    TABDRV TABRF TABKID_BARRIER TABKID_SLED TSW0 TSW1 TSW2
    TSWKID0_BARRIER TSWKID1_BARRIER TSWKID2_BARRIER
    TSWKID0_SLED TSWKID1_SLED TSWKID2_SLED
        T_KID_SLED T_KID_CAC T_ADULT_CAC
    TLV TLS TL;
RUN;
```

Prints the number of lives saved by each technology in each CY, and the sum of lives saved from 1975 through 2012.

```
PROC PRINT DATA=TRK3;
  FORMAT TLV226 TLS226 TL226 TLV214C TLS214C TL214C T_TORSO T_COMBO T_CURTAIN T_CURT_TORS 9.0;
  ID CY; VAR TLV226 TLS226 TL226 TLV214C TLS214C TL214C T_TORSO T_COMBO T_CURTAIN T_CURT_TORS;
  SUM TLV226 TLS226 TL226 TLV214C TLS214C TL214C T_TORSO T_COMBO T_CURTAIN T_CURT_TORS;
TITLE1 'LTV OCCUPANT LIVES SAVED BY ROLLOVER CURTAINS AND BY CURTAIN AND SIDE AIR BAGS IN NEARSIDE IMPACTS,
1975-2012';
TITLE2 ' ';
TITLE3 '...226 = ROLLOVER CURTAINS (ON 54.0% OF MY 2009 LTVs, FMVSS PHASE-IN TO BEGIN MY 2014)';
TITLE4 '...214C = ALL TYPES OF CURTAIN AND SIDE AIR BAGS (ON 69.7% OF MY 2009 LTVs, FMVSS NO. 214 POLE TEST
PHASE-IN BEGAN MY 2011)';
TITLE5 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS PHASE-IN';
TITLE6 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS PHASE-IN';
TITLE7 '...TORSO = TORSO BAG ONLY                COMBO = COMBINATION HEAD-TORSO BAG';
TITLE8 '...CURTAIN = CURTAIN ONLY                CURT_TORS = CURATAIN PLUS TORSO BAG';
RUN;

PROC PRINT DATA=TRK3;
  FORMAT TLV126 TLS126 TL126 TLV301 TLS301 TL301 TLV208J TLS208J TL208J 9.0;
  ID CY; VAR TLV126 TLS126 TL126 TLV301 TLS301 TL301 TLV208J TLS208J TL208J;
  SUM TLV126 TLS126 TL126 TLV301 TLS301 TL301 TLV208J TLS208J TL208J;
TITLE1 'LTV OCCUPANT LIVES SAVED BY ESC, FUEL SYSTEM INTEGRITY - REAR IMPACT UPGRADE, AND CENTER-REAR-SEAT 3-
POINT BELTS, 1975-2012';
TITLE2 ' ';
TITLE4 '...126 = ELECTRONIC STABILITY CONTROL (MEDIAN INSTALLATION YEAR 2008, FMVSS PHASE-IN BEGAN MY 2009)';
TITLE5 '...301 = FUEL SYSTEM INTEGRITY - REAR IMPACT UPGRADE (MEDIAN INSTALLATION YEAR 2007, FMVSS PHASE-IN BE-
GAN MY 2007)';
TITLE4 '...208J = 3-POINT BELTS FOR CENTER REAR SEAT PASSENGERS (MEDIAN INSTALLATION YEAR 2004, FMVSS PHASE-IN
BEGAN MY 2006)';
```

```
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS PHASE-IN';
TITLE7 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS PHASE-IN';
RUN;

PROC PRINT DATA=TRK3;
  FORMAT TLV208K TLS208K TL208K TLV201B TLS201B TL201B TLV108 TLS108 TL108 9.0;
  ID CY; VAR TLV208K TLS208K TL208K TLV201B TLS201B TL201B TLV108 TLS108 TL108;
  SUM TLV208K TLS208K TL208K TLV201B TLS201B TL201B TLV108 TLS108 TL108;
TITLE1 'LTV OCCUPANT LIVES SAVED BY PRETENSIONERS & LOAD LIMITERS, HEAD IMPACT UPGRADE, AND TRAILER CONSPICUITY
TAPE, 1975-2012';
TITLE2 ' ';
TITLE3 '...208K = PRETENSIONERS & LOAD LIMITERS FOR BELTS (ON 55.4% OF MY 2002 LTVs, NOT REQUIRED BY ANY
FMVSS)';
TITLE4 '...201B = INTERIOR PROTECTION - HEAD IMPACT UPGRADE (ON 75.6% OF MY 2002 LTVs, FMVSS PHASE-IN BEGAN MY
1999)';
TITLE5 '...108  = TRAILER CONSPICUITY TAPE (ON-ROAD FLEET 54% EQUIPPED IN 1996, FMVSS EFFECTIVE DATE 12/1/93,
RETROFIT REQUIREMENT 6/1/2001)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS PHASE-IN';
TITLE7 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS PHASE-IN';
RUN;

PROC PRINT DATA=TRK3;
  FORMAT TLV208I TLS208I TL208I T_BARRIER T_SLED T_CAC 9.0;
  ID CY; VAR TLV208I TLS208I TL208I T_BARRIER T_SLED T_CAC;
  SUM TLV208I TLS208I TL208I T_BARRIER T_SLED T_CAC;
TITLE1 'LTV OCCUPANT LIVES SAVED BY FRONTAL AIR BAGS, 1975-2012';
TITLE2 ' ';
TITLE3 '...208I = FRONTAL AIR BAGS (MEDIAN INSTALLATION YEAR 1995, FMVSS PHASE-IN BEGAN MY 1995)';
TITLE4 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS PHASE-IN';
TITLE5 '...S = STANDARD INSTALLATIONS, CARS BUILT ON OR AFTER FMVSS PHASE-IN';
TITLE6 '...BARRIER = FIRST-GENERATION, BARRIER CERTIFIED AIR BAGS';
TITLE7 '...SLED    = REDESIGNED (DEPOWERED), SLED-CERTIFIED AIR BAGS';
TITLE8 '...CAC     = CERTIFIED-ADVANCED COMPLIANT AIR BAGS (WITH SUPPRESSION OR LOW-RISK DEPLOYMENT FOR SMALL
PASSENGERS)';
RUN;

PROC PRINT DATA=TRK3;
  FORMAT TLV214A TLS214A TL214A TLV208G TLS208G TL208G TLV213 TLS213 TL213 9.0;
  ID CY; VAR TLV214A TLS214A TL214A TLV208G TLS208G TL208G TLV213 TLS213 TL213;
  SUM TLV214A TLS214A TL214A TLV208G TLS208G TL208G TLV213 TLS213 TL213;
TITLE1 'LTV OCCUPANT LIVES SAVED BY SIDE DOOR BEAMS, OUTBOARD-REAR-SEAT 3-POINT BELTS, AND CHILD SAFETY SEATS,
1975-2012';
TITLE2 ' ';
TITLE3 '...214A = SIDE DOOR BEAMS (MEDIAN INSTALLATION YEAR 1994, FMVSS EFFECTIVE 9/1/93)';
TITLE4 '...208G = 3-POINT BELTS FOR REAR SEAT OCCUPANTS (MEDIAN INSTALLATION YEAR 1990, FMVSS EFFECTIVE
9/1/91)';
TITLE5 '...213  = CHILD SAFETY SEATS (USE EXCEEDED 50% IN 1985, FMVSS EFFECTIVE 4/1/71, STATE LAWS 1978-85)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, LTVS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

PROC PRINT DATA=TRK3;
  FORMAT TLV212 TLS212 TL212 TLV208F TLS208F TL208F TLV203 TLS203 TL203 9.0;
  ID CY; VAR TLV212 TLS212 TL212 TLV208F TLS208F TL208F TLV203 TLS203 TL203;
  SUM TLV212 TLS212 TL212 TLV208F TLS208F TL208F TLV203 TLS203 TL203;
TITLE1 'LTV OCCUPANT LIVES SAVED BY ADHESIVE WINDSHIELD BONDING, FRONT-SEAT 3-POINT BELTS, AND EA STEERING AS-
SEMBLIES, 1975-2012';
TITLE2 ' ';
TITLE3 '...212  = ADHESIVE WINDSHIELD BONDING (MEDIAN INSTALLATION YEAR 1979, FMVSS EFFECTIVE 9/1/78)';
TITLE4 '...208F = 3-POINT BELTS FOR FRONT SEAT OCCUPANTS (MEDIAN INSTALLATION YEAR 1976, FMVSS EFFECTIVE
1/1/76)';
TITLE5 '...203  = ENERGY-ABSORBING STEERING ASSEMBLIES (MEDIAN IMPLEMENTATION YEAR EARLY 1976, FMVSS EFFECTIVE
9/1/81)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, LTVS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

PROC PRINT DATA=TRK3;
  FORMAT TLV201A TL201A TLV105B TLS105B TL105B TLV208E TLS208E TL208E 9.0;
  ID CY; VAR TLV201A TL201A TLV105B TLS105B TL105B TLV208E TLS208E TL208E;
  SUM TLV201A TL201A TLV105B TLS105B TL105B TLV208E TLS208E TL208E;
```

```
TITLE1 'LTV OCCUPANT LIVES SAVED BY SAFER INSTRUMENT PANELS, FRONT DISC BRAKES, AND CENTER-REAR-SEAT LAP BELTS,
1975-201A2';
TITLE2 ' ';
TITLE3 '...201A = VOLUNTARY INSTRUMENT PANEL IMPROVEMENTS (MEDIAN IMPLEMENTATION YEAR 1972, FMVSS EFFECTIVE
9/1/81)';
TITLE4 '...105B = FRONT DISC BRAKES (MEDIAN INSTALLATION YEAR 1971, FMVSS EFFECTIVE 9/1/83)';
TITLE5 '...208E = LAP BELTS FOR CENTER REAR SEAT PASSENGERS (MEDIAN INSTALLATION YEAR 1968, FMVSS EFFECTIVE
7/1/71)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, LTVS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

PROC PRINT DATA=TRK3;
  FORMAT TLV208D TLS208D TL208D TLV208C TLS208C TL208C TLV206 TLS206 TL206 9.0;
  ID CY; VAR TLV208D TLS208D TL208D TLV208C TLS208C TL208C TLV206 TLS206 TL206;
  SUM TLV208D TLS208D TL208D TLV208C TLS208C TL208C TLV206 TLS206 TL206;
TITLE1 'LTV OCCUPANT LIVES SAVED BY CENTER-FRONT-SEAT LAP BELTS, OUTBOARD-REAR-SEAT LAP BELTS, AND IMPROVED DOOR
LOCKS, 1975-2012';
TITLE2 ' ';
TITLE3 '...208D = LAP BELTS FOR CENTER FRONT SEAT PASSENGERS (MEDIAN INSTALLATION YEAR 1968, FMVSS EFFECTIVE
7/1/71)';
TITLE4 '...208C = LAP BELTS FOR OUTBOARD REAR SEAT PASSENGERS (MEDIAN INSTALLATION YEAR 1968, FMVSS EFFECTIVE
7/1/71)';
TITLE5 '...206  = IMPROVED DOOR LOCKS (MEDIAN INSTALLATION YEAR 1967, FMVSS EFFECTIVE 1/1/72)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, LTVS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

PROC PRINT DATA=TRK3;
  FORMAT TLV105A TLS105A TL105A TLV208B TLS208B TL208B TLV208A TLS208A TL208A 9.0;
  ID CY; VAR TLV105A TLS105A TL105A TLV208B TLS208B TL208B TLV208A TLS208A TL208A;
  SUM TLV105A TLS105A TL105A TLV208B TLS208B TL208B TLV208A TLS208A TL208A;
TITLE1 'LTV OCCUPANT LIVES SAVED BY DUAL MASTER CYLINDERS, LAP BELTS FOR CHILDREN AGE 1-4, AND OUTBOARD-FRONT-
SEAT LAP BELTS, 1975-2012';
TITLE2 ' ';
TITLE3 '...105A = DUAL MASTER CYLINDERS (MEDIAN INSTALLATION YEAR LATE 1966, FMVSS EFFECTIVE 9/1/83)';
TITLE4 '...208B = LAP BELT USE BY CHILDREN AGE 1-4 (MEDIAN INSTALLATION YEAR 1966, FMVSS EFFECTIVE 7/1/71)';
TITLE5 '...208A = LAP BELTS FOR OUTBOARD FRONT SEAT OCCUPANTS (MEDIAN INSTALLATION YEAR 1964, FMVSS EFFECTIVE
7/1/71)';
TITLE6 '...V = VOLUNTARY INSTALLATIONS, BEFORE FMVSS EFFECTIVE DATE';
TITLE7 '...S = STANDARD INSTALLATIONS, LTVS BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
RUN;

DATA TRK4; SET TRK3;
PCT_SAVE=100*TL/T_WTFA;
PROC PRINT DATA=TRK4;
  FORMAT T_ORIGWT T_WTFA TLV TLS TL 9.0 PCT_SAVE 6.2;
  ID CY; VAR T_ORIGWT T_WTFA TLV TLS TL PCT_SAVE;
  SUM T_ORIGWT T_WTFA TLV TLS TL;
TITLE1 'OVERALL LTV OCCUPANT LIVES SAVED BY VEHICLE SAFETY STANDARDS AND TECHNOLOGIES, 1975-2012';
TITLE2 ' ';
TITLE3 'T_ORIGWT = ACTUAL LTV OCCUPANT FATALITIES';
TITLE4 'T_WTFA = FATALITIES THAT WOULD HAVE OCCURRED WITHOUT ANY VEHICLE SAFETY IMPROVEMENTS';
TITLE5 'TLV = OVERALL LIVES SAVED BY VOLUNTARY IMPROVEMENTS, BEFORE FMVSS EFFECTIVE DATE';
TITLE6 'TLS = OVERALL LIVES SAVED IN LTVs BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
TITLE7 'TL = OVERALL LIVES SAVED BY VEHICLE SAFETY IMPROVEMENTS (TLV + TLS)';
TITLE8 'PCT_SAVE = PERCENT OF WOULD-HAVE-BEEN FATALITIES SAVED BY SAFETY STANDARDS AND TECHNOLOGIES';
RUN;


/* ----------------------------------------------------------------- */
/* ----------------------------------------------------------------- */
/*  SUMMARY OF LIVES SAVED BY FMVSS FOR CARS, LTVs, PEDS, & MCs      */
/* ----------------------------------------------------------------- */
/* ----------------------------------------------------------------- */
```

Adds up the lives saved among car occupants, LTV occupants, non-occupants and motorcyclists. PCT_SAVE is the percentage of potential car + LTV occupant fatalities saved.

```
DATA CTP3; MERGE CAR3 TRK3 PED3 MC3; BY CY;
SAVED=CL+TL+PL+ML;
```

```
VOL_SAVE=CLV+TLV+PLV+MLV;
STD_SAVE=CLS+TLS+PLS+MLS;
F_ACTUAL=C_ORIGWT+T_ORIGWT;
F_POTNTL=C_WTFA+T_WTFA;
PV_SAVE=CL+TL;
PCT_SAVE=100*PV_SAVE/F_POTNTL;
BELTS=CL208K+CL208J+CL208H+CL208G+CLNCAP+CL208F+CL208E+CL208D+CL208C+CL208B+CL208A;
  BELTS=BELTS+TL208K+TL208J+TL208G+TL208F+TL208E+TL208D+TL208C+TL208B+TL208A;
FRONTAL_BAGS=CL208I+TL208I;
SIDE_BAGS=CL226+TL226+CL214C+TL214C;
KIDSEATS=CL213+TL213;
FMVSS105=ML105B+ML105A+PL105B+PL105A+CL105B+CL105A+TL105B+TL105A;
FMVSS108=CL108+TL108;
FMVSS126=ML126+CL126+TL126;
FMVSS201=CL201B+CL201A+TL201B+TL201A;
FMVSS203=CL203+TL203;
FMVSS206=CL206+TL206;
FMVSS212=CL212+TL212;
FMVSS214=CL214C+TL214C+CL214B+CL214A+TL214A;
FMVSS216=CL216;
FMVSS226=CL226+TL226;
FMVSS301=CL301+TL301;
STDS11=FMVSS105+FMVSS108+FMVSS126+FMVSS201+FMVSS203+FMVSS206+FMVSS212+FMVSS214+FMVSS216+FMVSS226+FMVSS301;
AB_DRV=CABDRV+TABDRV;
AB_RF = CABRF+ TABRF;
AB_KID_BARRIER=CABKID_BARRIER+TABKID_BARRIER;
AB_KID_SLED=CABKID_SLED+TABKID_SLED;
SW0=CSW0+TSW0; SW1=CSW1+TSW1; SW2=CSW2+TSW2;
SWKID0_BARRIER=CSWKID0_BARRIER+TSWKID0_BARRIER;
SWKID1_BARRIER=CSWKID1_BARRIER+TSWKID1_BARRIER;
SWKID2_BARRIER=CSWKID2_BARRIER+TSWKID2_BARRIER;
SWKID0_SLED=CSWKID0_SLED+TSWKID0_SLED;
SWKID1_SLED=CSWKID1_SLED+TSWKID1_SLED;
SWKID2_SLED=CSWKID2_SLED+TSWKID2_SLED;
KID_SLED=C_KID_SLED+T_KID_SLED;
KID_CAC=C_KID_CAC+T_KID_CAC;
ADULT_CAC=C_ADULT_CAC+T_ADULT_CAC;
RUN;

PROC PRINT DATA=CTP3;
  FORMAT SAVED VOL_SAVE STD_SAVE CL TL PL ML COMMA11.0;
  ID CY; VAR SAVED VOL_SAVE STD_SAVE CL TL PL ML;
  SUM SAVED VOL_SAVE STD_SAVE CL TL PL ML;
TITLE1 'OVERALL CAR OCCUPANT, LTV OCCUPANT, PEDESTRIAN AND MOTORCYCLIST LIVES SAVED, 1975-2012';
TITLE2 ' ';
TITLE3 'SAVED = OVERALL LIVES SAVED BY VEHICLE SAFETY IMPROVEMENTS (VOL_SAVE + STD_SAVE)';
TITLE4 'VOL_SAVE = OVERALL LIVES SAVED BY VOLUNTARY IMPROVEMENTS, BEFORE FMVSS EFFECTIVE DATE';
TITLE5 'STD_SAVE = OVERALL LIVES SAVED BY VEHICLES BUILT ON OR AFTER FMVSS EFFECTIVE DATE';
TITLE6 'CL = CAR OCCUPANT LIVES SAVED';
TITLE7 'TL = LTV OCCUPANT LIVES SAVED';
TITLE8 'PL = PEDESTRIAN/NONOCCUPANT LIVES SAVED BY CAR AND LTV BRAKING IMPROVEMENTS';
TITLE9 'ML = MOTORCYCLIST LIVES SAVED BY CAR AND LTV BRAKING IMPROVEMENTS';
RUN;

PROC PRINT DATA=CTP3;
  FORMAT F_ACTUAL F_POTNTL PV_SAVE COMMA11.0 PCT_SAVE 6.2;
  ID CY; VAR F_ACTUAL F_POTNTL PV_SAVE PCT_SAVE;
  SUM F_ACTUAL F_POTNTL PV_SAVE;
TITLE1 'OVERALL LIVES SAVED AND NET EFFECTIVENESS OF SAFETY IMPROVEMENTS FOR PASSENGER VEHICLES (CARS + LTVs),
1975-2012';
TITLE2 ' ';
TITLE3 'F_ACTUAL = ACTUAL CAR + LTV OCCUPANT FATALITIES';
TITLE4 'F_POTNTL = FATALITIES THAT WOULD HAVE OCCURRED WITHOUT ANY VEHICLE SAFETY IMPROVEMENTS';
TITLE5 'PV_SAVE  = CAR + LTV OCCUPANT LIVES SAVED BY VEHICLE SAFETY IMPROVEMENTS';
TITLE6 'PCT_SAVE = PERCENT OF WOULD-HAVE-BEEN FATALITIES SAVED BY SAFETY STANDARDS AND TECHNOLOGIES';
RUN;

PROC PRINT DATA=CTP3;
  FORMAT BELTS FRONTAL_BAGS SIDE_BAGS KIDSEATS COMMA11.0;
  ID CY; VAR BELTS FRONTAL_BAGS SIDE_BAGS KIDSEATS;
  SUM BELTS FRONTAL_BAGS SIDE_BAGS KIDSEATS;
TITLE1 'LIVES SAVED IN CARS + LTVs BY SEAT BELTS, AIR BAGS AND CHILD SAFETY SEATS, 1975-2012';
```

```
TITLE2 ' ';
TITLE3 'BELTS        = LIVES SAVED BY SEAT BELTS (ALL TYPES, ALL SEATING POSITIONS)';
TITLE4 'FRONTAL_BAGS = LIVES SAVED BY FRONTAL AIR BAGS, DRIVERS + RIGHT FRONT PASSENGERS';
TITLE5 'SIDE_BAGS    = LIVES SAVED BY CURTAIN AND SIDE AIR BAGS, DRIVERS + RIGHT FRONT PASSENGERS';
TITLE6 'KIDSEATS     = LIVES SAVED BY CHILD SAFETY SEATS (ALL TYPES, ALL SEATING POSITIONS, ALL AGES)';
RUN;

PROC PRINT DATA=CTP3;
  FORMAT FMVSS105 FMVSS108 FMVSS126 FMVSS201 FMVSS203 FMVSS206 FMVSS212 FMVSS214 FMVSS216 FMVSS226 FMVSS301
STDS11 9.0;
  ID CY; VAR FMVSS105 FMVSS108 FMVSS126 FMVSS201 FMVSS203 FMVSS206 FMVSS212 FMVSS214 FMVSS216 FMVSS226 FMVSS301
STDS11;
  SUM FMVSS105 FMVSS108 FMVSS126 FMVSS201 FMVSS203 FMVSS206 FMVSS212 FMVSS214 FMVSS216 FMVSS226 FMVSS301 STDS11;
TITLE1 'LIVES SAVED BY THE OTHER SAFETY STANDARDS, 1975-2012';
TITLE2 ' ';
TITLE3 'FMVSS105 = DUAL MASTER CYLINDERS + FRONT DISC BRAKES    FMVSS108 = TRAILER CONSPICUITY TAPE (CARS/LTVs
NOT HITTING THE TRAILERS)';
TITLE4 'FMVSS126 = ELECTRONIC STABILITY CONTROL                FMVSS201 = VOLUNTARY INSTRUMENT PANEL IMPROVE-
MENTS & HEAD IMPACT UPGRADE';
TITLE5 'FMVSS203 = ENERGY-ABSORBING STEERING ASSEMBLIES (INCLUDES FMVSS 204)';
TITLE6 'FMVSS206 = IMPROVED DOOR LOCKS                        FMVSS212 = ADHESIVE WINDSHIELD BONDING';
TITLE7 'FMVSS214 = SIDE DOOR BEAMS IN CARS AND LTVs, TTI(d) BY STRUCTURE/PADDING IN CARS, CURTAIN & SIDE AIR
BAGS IN NEARSIDE IMPACTS';
TITLE8 'FMVSS216 = ROOF CRUSH RESISTANCE FOR PASSENGER CARS     FMVSS226 = ROLLOVER CURTAINS';
TITLE9 'FMVSS301 = FUEL SYSTEM INTEGRITY - REAR IMPACT UPGRADE';
TITLE10 'STDS11   = LIVES SAVED BY THESE ELEVEN STANDARDS (I.E., EVERTHING EXCEPT BELTS, FRONTAL AIR BAGS, AND
SAFETY SEATS)';
RUN;
```

Six pages of more detailed summary for air bags: (1) driver lives saved; (2) adult passenger lives saved in vehicles without manual on-off switches; (3) estimated net fatality increase for child passengers in vehicles without switches, separately calculated for barrier-certified and sled-certified air bags; (4) actual adult passenger lives saved in vehicles with manual on-off switches, and potential lives saved if the trucks did not have the switches (or if the air bags were always "on" for adults); (5) estimated actual net increase in child passenger fatalities in vehicles with switches, potential number of child fatalities if these vehicles had air bags and no switches, and lives saved because the switches were turned "off" for child passengers – separately calculated for barrier-certified and sled-certified air bags; (6) three estimates of hypothetical additional fatalities, namely (6a) if children exposed to sled-certified air bags had instead been exposed to barrier-certified air bags; (6b) if children at seats with advanced air bags had instead been exposed to barrier-certified air bags; (6c) if adult passengers in seats with advanced air bags and without manual on-off switches had instead been at seats with manual on-off switches, where a percentage of those switches would have been turned "off."

```
PROC PRINT DATA=CTP3;
  FORMAT AB_DRV CABDRV TABDRV COMMA11.0;
  ID CY; VAR AB_DRV CABDRV TABDRV;
  SUM AB_DRV CABDRV TABDRV;
TITLE1 'LIVES SAVED BY DRIVER AIR BAGS IN ALL CARS AND LTVs, 1975-2012';
TITLE2 ' ';
TITLE3 'AB_DRV = LIVES SAVED BY DRIVER AIR BAGS IN CARS + LTVs';
TITLE4 'CABDRV = LIVES SAVED BY DRIVER AIR BAGS IN CARS';
TITLE5 'TABDRV = LIVES SAVED BY DRIVER AIR BAGS IN LTVs';
RUN;

PROC PRINT DATA=CTP3;
  FORMAT AB_RF CABRF TABRF COMMA11.0;
  ID CY; VAR AB_RF CABRF TABRF;
  SUM AB_RF CABRF TABRF;
TITLE1 'ADULT (AGE 13+) LIVES SAVED BY PASSENGER AIR BAGS IN CARS AND LTVs WITHOUT ON-OFF SWITCHES';
TITLE2 ' ';
TITLE3 'AB_RF = ADULT LIVES SAVED BY PASSENGER AIR BAGS IN CARS + LTVs WITHOUT ON-OFF SWITCHES';
TITLE4 'CABRF = ADULT LIVES SAVED BY PASSENGER AIR BAGS IN CARS WITHOUT ON-OFF SWITCHES';
TITLE5 'TABRF = ADULT LIVES SAVED BY PASSENGER AIR BAGS IN LTVs WITHOUT ON-OFF SWITCHES';
RUN;

PROC PRINT DATA=CTP3;
```

```
  FORMAT AB_KID_BARRIER CABKID_BARRIER TABKID_BARRIER AB_KID_SLED CABKID_SLED TABKID_SLED COMMA11.0;
  ID CY; VAR AB_KID_BARRIER CABKID_BARRIER TABKID_BARRIER AB_KID_SLED CABKID_SLED TABKID_SLED;
  SUM AB_KID_BARRIER CABKID_BARRIER TABKID_BARRIER AB_KID_SLED CABKID_SLED TABKID_SLED;
TITLE1 'CHILD (AGE 0-12) FATALITIES DUE TO PRE-ADVANCED AIR BAGS IN CARS AND LTVs WITHOUT ON-OFF SWITCHES';
TITLE2 ' ';
TITLE3 'AB_KID_BARRIER = CHILD FATALITIES DUE TO FIRST-GENERATION AIR BAGS IN CARS + LTVs WITHOUT ON-OFF SWITCH-
ES';
TITLE4 'CABKID_BARRIER = CHILD FATALITIES DUE TO FIRST-GENERATION AIR BAGS IN CARS WITHOUT ON-OFF SWITCHES';
TITLE5 'TABKID_BARRIER = CHILD FATALITIES DUE TO FIRST-GENERATION AIR BAGS IN LTVs WITHOUT ON-OFF SWITCHES';
TITLE6 'AB_KID_SLED = CHILD FATALITIES DUE TO SLED-CERTIFIED AIR BAGS IN CARS + LTVs WITHOUT ON-OFF SWITCHES';
TITLE7 'CABKID_SLED = CHILD FATALITIES DUE TO SLED-CERTIFIED AIR BAGS IN CARS WITHOUT ON-OFF SWITCHES';
TITLE8 'TABKID_SLED = CHILD FATALITIES DUE TO SLED-CERTIFIED AIR BAGS IN LTVs WITHOUT ON-OFF SWITCHES';
RUN;

PROC PRINT DATA=CTP3;
  FORMAT SW0 SW1 SW2 COMMA11.0;
  ID CY; VAR SW0 SW1 SW2;
  SUM SW0 SW1 SW2;
TITLE1 'ADULT (AGE 13+) LIVES SAVED BY PASSENGER AIR BAGS IN PICKUP TRUCKS (AND OTHER VEHICLES) WITH ON-OFF
SWITCHES';
TITLE2 ' ';
TITLE3 'SW0 = ACTUAL ADULT LIVES SAVED BY AIR BAGS & SWITCHES LEFT ON';
TITLE4 'SW1 = THEORETICAL ADDITIONAL LIVES SAVED IF SWITCHES HAD NOT EXISTED';
TITLE5 'SW2 = LIVES LOST BECAUSE SWITCHES WERE TURNED OFF FOR ADULT PASSENGERS';
RUN;

PROC PRINT DATA=CTP3;
  FORMAT SWKID0_BARRIER SWKID1_BARRIER SWKID2_BARRIER SWKID0_SLED SWKID1_SLED SWKID2_SLED COMMA11.0;
  ID CY; VAR SWKID0_BARRIER SWKID1_BARRIER SWKID2_BARRIER SWKID0_SLED SWKID1_SLED SWKID2_SLED;
  SUM SWKID0_BARRIER SWKID1_BARRIER SWKID2_BARRIER SWKID0_SLED SWKID1_SLED SWKID2_SLED;
TITLE1 'CHILD (AGE 0-12) FATALITIES DUE TO PRE-ADVANCED AIR BAGS IN PICKUP TRUCKS (AND OTHER VEHICLES) WITH ON-
OFF SWITCHES';
TITLE2 ' ';
TITLE3 'SWKID0_BARRIER = ACTUAL ADDITIONAL CHILD PASSENGER FATALITIES DUE TO FIRST-GENERATION AIR BAGS & SWITCH-
ES LEFT ON';
TITLE4 'SWKID1_BARRIER = THEORETICAL ADDITIONAL FATALITIES IF SWITCHES HAD NOT EXISTED (1st GENERATION)';
TITLE5 'SWKID2_BARRIER = LIVES SAVED BECAUSE SWITCHES WERE TURNED OFF FOR CHILD PASSENGERS (1st GENERATION)';
TITLE6 'SWKID0_SLED = ACTUAL ADDITIONAL CHILD PASSENGER FATALITIES DUE TO SLED-CERTIFIED AIR BAGS & SWITCHES
LEFT ON';
TITLE7 'SWKID1_SLED = THEORETICAL ADDITIONAL FATALITIES IF SWITCHES HAD NOT EXISTED (SLED-CERTIFIED)';
TITLE8 'SWKID2_SLED = LIVES SAVED BECAUSE SWITCHES WERE TURNED OFF FOR CHILD PASSENGERS (SLED-CERTIFIED)';
RUN;

PROC PRINT DATA=CTP3;
  FORMAT KID_SLED KID_CAC ADULT_CAC COMMA11.0;
  ID CY; VAR KID_SLED KID_CAC ADULT_CAC;
  SUM KID_SLED KID_CAC ADULT_CAC;
TITLE1 'HYPOTHETICAL ADDITIONAL FATALITIES IF REDESIGNED OR ADVANCED AIR BAGS HAD SITLL BEEN FIRST-GENERATION
AIR BAGS';
TITLE2 ' ';
TITLE3 'KID_SLED  = ADDITIONAL FATALITIES IF CHILDREN EXPOSED TO REDESIGNED AIR BAGS HAD BEEN EXPOSED TO FIRST-
GENERATION AIR BAGS';
TITLE4 'KID_CAC   = ADDITIONAL FATALITIES IF CHILDREN WITH SUPPRESSED, ADVANCED AIR BAGS HAD BEEN EXPOSED TO
FIRST-GENERATION AIR BAGS';
TITLE5 'ADULT_CAC = ADDITIONAL ADULT FATALITIES IF CAC AIR BAGS, NOW WITHOUT SWITCHES, STILL HAD A SWITCH AND IT
WAS TURNED OFF';
RUN;
```

APPENDIX B: SUMMARIES OF PUBLISHED EVALUATION REPORTS

A systematic program to evaluate the effectiveness of the FMVSS was initiated in 1975, when NHTSA was just beginning to establish its own crash databases. The first "preliminary" evaluation of a standard was published in 1979 (side door strength) and the first "final" evaluations in 1981 (energy-absorbing steering assemblies, bumpers). Since 1979, 82 comprehensive evaluations of regulations, safety programs, consumer information programs, or safety technologies have been published. Here is a list of the 82 studies including summaries of principal findings [except where findings were superseded in a follow-up evaluation] and, where available, links to the reports for free downloading in PDF format from the Internet:

2014

Evaluation of FMVSS No. 301, "Fuel System Integrity," as Upgraded in 2005 to 2009 (NHTSA Report No. DOT HS 812 038)

In 2003, NHTSA upgraded FMVSS No. 301 with a 50 mph offset rear-impact test, which phased in during MY 2007 to 2009. Cars and LTVs certifying to the new test requirement have 57 percent lower odds of post-crash fire in rear-impact crashes than vehicles before the upgrade. That results in a 35-percent reduction of fatalities in rear-impact crashes with post-crash fires.

Updated Estimates of Fatality Reduction by ESC (NHTSA Report No. DOT HS 812 020, www-nrd.nhtsa.dot.gov/Pubs/812020.pdf)

ESC uses automatic, computer-controlled braking of individual wheels to enhance drivers' ability to keep vehicles under control in a wide variety of driving situations. Fatal first-event rollovers are reduced by 60 percent in cars and by 74 percent in LTVs. Other fatal single-vehicle crashes (excluding collisions with pedestrians or bicyclists) are reduced by 31 percent in cars and 45 percent in LTVs. Involvements as the culpable vehicle in fatal multivehicle crashes are reduced by 16 percent in cars and LTVs.

Updated Estimates of Fatality Reduction by Curtain and Side Air Bags in Side Impacts and Preliminary Analyses of Rollover Curtains (NHTSA Report No. DOT HS 811 882, www-nrd.nhtsa.dot.gov/Pubs/811882.pdf)

The four types of curtain and side air bags each significantly reduce fatality risk in near-side impacts of cars and LTVs: curtains plus torso bags by 31 percent, combination head/torso bags by 25 percent, curtains alone by 16 percent, and torso bags alone by 8 percent. Curtains that deploy in rollovers reduce fatality risk in first-event rollovers by 41 percent.

2013

Effectiveness of Pretensioners and Load Limiters for Enhancing Fatality Reduction by Seat Belts (NHTSA Report No. DOT HS 811 835, www-nrd.nhtsa.dot.gov/Pubs/811835.pdf)

Pretensioners and load limiters are technologies designed to make seat belts more effective. Belted drivers and RF passengers of cars, CUVs, and minivans have 12.8 percent lower fatality risk when their belt is equipped with a pretensioner and a load limiter than when it is not equipped with either. The current data does not show a significant effect in pickup trucks, SUVs with body-and-frame construction, or full-sized vans.

Evaluation of the Certified-Advanced Air Bags (NHTSA Report No. DOT HS 811 834, www-nrd.nhtsa.dot.gov/Pubs/811834.pdf)

Certified-advanced air bags are designed to not deploy at all for children or deploy only at a low level of force. There is no significant difference between the fatality risk with advanced air bags and with their predecessors, sled-certified air bags, for drivers and passengers of cars and LTVs. NHTSA has not seen any case of an infant or a small child with fatal injuries from advanced air bags.

Injury Vulnerability and Effectiveness of Occupant Protection Technologies for Older Occupants and Women (NHTSA Report No. DOT HS 811 766, www-nrd.nhtsa.dot.gov/Pubs/811766.pdf)

In crashes of cars and LTVs of the past 50 model years, fatality risk increases by an average of 3.11 percent per year that an occupant gets older; risk is, on average, 17.0 percent higher for a female than for a male of the same age (but this has dropped below 10 percent in MY 2000 to 2011). Older occupants are susceptible to thoracic injuries, especially multiple rib fractures. Females are susceptible to neck and abdominal injuries and, at lower severity levels, highly susceptible to arm and leg fractures. All of the major occupant protection technologies in vehicles of recent model years have at least some benefit for adults of all age groups and of either gender; none of them are harmful for a particular age group or gender.

Effectiveness of LED Stop Lamps for Reducing Rear-End Crashes: Analyses of State Crash Data (NHTSA Report No. DOT HS 811 712, www-nrd.nhtsa.dot.gov/Pubs/811712.PDF)

Vehicles equipped with LED stop lamps and CHMSL had a statistically significant 3.6-percent lower rate of involvement in rear-impact crashes than vehicles of the same makes and models with incandescent lamps. However, the analysis does not support a firm conclusion about whether LED stop lamps are more effective than incandescent lamps, because (1) rear impacts increased with LED for over half of the individual makes and models and (2) all of the models that shifted to LED simultaneously changed other aspects of the rear-lighting configuration – thus, changes in rear-impact crash rates need not be solely due to LED.

2012

Evaluation of the Effectiveness of TPMS in Proper Tire Pressure Maintenance (NHTSA Report No. DOT HS 811 681, www-nrd.nhtsa.dot.gov/Pubs/811681.pdf)

In a CY 2011 survey, MY 2004- 2007 cars and LTVs equipped with TPMS were 56 percent less likely to have one or more severely underinflated tires (25% or more below the vehicle manufacturer's recommended cold tire pressure) than vehicles of the same MY without TPMS. They were also 31percent less likely to have tires that are overinflated by 25 percent or more above the recommended pressure. During the first 8 years of operation TPMS is estimated to save 9 gallons of fuel per car and 28 gallons per LTV.

Traffic Safety Facts Research Note: National Child Restraint Use Special Study (NHTSA Report No. DOT HS 811 679, www-nrd.nhtsa.dot.gov/Pubs/811679.pdf)

The five significant mistakes in CRS or booster-seat installation most commonly observed during a 2011 national survey were: (1) Use of the wrong harness slot; (2) The harness retainer or chest clip incorrectly positioned or not used at all; (3) Loose CRS installation (more than two inches of side-to-side or front-to-back movement); (4) Loose harness strap (more than two inches of slack); and (5) Improper belt placement with booster seats.

Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs – Final Report (NHTSA Report No. DOT HS 811 665, www-nrd.nhtsa.dot.gov/Pubs/811665.PDF)

The report statistically analyzes the potential effects of mass reduction while holding footprint constant on societal fatality rates per VMT for MY 2000 to 2007 vehicles during CY 2002 to 2008. These rates include occupants of all vehicles in the crash as well as pedestrians. For 100-pound mass reductions, societal risk in cars weighing less than 3,106 pounds increases by a statistically significant 1.56 percent. There are non-significant increases in the heavier cars and the lighter truck-based LTVs and non-significant societal benefits for mass reduction in CUVs, minivans, and the heavier truck-based LTVs. Potential combinations of mass reductions – that maintain footprint and are proportionately somewhat higher for the heavier vehicles – may be safety-neutral.

Evaluation of the Enhancing Vehicle-to-Vehicle Crash Compatibility Agreement: Effectiveness of the Primary and Secondary Energy-Absorbing Structures on Pickup Trucks and SUVs (NHTSA Report No. DOT HS 811 621, www-nrd.nhtsa.dot.gov/Pubs/811621.PDF)

In crashes between cars and LTVs, there was a statistically significant 8-percent reduction in car-occupant fatalities after the LTVs self-certified to the EVC agreement (voluntary standards for LTVs to reduce height mismatches between LTVs and passenger cars). However, the results for pickup trucks and SUVs, separately, were inconsistent. Furthermore, a supplementary non-parametric analysis does not show fatality reduction for significantly more than 50 percent of the makes and models. Overall, these results provide some evidence that the EVC has reduced fatalities but do not permit an unequivocal conclusion that it has been effective in reducing fatality risk.

2011

Evaluation of the 1999-2003 Head Impact Upgrade of FMVSS No. 201 – Upper-Interior Components: Effectiveness of Energy-Absorbing Materials Without Head-Protection Air Bags (NHTSA Report No. DOT HS 811 538, www-nrd.nhtsa.dot.gov/Pubs/811538.PDF)

FMVSS No. 201 was upgraded in MY 1999 to 2003 to reduce occupants' risk of head injury from contact with a vehicle's upper interior. Initially, energy-absorbing materials alone were used to meet the standard. These materials reduce AIS 4-to-6 head injuries due to contact with upper-interior components by an estimated 24 percent. That is equivalent to a 4.3-percent reduction of overall fatality risk.

Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs – Preliminary Report (Submission to Docket No. NHTSA-2010-0152-0023, www.regulations.gov/#!documentDetail;D=NHTSA-2010-0152-0023)

[Findings have been superseded by the 2012 evaluation - see above.]

A Study of NMVCCS to Identify Critical Precrash Factors in Fatal Crashes (Proceedings of the 22nd Conference on Enhanced Safety of Vehicles, Paper No. 11-0168, www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000168.pdf)

In 111 fatal crashes of the NMVCCS, 94 percent of the critical pre-crash factors were driver-related, 3 percent pedestrian/bicyclist-related, 2 percent vehicle-related, and 1 percent environment-related. Alcohol and/or drugs were the critical factor in 32 percent of the cases, speeding/loss of control in 14 percent, distraction in 8 percent, and drivers' illness or medical conditions in 7 percent (typically older drivers). Technologies that might conceivably have helped, if the vehicle had been equipped with them, were: ESC (32% of the cases), lane-keeping assistance (32%), drunk-driver detection (27%), crash-imminent braking (23%), and distraction/drowsiness detection (7%).

Crash Prevention Effectiveness of Light-Vehicle Electronic Stability Control: An Update of the 2007 NHTSA Evaluation (NHTSA Report No. DOT HS 811 486, www-nrd.nhtsa.dot.gov/Pubs/811486.pdf)

ESC systems use automatic computer-controlled braking of individual wheels to assist the driver in maintaining control in critical driving situations. Overall, ESC reduces police-reported crash involvements of passenger cars by 5 percent and fatal involvements by 23 percent. For LTVs, these reductions are 7 percent and 20 percent. Each reduction is statistically significant except the 5 percent overall effect for cars. [This report also estimates fatality reduction, but the findings are superseded by the 2014 evaluation – see above.]

2010

The Effectiveness of Underride Guards for Heavy Trailers (NHTSA Report No. DOT HS 811 375, www-nrd.nhtsa.dot.gov/Pubs/811375.pdf)

Florida and North Carolina data on crashes where a car or LTV rear-ended a tractor trailer show decreases in fatalities and serious injuries to the car/LTV occupants when the trailer is equipped with underride guards meeting FMVSS Nos. 223 and 224. However, the observed decreases are not statistically significant at the 0.05 level. Passenger-compartment intrusion in the car or LTV is significantly more apt to occur when the corner of the trailer is impacted than when the center of the trailer is impacted.

The Effectiveness of ABS in Heavy Truck Tractors and Trailers (NHTSA Report No. DOT HS 811 339, www-nrd.nhtsa.dot.gov/Pubs/811339.pdf)

ABS on the tractor unit is estimated to reduce involvement in police-reported crashes for air-braked tractor-trailers by a statistically significant 3 percent. There is a non-significant 2-percent reduction in fatal crash involvements. ABS reduces jack-knives, off-road overturns, and at-fault involvements in collisions with other vehicles (except front-to-rear collisions).

Booster Seat Effectiveness Estimates Based on CDS and State Data (NHTSA Report No. DOT HS 811 338, www-nrd.nhtsa.dot.gov/Pubs/811338.pdf)

Among 4-to-8 year olds there is strong evidence of reduced risk of injury when restrained by booster seats rather than just by lap and shoulder belts. The estimated magnitude of this effect is a 14-percent reduction in risk of any type of injury. Among 3- and 4-year-olds there is evidence of increased risk of injury when restrained in booster seats rather than with the recommended child restraints. The increase depends on the injury severity. The effect may be more pronounced in the 3-year-olds, although sample sizes are too small to draw statistical conclusions.

Relationships Between Fatality Risk, Mass, and Footprint in Model Year 1991-1999 and Other Passenger Cars and LTVs (Pages 464-542 of Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2012-MY 2016 Passenger Cars and Light Trucks, www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/CAFE_2012-2016_FRIA_04012010.pdf)

[Findings have been superseded by the 2012 evaluation - see above.]

2009

Fatalities in Frontal Crashes Despite Seat Belts and Air Bags – Review of All CDS Cases – Model and Calendar Years 2000-2007 – 122 Fatalities (NHTSA Report No. DOT HS 811 202, www-nrd.nhtsa.dot.gov/pubs/811102.pdf [sic])

Why are people still dying in frontal crashes despite seat belt use, frontal air bags, and the crashworthy structures of MY 2000 and later vehicles? Aside from a substantial proportion of the crashes that are just exceedingly severe, the main reason people are still dying in these 122 frontal impacts in CDS is that many involve poor structural engagement between the vehicle and its collision partner: corner impacts, oblique crashes, impacts with narrow objects, and underrides. By contrast, few if any of the 122 fatal crashes were full-frontal or offset-frontal impacts with good structural engagement, unless the crashes were of extreme severity or the occupants exceptionally vulnerable.

The Long-Term Effect of ABS in Passenger Cars and LTVs (NHTSA Report No. DOT HS 811 182, www-nrd.nhtsa.dot.gov/Pubs/811182.PDF)

ABS has close to a zero net effect on fatal crash involvements: statistically significant increases in run-off-road crashes are more or less offset by significant reductions in collisions with pedestrians and in collisions with other vehicles on wet roads. However, ABS is quite effective in nonfatal crashes, reducing the overall crash-involvement rate by 6 percent in passenger cars and by 8 percent in LTVs.

The Effectiveness of Amber Rear Turn Signals for Reducing Rear Impacts (NHTSA Report No. DOT HS 811 115, www-nrd.nhtsa.dot.gov/Pubs/811115.PDF)

FMVSS No. 108 allows rear turn signals to be either red or amber in color. Cars and LTVs with amber turn signals have significantly fewer involvements than corresponding vehicles with red turn signals in two-vehicle crashes where a lead vehicle is rear-struck in the act of turning left, turning right, merging into traffic, changing lanes, or entering/leaving a parking space. The estimated reduction is 5.3 percent.

An In-Service Analysis of Maintenance and Repair Expenses for the Anti-Lock Brake System and Underride Guard for Tractors and Trailers (NHTSA Report No. DOT HS 811 109, www-nrd.nhtsa.dot.gov/Pubs/811109.PDF)

The presence of the ABS system does not appear to increase overall maintenance expenses to the brake systems of truck tractors and heavy trailers. Across a vehicle lifetime, the net present value of the expenses for maintaining and repairing ABS is estimated to range from $56 to $102 for tractors and from $16 to $30 for trailers, in 2007 dollars. These values are relatively small compared to the cost of equipping new vehicles with ABS systems. The net present value of the lifetime maintenance and repair expenses to underride guards meeting FMVSS Nos. 223 and 224 is an estimated $15.

2008

Statistical Analysis of Alcohol-Related Driving Trends, 1982-2005 (NHTSA Report No. DOT HS 810 942, www-nrd.nhtsa.dot.gov/Pubs/810942.PDF)

The percentage of drivers involved in fatal crashes who had blood alcohol concentrations (BACs) of .08 grams per deciliter or above steadily decreased from 1982 to 1997 and then leveled off. Legislation (.10 BAC, .08 BAC, administrative license revocation, and minimum-legal-drinking-age laws), demographic factors (median age of the population and the proportion of female drivers grew from 1982 to 1997), and changes in per-capita alcohol consumption largely explain both the initial decrease in BAC ≥ .08 and its leveling off after 1997. The leveling off does not imply that laws are becoming less effective. On the contrary, they have effectively maintained the proportion of drivers in fatal crashes with BAC ≥ .08 at the lowest level since 1982.

2007

Statistical Analysis of the Effectiveness of Electronic Stability Control (ESC) Systems – Final Report (NHTSA Report No. DOT HS 810 794, www-nrd.nhtsa.dot.gov/Pubs/810794.PDF)

[Findings have been superseded by the 2011 evaluation - see above.]

An Evaluation of Side Impact Protection – FMVSS 214 TTI(d) Improvements and Side Air Bags (NHTSA Report No. DOT HS 810 748, www-nrd.nhtsa.dot.gov/Pubs/810748.PDF)

A dynamic crash test was added to FMVSS No. 214 and phased into new passenger cars during 1994 to 1997. Manufacturers first upgraded side structures and affixed padding, then equipped many vehicles with side air bags designed to protect the occupant's torso, the head, or both. The test criterion TTI(d) improved in 2-door cars from an average of 114 in 1981 to 1985 to 44 in cars with side air bags, and from 85 to 48 in 4-door cars. Upgraded structures and padding reduced fatality risk for near-side occupants in multivehicle crashes by an estimated 33 percent in 2-door cars and 17 percent in 4-door cars. [This report also evaluates side air bags, but the findings are superseded by the 2014 evaluation – see above.]

2006

HIC Test Results before and after the 1999-2003 Head Impact Upgrade of FMVSS 201 (NHTSA Report No. DOT HS 810 739, www-nrd.nhtsa.dot.gov/Pubs/810739.PDF)

Upgraded requirements in FMVSS No. 201 were phased into new vehicles in 1999 to 2003 to reduce occupants' risk of head injury from contact with the upper interior, including the pillars, roof headers, side rails, and upper roof. Initially, energy-absorbing materials alone were added; later, some vehicles also received head-protection air bags. NHTSA conducted impact tests in pre- and post-standard vehicles, without head-protection air bags, of the same makes and models. The head injury criterion, HIC(d) averaged 909.9 pre-standard and 667.5 post-standard: a statistically significant average improvement of 242.4 units of HIC.

An Evaluation of the 1998-1999 Redesign of Frontal Air Bags (NHTSA Report No. DOT HS 810 685, www-nrd.nhtsa.dot.gov/Pubs/810685.PDF)

In 1998 and 1999, air bags were redesigned to make deployments less harmful to child passengers and other out-of-position occupants by removing some of the propellant or gas from their inflators and/or by reducing volume or rearward extent, positioning them further from occupants, tethering, and hybrid inflators. Compared to earlier air bags, these redesigned air bags reduced fatalities to infants and children by 83 percent and to out-of-position drivers by 70 percent in low-to-moderate speed crashes. Yet they entirely preserved the overall life-saving benefits of earlier air bags for belted drivers and for passengers 13 and older.

Child Restraint Use Survey – LATCH Use and Misuse (NHTSA Report No. DOT HS 810 679, www-nrd.nhtsa.dot.gov/Pubs/810679.PDF)

LATCH (Lower Anchors and Tethers for Children) consists of an upper tether that provides an additional point of attachment for greater safety, and lower attachments that simplify installation of child safety seats. NHTSA's 2005 survey found 55 percent use of the upper tether and 60 percent use of the lower attachments. (People who did not use the lower attachments used the vehicle's seat belts to install the child safety seat.) Most of the non-users said they had not heard of LATCH, did not realize their vehicle was equipped with it, did not know why it was important, or did not know how to use it.

2005

Trends in the Static Stability Factor of Passenger Cars, Light Trucks, and Vans (NHTSA Report No. DOT HS 809 868, www-nrd.nhtsa.dot.gov/Pubs/809868.PDF)

The static stability factor is a measurement of a vehicle's resistance to rollover. NHTSA has included rollover information as part of its NCAP ratings since model year 2001. Passenger cars have the highest average SSF, and they have remained high. SUVs have substantially improved their SSF values over time, especially after model year 2000, whereas those of pickup trucks have remained consistent over the years. Minivans showed considerable improvement since they were first introduced. In model year 2003, the sales-weighted average SSF was 1.41 for passenger cars, 1.17 for SUVs, 1.18 for pickup trucks, 1.24 for minivans, and 1.12 for full-size vans.

2004

Cost per Life Saved by the Federal Motor Vehicle Safety Standards (NHTSA Report No. DOT HS 809 835, www-nrd.nhtsa.dot.gov/Pubs/809835.PDF)

NHTSA has evaluated the life-saving benefits as well as the consumer cost for a substantial "core" group of safety technologies for passenger cars and LTVs (pickup trucks, SUVs, and vans). In 2002, these technologies added an estimated $11,353,000,000 (in 2002 dollars) to the consumer cost of new cars and LTVs of that model year, while saving 20,851 lives in the vehicles on the road during that calendar year. That amounts to $544,482 per life saved in 2002. They added $189,842,000,000 to the cost of new cars and LTVs over model years 1968 to 2002, while saving 252,989 lives in model year 1968 and later vehicles during calendar years 1968 to 2002. That amounts to $750,782 per life saved in 1968 to 2002.

Cost and Weight Added by the Federal Motor Vehicle Safety Standards for Model Years 1968-2001 in Passenger Cars and Light Trucks (NHTSA Report No. DOT HS 809 834, www-nrd.nhtsa.dot.gov/Pubs/809834.PDF)

NHTSA performs engineering "teardown" analyses to estimate how much a specific FMVSS adds to the weight and the retail price of vehicles. NHTSA has evaluated virtually all the cost- and weight-adding technologies introduced by 2001 in cars and LTVs in response to the FMVSS. NHTSA estimates that the FMVSS added an average of $839 (in 2002 dollars) and 125 pounds to the average passenger car in model year 2001. This was approximately 4 percent of the cost and 4 percent of the weight of a new car. An average of $711 (in 2002 dollars) and 86 pounds was added to the average LTV in model year 2001. This was approximately 3 percent of the cost and 2 percent of the weight of a new LTV.

Lives Saved by the Federal Motor Vehicle Safety Standards and Other Vehicle Safety Technologies, 1960-2002 – Passenger Cars and Light Trucks – With a Review of 19 FMVSS and their Effectiveness in Reducing Fatalities, Injuries and Crashes (NHTSA Report No. DOT HS 809 833, www-nrd.nhtsa.dot.gov/Pubs/809833.PDF)

NHTSA has evaluated the effectiveness of virtually all the life-saving technologies introduced in passenger cars, pickup trucks, SUVs, and vans from about 1960 up through the later 1990s. A statistical model estimates the number of lives saved from 1960 to 2002 by the combination of these technologies – including safety equipment meeting specific FMVSS, equipment installed in advance of the FMVSS, and noncompulsory improvements such as the redesign of middle and lower instrument panels. Vehicle safety technologies saved an estimated 328,551 lives from 1960 through 2002. The annual number of lives saved grew steadily from 115 in 1960 to 24,561 in 2002.

Impaired-Driving Program Assessments: A Summary of Recommendations (1991 to 2003) (NHTSA Report No. DOT HS 809 815, www-nrd.nhtsa.dot.gov/Pubs/809815.PDF)

NHTSA's assessment process allows States to have their impaired-driving programs reviewed by outside teams of nationally recognized experts. NHTSA examined 38 State assessment reports. Most of the teams' 2,982 individual recommendations fit into 10 thematic areas: (1) enforcement and the arrest, prosecution, and adjudication process; (2) public information and education; (3) DUI data and records; (4) enacting or revising laws; (5) enhanced training for personnel; (6) program evaluation; (7) resources for treatment and rehabilitation; (8) inter/intra-governmental coordination; (9) sources of funding; and (10) task forces and/or community involvement.

Preliminary Results Analyzing the Effectiveness of Electronic Stability Control (ESC) Systems (NHTSA Report No. DOT HS 809 790, www-nrd.nhtsa.dot.gov/Pubs/809790.PDF)

[Findings have been superseded by the 2011 evaluation - see above.]

Evaluation of Rear-Window Defrosting and Defogging Systems (NHTSA Report No. DOT HS 809 724, www-nrd.nhtsa.dot.gov/Pubs/809724.PDF)

Almost all new cars, minivans and SUVs have rear-window defoggers, even though Federal standards do not require them. Analyses of crashes where drivers were backing up or changing lanes during rain or snow, early morning hours, or in the winter did not show a statistically significant reduction with defoggers. Nevertheless, NHTSA would expect consumers to continue wanting rear-window defoggers for their vehicles because they conveniently clear condensation, frost, ice, and snow from the back window.

Evaluation of FMVSS 214 Side Impact Protection for Light Trucks: Crush Resistance Requirements for Side Doors (NHTSA Report No. DOT HS 809 719, www-nrd.nhtsa.dot.gov/Pubs/809719.PDF)

LTVs were required to meet a crush resistance standard for side doors beginning September 1, 1993. Side door beams were installed to reduce the velocity and depth of door intrusion in side impact crashes. The beams are estimated to reduce fatalities by 19 percent in single vehicle side impacts. When all LTVs on the road have side door beams, they will save an estimated 151 lives per year. Little or no fatality reduction was found in multivehicle crashes.

2003

Results of the Survey on the Use of Passenger Air Bag On-Off Switches (NHTSA Report No. DOT HS 809 689, www-nrd.nhtsa.dot.gov/Pubs/809689.PDF)

On-off switches allow drivers to temporarily deactivate air bags when children must ride in the front seats of pickup trucks and other vehicles that cannot accommodate rear-facing child safety seats in the rear seats. NHTSA recommends that the passenger air bag be turned off when a child 12 or younger must ride in the front seat, and turned on if all front seat occupants are 13 or older. In a 2000 survey, switches were left on for 14 percent of infants and 26 percent of child passengers age 1 to 6, but turned off for 17 percent of the adult passengers.

Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks (NHTSA Report No. DOT HS 809 662, www-nrd.nhtsa.dot.gov/Pubs/809662.PDF)

[Findings have been superseded by the 2012 evaluation - see above.]

NCAP Test Improvements with Pretensioners and Load Limiters (NHTSA Report No. DOT HS 809 562, www-nrd.nhtsa.dot.gov/Pubs/809562.PDF)

Seat belt pretensioners pull belts snug as a crash begins. Load limiters allow belts to yield slightly during a crash to reduce the force on the wearer's chest. In the New Car Assessment Program's frontal barrier crashes at 35 mph, the combination of pretensioners and load limiters reduced average HIC by 232, chest acceleration by 6.6 g's and chest deflection by 10.6 mm, for driver and RF passenger dummies, relative to cars and LTVs of the same makes and models without these features.

2002

Evaluation of Child Safety Seat Registration (NHTSA Report No. DOT HS 809 518, www-nrd.nhtsa.dot.gov/Pubs/809518.PDF)

Since March 1993, manufacturers of child safety seats have been required to provide a postage-paid registration form with each new child safety seat. Seat registration has increased from 3 percent prior to 1993 to 27 percent in 1996 to 2000. The repair rate for recalled child safety seats increased from 13.8 percent prior to 1993 to 21.5 percent in 1993 to 2000.

Preliminary Report: The Incidence Rate of Odometer Fraud (NHTSA Report No. DOT HS 809 441, www-nrd.nhtsa.dot.gov/Pubs/809441.PDF)

There are an estimated 452,000 cases of odometer rollback per year in the United States. The difference between the inflated prices that consumers paid for rolled-back vehicles and the prices they would have been willing to pay if they had known the true mileage average $2,336 per case of odometer rollback, amounting to $1,056 million per year in the United States.

2001

The Effectiveness of Head Restraints in Light Trucks (NHTSA Report No. DOT HS 809 247, www-nrd.nhtsa.dot.gov/Pubs/809247.PDF)

The purpose of a head restraint is to prevent whiplash injuries in rear-impact crashes. Head restraints reduce overall injury risk in LTVs in rear impacts by a statistically significant 6 percent. When all LTVs on the road have head restraints, they will be preventing approximately 15,000 nonfatal injuries per year. (See also the 1982 evaluation of head restraints in passenger cars.)

The Effectiveness of Retroreflective Tape on Heavy Trailers (NHTSA Report No. DOT HS 809 222, www-nrd.nhtsa.dot.gov/Pubs/809222.PDF)

Retroreflective tape enhances the visibility of heavy trailers in the dark. The tape reduces side and rear impacts by other vehicles into trailers by 29 percent in dark conditions (including dark-not-lighted, dark-lighted, dawn and dusk). In dark-not-lighted conditions, the tape reduces side and rear impacts by 41 percent. When all heavy trailers have the tape, it will prevent an estimated 191 to 350 fatalities, 3,100 to 5,000 injuries and 7,800 crashes per year.

Evaluation of the American Automobile Labeling Act (NHTSA Report No. DOT HS 809 208, www-nrd.nhtsa.dot.gov/Pubs/809208.PDF)

In a survey of 646 recent or imminent new-vehicle buyers, over 75 percent were unaware of the existence of automobile parts content labels. Among those who had read the labels, many said they used the country-of-assembly information, but none said they used the numerical U.S./Canadian parts content score. Overall U.S./Canadian parts content in new cars and LTVs dropped from an average of 70 percent in model year 1995 to 67.6 percent in 1998. However, it increased from 47 to 59 percent in transplants while dropping from 89 to 84 percent in Big 3 vehicles: trends undoubtedly influenced by the 1995 U.S.-Japan Agreement on Autos and Auto Parts and the North American Free Trade Agreement.

2000

Fatality Reduction by Safety Belts for Front-Seat Occupants of Cars and Light Trucks: Updated and Expanded Estimates Based on 1986-99 FARS Data (NHTSA Report No. DOT HS 809 199, www-nrd.nhtsa.dot.gov/Pubs/809199.PDF)

> Manual three-point belts reduce fatality risk, relative to the unrestrained front seat occupant, by 45 percent in passenger cars and by 60 percent in pickup trucks, vans, and sport utility vehicles. The analyses reconfirm the agency's earlier (1984 to 1989) estimates of fatality reduction.

1999

Evaluation of FMVSS 214 - Side Impact Protection: Dynamic Performance Requirement; Phase 1: Correlation of TTI(d) With Fatality Risk in Actual Side Impact Collisions of Model Year 1981-1993 Passenger Cars (NHTSA Report No. DOT HS 809 004, www-nrd.nhtsa.dot.gov/Pubs/809004.PDF)

> [Findings have been superseded by the 2007 evaluation - see above.]

Effectiveness of Lap/Shoulder Belts in the Back Outboard Seating Positions (NHTSA Report No. DOT HS 808 945, www-nrd.nhtsa.dot.gov/Pubs/808945.PDF)

> Lap/shoulder belts reduce fatality risk by 44 percent relative to unrestrained rear seat occupants of passenger cars, and by 15 percent relative to lap-belted occupants. Lap belts reduce fatality risk by 32 percent relative to unrestrained occupants. Lap/shoulder belts are effective in all crashes, but lap belts only in non-frontal crashes. Lap-belted occupants have substantially higher abdominal-injury risk than unrestrained rear seat occupants in frontal crashes, but lap/shoulder belts reduce abdominal injuries by 52 percent and head injuries by 47 percent relative to lap belts.

1998

Highway Safety Assessment: A Summary of Findings in Ten States (NHTSA Report No. DOT HS 808 796, www-nrd.nhtsa.dot.gov/Pubs/808796.PDF)

> Assessment of safety programs in 10 States from 1980 to 1993 showed that Federal grants and technology were used to address safety priorities as intended by Congress. Federal grants, amounting to less than 2 percent of total safety spending by States and communities, have acted as seed money to resolve important highway safety problems. Programs started with Federal funds were often extended or replicated elsewhere with State funds. Occupant protection programs, however, remain heavily dependent on Federal funds.

Auto Theft and Recovery - Effects of the Anti Car Theft Act of 1992 and the Motor Vehicle Theft Law Enforcement Act of 1984 - Report to the Congress (NHTSA Report No. DOT HS 808 761, www-nrd.nhtsa.dot.gov/Pubs/808761.PDF)

> Theft rates, which had increased during the 1980s, declined from 714 per million in 1990 to 597 in 1995. Parts marking and factory-installed anti-theft devices have had beneficial and complementary effects on auto thefts and/or recoveries. The Acts have given law enforcement tools to deter thefts, trace stolen vehicles and parts, and apprehend and convict thieves.

The Long-Term Effectiveness of Center High Mounted Stop Lamps in Passenger Cars and Light Trucks (NHTSA Report No. DOT HS 808 696, www-nrd.nhtsa.dot.gov/Pubs/808696.PDF)

Throughout 1989 to 1995, cars equipped with center high-mounted stop lamps were 4.3 percent less likely to be struck in the rear than cars without the lamps. (In 1987, when the lamps were first introduced, the reduction was 8.5 percent.) The effectiveness of CHMSL in LTVs is about the same as in cars. At the 1989-to-1995 effectiveness level, when all cars and LTVs on the road have the lamps, they would prevent 194,000 to 239,000 crashes, 58,000 to 70,000 nonfatal injuries and $655 million in property damage per year.

1997

Relationship of Vehicle Weight to Fatality and Injury Risk in Model Year 1985-93 Passenger Cars and Light Trucks (NHTSA Report No. DOT HS 808 569, www-nrd.nhtsa.dot.gov/Pubs/808570.PDF); **Relationships Between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks** (NHTSA Report No. DOT HS 808 570, www-nrd.nhtsa.dot.gov/Pubs/808569.PDF)

[Findings have been superseded by the 2012 evaluation - see above.]

1996

Fatality Reduction by Air Bags: Analyses of Accident Data through Early 1996 (NHTSA Report No. DOT HS 808 470, www-nrd.nhtsa.dot.gov/Pubs/808470.PDF)

Driver air bags reduce overall fatality risk by an estimated 11 percent in passenger cars and LTVs (essentially unchanged from the 1994 and 1992 NHTSA analyses). Passenger air bags are beneficial for RF passengers 13 or older. Air bags provide a life-saving benefit for belted as well as unbelted drivers. The fatality risk for child passengers up to age 12 in cars with passenger air bags is currently higher than in cars without them. Current air bags are significantly less effective for drivers 70 or older than for younger drivers.

1995

Preliminary Evaluation of the Effectiveness of Antilock Brake Systems for Passenger Cars (NHTSA Report No. DOT HS 808 206, www-nrd.nhtsa.dot.gov/Pubs/808206.PDF)

[Findings have been superseded by the 2009 evaluation - see above.]

1994

Fatality Reduction by Automatic Occupant Protection in the United States (Proceedings of the 14th Conference on Enhanced Safety of Vehicles, Paper No. 94-S5-O-08, www-nrd.nhtsa.dot.gov/Pubs/94S5O08.PDF)

The fatality risk of outboard front seat occupants in cars with motorized 2-point belts (without disconnect) is 6 percent lower than in cars with manual belts; the risk in cars with nonmotorized 3-point belts is the same as in cars with manual belts. [This report's findings on air bags have been superseded by the 1996 evaluation - see above.]

An Evaluation of the Effects of Glass-Plastic Windshield Glazing in Passenger Cars (NHTSA Report No. DOT HS 808 062, www-nrd.nhtsa.dot.gov/Pubs/808062.PDF)

Following an amendment to the glazing standard (FMVSS No. 205) in 1983, two manufacturers equipped some of their cars with glass-plastic windshields. Crash data indicates the injury reduction potential of these windshields is less than predicted. Fleet and warranty data show that durability problems are greater than anticipated. While glass-plastic windshields add $65 to the cost of a new car, their replacement costs are estimated to exceed $1,700.

Correlation of NCAP Performance With Fatality Risk in Actual Head-On Collisions (NHTSA Report No. DOT HS 808 061, www-nrd.nhtsa.dot.gov/Pubs/808061.PDF)

There is a statistically significant correlation between the performance of passenger cars on the NCAP frontal-barrier test and the fatality risk of belted drivers in actual head-on collisions. In a head-on collision between a car with "good" NCAP performance and a car of equal mass with "poor" performance, the driver of the "good" car has, on the average, about 15-to-25 percent lower fatality risk. The steady improvement in NCAP scores during 1979 to 1991 was paralleled by a 20-to-25 percent reduction of fatality risk for belted drivers in actual head-on collisions.

1993

Preliminary Evaluation of the Effectiveness of Rear-Wheel Antilock Brake Systems for Light Trucks (Submitted to NHTSA Docket No. 70-27-GR-026, www-nrd.nhtsa.dot.gov/Pubs/7027GR.PDF)

[Findings have been superseded by the 2009 evaluation - see above.]

1992

Evaluation of the Effectiveness of Occupant Protection - Federal Motor Vehicle Safety FMVSS 208 - Interim Report (NHTSA Report No. DOT HS 807 843, www-nrd.nhtsa.dot.gov/Pubs/807843.pdf)

Air bags and automatic belts have significantly reduced the risk of nonfatal injury and occupant ejection. [This report's findings on fatality reduction for air bags have been superseded by the 1996 evaluation; for automatic belts - by the 1994 evaluation.]

An Evaluation of the Uniform Tire Quality Grading Standards and Other Tire Labeling Requirements (NHTSA Report No. DOT HS 807 805, www-nrd.nhtsa.dot.gov/Pubs/807805.PDF)

Consumers and tire dealers were surveyed about their knowledge and use of tire quality grades and other tire information supplied in response to Federal regulations. The ratings for treadwear were viewed as "important" by 29 percent of consumers who had recently purchased tires, and the ratings for traction, by 27 percent. The majority of consumers are not aware that these ratings are printed on the tires.

1991

Auto Theft and Recovery - Effects of the Motor Vehicle Theft Law Enforcement Act of 1984 - Report to the Congress (NHTSA Report No. DOT HS 807 703, www-nrd.nhtsa.dot.gov/Pubs/807703.pdf)

[Findings have been superseded by the 1998 evaluation - see above.]

Effect of Car Size on Fatality and Injury Risk

[Findings have been superseded by the 2012 evaluation - see above.]

1990

Motor Vehicle Fires in Traffic Crashes and the Effects of the Fuel System Integrity Standard (NHTSA Report No. DOT HS 807 675, www-nrd.nhtsa.dot.gov/Pubs/807675.PDF)

Modifications to fuel systems in response to FMVSS No. 301 reduced the frequency of fires in nonfatal crashes of passenger cars by an estimated 14 percent; fatalities in cars and LTVs, however, were not affected. During 1975 to 1988, the number of fire-related fatalities increased from 1,300 to 1,800, primarily due to an aging vehicle fleet.

1989

An Evaluation of Door Locks and Roof Crush Resistance of Passenger Cars - Federal Motor Vehicle Safety Standards 206 and 216 (NHTSA Report No. DOT HS 807 489, www-nrd.nhtsa.dot.gov/Pubs/807489.PDF)

Door latch improvements implemented during 1963 to 1968 (preceding or responding to FMVSS No. 206) save an estimated 400 lives per year, reducing the risk of ejection in rollover crashes by 15 percent. The shift from hardtops to pillared cars with stronger roof support, in response to FMVSS No. 216, saves an estimated 110 lives per year.

An Evaluation of Center High Mounted Stop Lamps Based on 1987 Data (NHTSA Report No. DOT HS 807 442, www-nrd.nhtsa.dot.gov/Pubs/807442.PDF)

[Findings have been superseded by the 1998 evaluation - see above.]

1988

An Evaluation of Occupant Protection in Frontal Interior Impact for Unrestrained Front Seat Occupants of Cars and Light Trucks (NHTSA Report No. DOT HS 807 203, www-nrd.nhtsa.dot.gov/Pubs/807203.PDF)

During the 1960s and early 1970s, the manufacturers modified instrument panels of cars and LTVs, installing padding, reducing the rigidity of structures and extending the panel downward and toward the passenger. The improvements reduced fatality risk and serious injury risk by nearly 25 percent for unrestrained RF passengers of cars in frontal crashes, saving up to 700 lives per year.

1987

An Evaluation of the Bumper Standard - As Modified in 1982 (NHTSA Report No. DOT HS 807 072, www-nrd.nhtsa.dot.gov/Pubs/807072.PDF)

To reduce regulatory burden on manufacturers, damage resistance requirements for bumpers were relaxed in model year 1983: the impact test speed was lowered from 5 to 2.5 mph. The net costs to consumers did not significantly change. A small increase in the repair cost over the lifetime of the car is offset by a reduction in the initial cost of the lighter bumpers. (See also the 1981 evaluation of bumpers.)

A Preliminary Evaluation of Seat Back Locks for Two-Door Passenger Cars With Folding Front Seatbacks (NHTSA Report No. DOT HS 807 067, www-nrd.nhtsa.dot.gov/Pubs/807067.PDF)

FMVSS No. 207 requires a locking device for front seats with folding seat backs, designed to limit the forward motion of the seat back in a collision. These locks or other seat components sometimes separate at moderate crash speeds when the seat backs are hit by rear seat occupants in frontal impacts. No statistically significant injury or fatality reductions were found for seat back locks in any of the crash data files or in sled tests.

Fatality and Injury Reducing Effectiveness of Lap Belts for Back Seat Occupants (SAE Paper 870486)

[Findings have been superseded by the 1999 evaluation - see above.]

The Effectiveness of Center High-Mounted Stop Lamps - A Preliminary Evaluation (NHTSA Report No. DOT HS 807 076, www-nrd.nhtsa.dot.gov/Pubs/HS807076.PDF)

[Findings have been superseded by the 1998 evaluation - see above.]

1986

Fuel Economy and Annual Travel for Passenger Cars and Light Trucks: National On-Road Survey (NHTSA Report No. DOT HS 806 971, www-nrd.nhtsa.dot.gov/Pubs/806971.PDF)

The actual fuel economy of model year 1978-to-1981 vehicles was measured by a national survey in which drivers maintained log books of mileage and fuel purchases. On-road fuel economy of cars increased by 41 percent during model years 1977 to 1981; the fuel economy of LTVs increased by 17 to 26 percent. However, the actual on-road fuel economy is consistently 15 to 20 percent below laboratory (EPA) ratings.

An Evaluation of Child Passenger Safety: The Effectiveness and Benefits of Safety Seats (NHTSA Report No. DOT HS 806 890, www-nrd.nhtsa.dot.gov/Pubs/806890.PDF)

A correctly used safety seat reduces fatality risk by an estimated 71 percent and serious injury risk by 67 percent. But misuse can partially or completely nullify this effect. In 1984, when 39 percent of safety seats were correctly used and 61 percent were misused, the average overall fatality reduction for safety seats (correct users plus misusers) was 46 percent. In all, 192 children were saved by safety seats and lap belts in 1984.

1985

An Evaluation of Windshield Glazing and Installation Methods for Passenger Cars (NHTSA Report No. DOT HS 806 693, www-nrd.nhtsa.dot.gov/Pubs/806693.PDF)

The high-penetration-resistant windshield doubled the impact velocity needed for the occupant's head to penetrate the windshield, reducing serious facial lacerations by 74 percent, preventing 39,000 serious lacerations and 8,000 facial fractures per year. Adhesive bonding of the windshield halved the incidence of bond separation and occupant ejection through the windshield portal in crashes, saving 105 lives per year.

1984

Effectiveness - Manual Lap and Lap/Shoulder Belts (Chapter IV-A of "Final Regulatory Impact Analysis - Amendment to Federal Motor Vehicle Safety Standard 208 - Passenger Car Front Seat Occupant Protection," NHTSA Report No. DOT HS 806 572)

Manual lap-shoulder belts are estimated to reduce the fatality risk of drivers and RF passengers by 40 to 50 percent [reconfirmed and superseded by the 2000 evaluation - see above], and serious injury risk by 45 to 55 percent, relative to an unrestrained occupant. The manual lap belt, alone, is estimated to reduce fatality risk by 30 to 40 percent and serious injury risk by 25 to 35 percent.

1983

An Evaluation of Side Marker Lamps for Cars, Trucks and Buses (NHTSA Report No. DOT HS 806 430, www-nrd.nhtsa.dot.gov/Pubs/806430.PDF)

Side marker lamps were installed in response to FMVSS No. 108 to enable a driver to see another vehicle that is approaching at an angle at night. The lamps reduced nonfatal nighttime angle collisions by 16 percent, preventing 106,000 crashes, 93,000 injuries, and $347 million in property damage per year. The lamps have not been effective in reducing fatalities.

A Preliminary Evaluation of Two Braking Improvements for Passenger Cars - Dual Master Cylinders and Front Disc Brakes (NHTSA Report No. DOT HS 806 359, www-nrd.nhtsa.dot.gov/Pubs/806359.PDF)

Dual master cylinders, by providing a backup braking system in case of certain types of brake failure, prevent 40,000 crashes, 260 fatalities, 24,000 injuries and $132 million in property damage per year. Front disc brakes, which improve vehicle handling under various braking conditions, are estimated to prevent 10,000 crashes, 64 fatalities, 5,700 injuries and $32 million in property damage per year.

Evaluation of Federal Motor Vehicle Safety Standard 301-75, Fuel System Integrity: Passenger Cars (NHTSA Report No. DOT HS 806 335, www-nrd.nhtsa.dot.gov/Pubs/HS806335.pdf)

[Findings have been superseded by the 1990 evaluation - see above.]

1982

An Evaluation of Side Structure Improvements in Response to Federal Motor Vehicle Safety Standard 214 (NHTSA Report No. DOT HS 806 314, www-nrd.nhtsa.dot.gov/Pubs/806314.PDF)

Side door beams were installed in passenger cars to reduce the velocity and depth of door intrusion in side-impact crashes. The beams are especially effective in side impacts with fixed objects, preventing 480 fatalities and 4,500 hospitalizations per year. In vehicle-to-vehicle side impacts, they prevent 4,900 nonfatal hospitalizations per year, but have not reduced fatality risk.

An Evaluation of Head Restraints - Federal Motor Vehicle Safety Standard 202 (NHTSA Report No. DOT HS 806 108, www-nrd.nhtsa.dot.gov/Pubs/806108.PDF)

The purpose of a head restraint is to prevent whiplash injury in rear-impact crashes. There are integral (fixed) and adjustable head restraints; 75 percent of adjustable restraints are left in the "down" position by occupants. In 1982, integral head restraints reduced injury risk in rear impacts by 17 percent; adjustable restraints by 10 percent. The 1982 mix of head restraints prevented 64,000 whiplash injuries per year. [Subsequently, manufacturers have enlarged adjustable restraints to provide better protection, even in the "down" position. See also the 2001 evaluation of head restraints in LTVs.]

1981

An Evaluation of the Bumper Standard (NHTSA Report No. DOT HS 805 866, www-nrd.nhtsa.dot.gov/Pubs/HS805866.pdf)

In order to reduce car repair costs for consumers, damage resistance tests were established for bumpers in model year 1973 and upgraded in 1974 and 1979. The bumper standards did not significantly change net costs for consumers: the savings in repair costs over the lifetime of the car are almost equal to the increase in the initial cost of the bumpers. (See also the 1987 evaluation of bumpers.)

An Evaluation of Federal Motor Vehicle Safety Standards for Passenger Car Steering Assemblies: Standard 203 - Impact Protection for the Driver; Standard 204 - Rearward Column Displacement (NHTSA Report No. DOT HS 805 705, www-nrd.nhtsa.dot.gov/Pubs/805705.PDF)

Energy-absorbing, telescoping steering columns reduced the risk of serious injury due to steering-assembly contact by 38 percent. Rearward column displacement was reduced by 81 percent. The standards prevent 1,300 fatalities and 23,000 hospitalizations per year. The performance of energy-absorbing steering assemblies is degraded under non-axial impact conditions.

1979

An Evaluation of Standard 214 (NHTSA Report No. DOT HS 804 858, www-nrd.nhtsa.dot.gov/Pubs/HS804858.pdf)

[Findings have been superseded by the 1982 evaluation - see above.]

APPENDIX C

Year-by-Year Percentages of Cars and LTVs Equipped With Safety Technologies

New Vehicles (by Model Year) and All Vehicles on the Road (by Calendar Year)

In Tables C-1 and C-3, the **median installation year** for selected technologies (the first model year in which 50 percent or more of new vehicles were equipped with the technology) is shown in **bold red type**.

Table C-1

Percent of New Passenger Cars With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	OUTBOARD FRONT LAP BELTS	IMPROVED DOOR LOCKS	OUTBOARD REAR LAP BELTS	WINDSHIELD BONDING	FRONT LAP BELTS	MASTER CYLINDERS
1960	20.00	0.00	0.00	0.00	0.00	0.00
1961	35.00	0.00	10.00	0.00	9.00	0.00
1962	**50.00**	14.29	20.00	0.00	18.00	9.00
1963	65.00	28.57	30.00	2.14	27.00	9.00
1964	80.00	42.86	40.00	11.63	36.00	7.00
1965	99.72	**57.14**	**50.00**	48.92	45.00	7.00
1966	99.68	71.43	75.00	**57.05**	**54.00**	**54.00**
1967	99.35	85.71	100.00	60.80	100.00	100.00
1968	85.79	100.00	100.00	65.39	100.00	100.00
1969	72.32	100.00	100.00	75.17	100.00	100.00
1970	72.94	100.00	100.00	74.51	100.00	100.00
1971	72.26	100.00	99.55	74.91	100.00	100.00
1972	74.50	100.00	99.62	74.99	100.00	100.00
1973	74.20	100.00	99.65	77.37	100.00	100.00
1974	0.00	100.00	99.39	69.62	100.00	100.00
1975	0.00	100.00	99.04	71.78	100.00	100.00
1976	0.00	100.00	99.29	73.39	100.00	100.00
1977	0.00	100.00	99.46	76.64	100.00	100.00
1978	0.00	100.00	99.39	82.46	100.00	100.00
1979	0.00	100.00	99.36	83.50	100.00	100.00
1980	0.00	100.00	99.26	100.00	100.00	100.00
1981	0.00	100.00	98.29	100.00	100.00	100.00
1982	0.00	100.00	95.92	100.00	100.00	100.00
1983	0.00	100.00	94.18	100.00	100.00	100.00
1984	0.00	100.00	94.45	100.00	100.00	100.00
1985	0.00	100.00	94.25	100.00	100.00	100.00
1986	0.00	100.00	93.14	100.00	100.00	100.00
1987	0.00	100.00	90.38	100.00	100.00	100.00
1988	0.00	100.00	69.33	100.00	100.00	100.00
1989	0.00	100.00	32.33	100.00	100.00	100.00
1990	0.00	100.00	0.00	100.00	100.00	100.00
1991	0.00	100.00	0.00	100.00	100.00	100.00
1992	0.00	100.00	0.00	100.00	100.00	100.00
1993	0.00	100.00	0.00	100.00	100.00	100.00
1994	0.00	100.00	0.00	100.00	100.00	100.00
1995	0.00	100.00	0.00	100.00	100.00	100.00
1996	0.00	100.00	0.00	100.00	100.00	100.00
1997	0.00	100.00	0.00	100.00	100.00	100.00
1998	0.00	100.00	0.00	100.00	100.00	100.00
1999	0.00	100.00	0.00	100.00	100.00	100.00
2000	0.00	100.00	0.00	100.00	100.00	100.00
2001	0.00	100.00	0.00	100.00	100.00	100.00
2002	0.00	100.00	0.00	100.00	100.00	100.00
2003	0.00	100.00	0.00	100.00	100.00	100.00
2004	0.00	100.00	0.00	100.00	100.00	100.00
2005	0.00	100.00	0.00	100.00	100.00	100.00
2006	0.00	100.00	0.00	100.00	100.00	100.00
2007	0.00	100.00	0.00	100.00	100.00	100.00
2008	0.00	100.00	0.00	100.00	100.00	100.00
2009	0.00	100.00	0.00	100.00	100.00	100.00
2010	0.00	100.00	0.00	100.00	100.00	100.00
2011	0.00	100.00	0.00	100.00	100.00	100.00
2012	0.00	100.00	0.00	100.00	100.00	100.00

Table C-1 (continued)

Percent of New Passenger Cars With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	CENTER REAR LAP BELTS	ENERGY-ABSORBING STEERING ASSEMBLY	IMPROVED INSTRUMENT PANELS	FRONT DISC BRAKES	SIDE DOOR BEAMS	ROOF CRUSH STRENGTH (1970s)
1960	0.00	0.00	0.00	0.00	0.00	0.00
1961	8.00	0.00	0.00	0.00	0.00	0.00
1962	16.00	0.00	0.00	0.00	0.00	0.00
1963	24.00	0.00	0.00	0.00	0.00	0.00
1964	32.00	0.00	0.00	0.00	0.00	0.00
1965	40.00	0.00	0.00	2.00	0.00	0.00
1966	48.00	0.00	0.00	3.00	0.00	0.00
1967	**75.00**	**63.37**	25.00	6.00	0.00	0.00
1968	100.00	100.00	**50.00**	13.00	0.00	0.00
1969	100.00	100.00	60.00	28.00	17.64	0.00
1970	100.00	100.00	70.00	41.00	36.17	12.50
1971	100.00	100.00	80.00	**63.00**	44.04	25.00
1972	100.00	100.00	90.00	74.00	49.33	37.50
1973	100.00	100.00	100.00	86.00	**85.02**	**50.00**
1974	100.00	100.00	100.00	84.00	100.00	62.50
1975	100.00	100.00	100.00	93.00	100.00	75.00
1976	100.00	100.00	100.00	99.00	100.00	87.50
1977	100.00	100.00	100.00	100.00	100.00	100.00
1978	100.00	100.00	100.00	100.00	100.00	100.00
1979	100.00	100.00	100.00	100.00	100.00	100.00
1980	100.00	100.00	100.00	100.00	100.00	100.00
1981	100.00	100.00	100.00	100.00	100.00	100.00
1982	100.00	100.00	100.00	100.00	100.00	100.00
1983	100.00	100.00	100.00	100.00	100.00	100.00
1984	100.00	100.00	100.00	100.00	100.00	100.00
1985	100.00	100.00	100.00	100.00	100.00	100.00
1986	100.00	100.00	100.00	100.00	100.00	100.00
1987	100.00	100.00	100.00	100.00	100.00	100.00
1988	100.00	100.00	100.00	100.00	100.00	100.00
1989	100.00	100.00	100.00	100.00	100.00	100.00
1990	100.00	100.00	100.00	100.00	100.00	100.00
1991	100.00	100.00	100.00	100.00	100.00	100.00
1992	100.00	100.00	100.00	100.00	100.00	100.00
1993	100.00	100.00	100.00	100.00	100.00	100.00
1994	99.56	100.00	100.00	100.00	100.00	100.00
1995	99.50	100.00	100.00	100.00	100.00	100.00
1996	98.46	100.00	100.00	100.00	100.00	100.00
1997	89.29	100.00	100.00	100.00	100.00	100.00
1998	75.40	100.00	100.00	100.00	100.00	100.00
1999	71.68	100.00	100.00	100.00	100.00	100.00
2000	60.39	100.00	100.00	100.00	100.00	100.00
2001	44.88	100.00	100.00	100.00	100.00	100.00
2002	40.51	100.00	100.00	100.00	100.00	100.00
2003	24.65	100.00	100.00	100.00	100.00	100.00
2004	17.04	100.00	100.00	100.00	100.00	100.00
2005	10.63	100.00	100.00	100.00	100.00	100.00
2006	7.02	100.00	100.00	100.00	100.00	100.00
2007	5.94	100.00	100.00	100.00	100.00	100.00
2008	0.00	100.00	100.00	100.00	100.00	100.00
2009	0.00	100.00	100.00	100.00	100.00	100.00
2010	0.00	100.00	100.00	100.00	100.00	100.00
2011	0.00	100.00	100.00	100.00	100.00	100.00
2012	0.00	100.00	100.00	100.00	100.00	100.00

Table C-1 (continued)

Percent of New Passenger Cars With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	OUTBOARD FRONT 3-POINT BELTS	NCAP IMPROVEMENT, W/O AIR BAGS	OUTBOARD REAR 3-POINT BELTS	AUTOMATIC 2-POINT BELTS	ANY FRONTAL AIR BAGS	BARRIER-CERTIFIED FRONTAL AIR BAGS
1960	0.00	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.28	0.00	0.00	0.00	0.00	0.00
1966	0.32	0.00	0.00	0.00	0.00	0.00
1967	0.65	0.00	0.00	0.00	0.00	0.00
1968	14.21	0.00	0.00	0.00	0.00	0.00
1969	27.68	0.00	0.00	0.00	0.00	0.00
1970	27.06	0.00	0.00	0.00	0.00	0.00
1971	27.74	0.00	0.45	0.00	0.00	0.00
1972	25.50	0.00	0.38	0.00	0.00	0.00
1973	25.80	0.00	0.35	0.00	0.00	0.00
1974	**100.00**	0.00	0.61	0.00	0.00	0.00
1975	99.57	0.00	0.96	0.43	0.00	0.00
1976	99.65	0.00	0.71	0.35	0.00	0.00
1977	99.59	0.00	0.54	0.41	0.00	0.00
1978	99.59	0.00	0.61	0.41	0.00	0.00
1979	99.51	0.00	0.64	0.49	0.00	0.00
1980	99.44	0.00	0.74	0.56	0.00	0.00
1981	98.97	0.00	1.71	1.03	0.00	0.00
1982	99.29	23.73	4.08	0.71	0.00	0.00
1983	99.35	48.04	5.82	0.65	0.00	0.00
1984	99.67	**64.98**	5.55	0.33	0.00	0.00
1985	99.72	80.62	5.75	0.28	0.11	0.11
1986	99.69	96.78	6.86	0.31	0.53	0.53
1987	93.37	90.52	9.62	6.63	0.92	0.92
1988	87.77	84.91	30.67	12.23	1.23	1.23
1989	83.96	78.85	**67.67**	16.04	3.22	3.22
1990	59.88	32.79	100.00	40.12	25.68	25.68
1991	58.92	25.05	100.00	**41.08**	32.83	32.83
1992	71.80	21.27	100.00	28.20	**51.15**	51.15
1993	73.49	16.78	100.00	26.51	62.77	62.77
1994	80.68	7.94	100.00	19.32	83.61	83.61
1995	93.55	0.05	100.00	6.45	99.54	99.54
1996	97.31	0.02	100.00	2.69	99.98	99.98
1997	100.00	0.00	100.00	0.00	100.00	100.00
1998	100.00	0.00	100.00	0.00	100.00	20.22
1999	100.00	0.00	100.00	0.00	100.00	2.35
2000	100.00	0.00	100.00	0.00	100.00	0.00
2001	100.00	0.00	100.00	0.00	100.00	0.00
2002	100.00	0.00	100.00	0.00	100.00	0.00
2003	100.00	0.00	100.00	0.00	100.00	0.00
2004	100.00	0.00	100.00	0.00	100.00	0.00
2005	100.00	0.00	100.00	0.00	100.00	0.00
2006	100.00	0.00	100.00	0.00	100.00	0.00
2007	100.00	0.00	100.00	0.00	100.00	0.00
2008	100.00	0.00	100.00	0.00	100.00	0.00
2009	100.00	0.00	100.00	0.00	100.00	0.00
2010	100.00	0.00	100.00	0.00	100.00	0.00
2011	100.00	0.00	100.00	0.00	100.00	0.00
2012	100.00	0.00	100.00	0.00	100.00	0.00

Table C-1 (continued)

Percent of New Passenger Cars With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	RF PASSENGER AIR BAGS	FMVSS 214 DYNAMIC TEST UPGRADE	SLED-CERTIFIED FRONTAL AIR BAGS	FMVSS 201 HEAD IMPACT UPGRADE	CENTER REAR 3-POINT BELTS	PRETENSIONER AND LOAD LIMITER
1960	0.00	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.05	0.00	0.00	0.00	0.00	0.00
1988	0.03	0.00	0.00	0.00	0.00	0.00
1989	0.39	0.00	0.00	0.00	0.00	0.00
1990	1.40	0.00	0.00	0.00	0.00	0.00
1991	0.59	0.00	0.00	0.00	0.00	0.00
1992	4.45	0.00	0.00	0.00	0.00	0.00
1993	12.30	0.00	0.00	0.00	0.00	0.00
1994	54.88	18.28	0.00	0.00	0.49	0.00
1995	88.77	41.36	0.00	0.00	0.56	0.27
1996	93.24	**64.56**	0.00	0.00	1.68	0.51
1997	100.00	100.00	0.00	0.00	11.60	1.01
1998	100.00	100.00	79.78	0.00	26.63	10.67
1999	100.00	100.00	97.65	20.53	30.86	13.84
2000	100.00	100.00	100.00	47.54	43.00	30.04
2001	100.00	100.00	100.00	**63.43**	**59.59**	49.87
2002	100.00	100.00	100.00	71.55	64.86	**55.11**
2003	100.00	100.00	100.00	100.00	82.13	62.11
2004	100.00	100.00	87.25	100.00	89.60	70.62
2005	100.00	100.00	60.95	100.00	95.15	79.05
2006	100.00	100.00	15.75	100.00	99.60	99.57
2007	100.00	100.00	0.00	100.00	99.71	100.00
2008	100.00	100.00	0.00	100.00	100.00	100.00
2009	100.00	100.00	0.00	100.00	100.00	100.00
2010	100.00	100.00	0.00	100.00	100.00	100.00
2011	100.00	100.00	0.00	100.00	100.00	100.00
2012	100.00	100.00	0.00	100.00	100.00	100.00

Table C-1 (continued)

Percent of New Passenger Cars With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	ADVANCED FRONTAL AIR BAGS	ANY SIDE AIR BAGS	CURTAIN PLUS TORSO BAGS	FMVSS 301 REAR IMPACT UPGRADE	ELECTRONIC STABILITY CONTROL	ROLLOVER CURTAINS
1960	0.00	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.49	0.00	0.00	0.00	0.00
1997	0.00	2.82	0.00	0.00	0.00	0.00
1998	0.00	8.55	0.54	0.00	0.26	0.00
1999	0.00	12.98	1.53	0.00	1.91	0.00
2000	0.00	22.36	2.02	0.00	4.98	0.00
2001	0.00	30.33	6.48	0.00	7.20	0.00
2002	0.00	31.73	8.33	0.00	8.01	0.00
2003	0.00	32.84	12.95	0.00	11.77	0.36
2004	12.99	35.51	17.22	0.00	12.52	0.37
2005	42.10	37.10	20.37	0.00	12.50	0.40
2006	88.07	**50.08**	31.16	13.92	19.75	1.14
2007	100.00	70.08	49.33	45.58	20.17	1.04
2008	100.00	88.79	67.00	**70.65**	30.04	1.52
2009	100.00	96.95	82.27	100.00	36.05	1.33
2010	100.00	99.62	87.85	100.00	**74.89**	7.68
2011	100.00	99.65	92.78	100.00	88.72	9.00
2012	100.00	96.09	91.35	100.00	100.00	12.86

Table C-2:

Percent of Passenger Cars on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	OUTBOARD FRONT LAP BELTS	IMPROVED DOOR LOCKS	OUTBOARD REAR LAP BELTS	ADHESIVE WINDSHIELD BONDING	CENTER FRONT LAP BELTS	DUAL MASTER CYLINDERS
1975	66.51	86.74	87.56	63.70	85.74	81.91
1976	60.71	89.83	90.55	65.51	89.13	86.12
1977	52.55	92.28	92.71	67.50	91.74	89.48
1978	46.17	94.17	94.31	69.93	93.77	92.05
1979	39.21	95.59	95.63	71.99	95.28	93.99
1980	33.14	96.65	96.58	75.08	96.43	95.48
1981	27.91	97.17	96.91	77.43	96.98	96.13
1982	24.32	97.52	96.95	79.37	97.36	96.67
1983	20.33	98.10	97.21	81.68	97.99	97.50
1984	16.50	98.54	97.32	83.40	98.47	98.04
1985	12.43	98.80	97.25	86.50	98.72	98.34
1986	10.55	98.97	96.76	88.32	98.91	98.63
1987	7.53	99.23	96.21	90.57	99.18	98.97
1988	5.58	99.42	94.26	92.21	99.36	99.17
1989	4.23	99.52	89.41	94.09	99.50	99.35
1990	3.49	99.53	82.79	94.63	99.49	99.35
1991	2.64	99.65	76.02	96.00	99.64	99.54
1992	2.19	99.73	69.98	96.57	99.70	99.61
1993	1.78	99.74	63.92	97.18	99.74	99.65
1994	1.59	99.72	56.67	97.76	99.69	99.61
1995	1.18	99.79	49.88	98.19	99.77	99.71
1996	1.00	99.80	42.42	98.58	99.79	99.75
1997	0.84	99.82	37.76	98.81	99.81	99.77
1998	0.75	99.85	32.50	99.29	99.84	99.80
1999	0.57	99.87	26.81	99.24	99.87	99.84
2000	0.50	99.88	21.48	99.44	99.87	99.85
2001	0.38	99.90	16.82	99.54	99.89	99.86
2002	0.42	99.90	13.65	99.60	99.89	99.87
2003	0.32	99.92	10.23	99.65	99.92	99.89
2004	0.27	99.93	7.90	99.69	99.93	99.91
2005	0.20	99.93	5.94	99.77	99.93	99.91
2006	0.16	99.95	4.51	99.83	99.95	99.94
2007	0.17	99.94	3.51	99.78	99.93	99.93
2008	0.12	99.93	3.10	99.85	99.93	99.92
2009	0.17	99.94	2.63	99.85	99.93	99.92
2010	0.10	99.88	2.04	99.82	99.88	99.88
2011	0.20	99.90	1.89	99.79	99.89	99.87
2012	0.10	99.94	1.70	99.86	99.94	99.94

Table C-2 (continued):

Percent of Passenger Cars on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	CENTER REAR LAP BELTS	ENERGY-ABSORBING STEERING ASSEMBLY	IMPROVED INSTRUMENT PANELS	FRONT DISC BRAKES	SIDE DOOR BEAMS	ROOF CRUSH STRENGTH (1970s)
1975	83.00	74.61	58.87	42.96	37.23	22.55
1976	86.76	80.08	65.12	49.71	44.37	28.97
1977	89.93	84.99	71.75	57.69	52.47	37.83
1978	92.36	88.51	77.09	64.48	60.60	46.11
1979	94.18	91.14	81.77	70.84	68.20	54.38
1980	95.58	93.33	85.56	76.01	74.15	61.10
1981	96.31	94.38	88.09	79.91	78.08	66.75
1982	96.75	95.10	89.75	82.59	81.19	70.84
1983	97.51	96.19	91.66	85.42	84.34	75.09
1984	98.08	97.08	93.46	88.30	87.36	79.56
1985	98.40	97.48	94.87	90.98	90.27	84.30
1986	98.66	97.97	95.72	92.33	92.03	86.44
1987	99.00	98.49	96.83	94.39	93.84	90.13
1988	99.22	98.78	97.60	95.82	95.53	92.66
1989	99.38	99.07	98.14	96.77	96.35	94.39
1990	99.40	99.10	98.34	97.23	96.99	95.24
1991	99.55	99.32	98.72	97.88	97.69	96.45
1992	99.64	99.43	98.94	98.24	98.10	97.02
1993	99.68	99.53	99.11	98.56	98.47	97.58
1994	99.63	99.46	99.08	98.61	98.48	97.86
1995	99.68	99.59	99.31	98.93	98.76	98.30
1996	99.64	99.63	99.40	99.11	99.03	98.66
1997	99.15	99.70	99.48	99.23	99.15	98.83
1998	97.86	99.72	99.56	99.36	99.30	99.03
1999	96.79	99.77	99.63	99.47	99.37	99.23
2000	94.40	99.80	99.65	99.49	99.40	99.28
2001	90.86	99.81	99.73	99.62	99.55	99.46
2002	87.17	99.83	99.73	99.61	99.55	99.43
2003	82.84	99.85	99.78	99.70	99.68	99.57
2004	78.37	99.87	99.82	99.75	99.72	99.65
2005	72.52	99.88	99.83	99.76	99.72	99.68
2006	66.89	99.91	99.88	99.83	99.78	99.75
2007	59.94	99.90	99.86	99.81	99.75	99.75
2008	55.24	99.91	99.87	99.84	99.82	99.80
2009	49.85	99.89	99.86	99.81	99.77	99.75
2010	46.40	99.85	99.83	99.80	99.80	99.78
2011	43.93	99.86	99.80	99.75	99.73	99.69
2012	39.39	99.91	99.89	99.86	99.85	99.83

Table C-2 (continued):

Percent of Passenger Cars on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	OUTBOARD FRONT 3-POINT BELTS	NCAP IMPROVEMENT, NO AIR BAG	OUTBOARD REAR 3-POINT BELTS	AUTOMATIC 2-POINT BELTS	ANY FRONTAL AIR BAG	BARRIER-CERTIFIED FRONTAL AIR BAGS
1975	28.89	0.00	0.16	0.02	0.00	0.00
1976	35.95	0.00	0.14	0.05	0.00	0.00
1977	44.79	0.00	0.23	0.11	0.00	0.00
1978	51.84	0.00	0.39	0.14	0.00	0.00
1979	59.18	0.00	0.37	0.22	0.00	0.00
1980	65.54	0.00	0.40	0.25	0.00	0.00
1981	70.82	0.06	0.50	0.34	0.00	0.00
1982	74.57	1.39	0.80	0.30	0.00	0.00
1983	78.63	4.69	1.09	0.38	0.00	0.00
1984	82.57	10.41	1.37	0.46	0.00	0.00
1985	86.77	17.91	1.67	0.44	0.01	0.01
1986	88.68	25.54	2.30	0.40	0.04	0.04
1987	91.46	33.71	3.09	0.74	0.08	0.08
1988	92.22	40.64	5.20	2.03	0.27	0.27
1989	91.99	45.82	10.15	3.61	0.46	0.46
1990	89.78	46.09	16.77	6.55	2.31	2.31
1991	88.20	47.22	23.67	9.02	4.48	4.48
1992	86.93	47.96	29.76	10.80	7.08	7.08
1993	85.56	47.52	35.84	12.55	11.26	11.26
1994	84.10	46.96	43.06	14.19	16.08	16.08
1995	84.73	44.91	49.92	14.00	23.43	23.43
1996	84.16	41.94	57.40	14.76	30.67	30.67
1997	85.03	40.44	62.07	14.05	35.50	35.31
1998	85.42	36.70	67.35	13.76	41.97	37.99
1999	85.87	32.72	73.07	13.50	48.57	38.74
2000	86.49	28.44	78.40	12.93	54.72	38.48
2001	87.90	24.68	83.08	11.67	61.18	38.48
2002	88.65	20.59	86.25	10.87	66.72	37.61
2003	89.83	17.07	89.70	9.83	72.50	37.52
2004	90.56	13.81	92.03	9.14	77.00	36.25
2005	92.06	11.09	93.99	7.70	81.45	34.22
2006	93.11	8.93	95.45	6.70	84.72	31.39
2007	94.61	6.78	96.42	5.17	88.26	28.77
2008	95.56	5.76	96.83	4.27	90.09	25.05
2009	95.98	4.81	97.31	3.82	91.35	22.79
2010	96.77	3.69	97.84	3.03	93.46	21.48
2011	96.93	3.08	98.01	2.79	94.05	19.66
2012	97.72	2.62	98.24	2.14	95.10	17.36

Table C-2 (continued):

Percent of Passenger Cars on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	RF PASSENGER AIR BAG	FMVSS 214 DYNAMIC TEST UPGRADE	SLED-CERTIFIED FRONTAL AIR BAGS	FMVSS 201 HEAD IMPACT UPGRADE	CENTER REAR 3-POINT BELTS	PRETENSIONER AND LOAD LIMITER
1975	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.01	0.00	0.00	0.00	0.00	0.00
1989	0.03	0.00	0.00	0.00	0.00	0.00
1990	0.15	0.00	0.00	0.00	0.00	0.00
1991	0.13	0.00	0.00	0.00	0.00	0.00
1992	0.29	0.00	0.00	0.00	0.00	0.00
1993	1.18	0.07	0.00	0.00	0.00	0.00
1994	4.17	0.91	0.00	0.00	0.01	0.00
1995	10.39	3.75	0.00	0.00	0.05	0.01
1996	16.96	7.79	0.00	0.00	0.12	0.05
1997	22.10	13.03	0.19	0.00	0.64	0.10
1998	28.08	18.60	3.96	0.11	2.02	0.69
1999	34.75	25.25	9.76	0.97	3.17	1.27
2000	40.76	31.49	16.11	3.44	5.71	2.85
2001	48.12	38.54	22.57	7.17	9.46	5.69
2002	54.27	44.96	28.90	11.39	13.35	9.17
2003	60.58	51.19	34.78	17.29	18.04	12.69
2004	65.81	56.49	39.88	22.92	22.83	16.50
2005	71.47	63.22	44.10	29.74	29.10	21.87
2006	75.75	68.35	45.68	35.51	35.12	27.48
2007	80.61	73.51	45.72	42.05	42.54	34.36
2008	83.80	78.14	46.54	48.06	47.48	40.10
2009	85.68	80.50	45.72	52.19	53.01	43.86
2010	88.37	83.44	44.99	55.86	56.35	48.69
2011	89.33	85.11	43.81	59.08	59.09	51.51
2012	91.26	87.38	42.93	63.64	63.48	55.90

Table C-2 (continued):

Percent of Passenger Cars on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	ADVANCED FRONTAL AIR BAGS	ANY SIDE AIR BAGS	CURTAIN PLUS TORSO BAGS	FMVSS 301 REAR IMPACT UPGRADE	ELECTRONIC STABILITY CONTROL	ROLLOVER CURTAINS
1975	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.02	0.00	0.00	0.00	0.00
1997	0.00	0.20	0.00	0.00	0.00	0.00
1998	0.00	0.63	0.01	0.00	0.01	0.00
1999	0.00	1.25	0.05	0.00	0.06	0.00
2000	0.00	2.04	0.14	0.00	0.41	0.00
2001	0.00	3.73	0.48	0.00	0.77	0.00
2002	0.00	5.73	0.88	0.00	0.96	0.00
2003	0.03	7.51	1.56	0.00	1.65	0.01
2004	0.76	9.61	2.40	0.00	2.32	0.04
2005	3.00	12.62	3.78	0.07	3.42	0.10
2006	7.53	15.20	5.46	0.92	4.23	0.06
2007	13.78	20.50	8.97	3.16	6.03	0.20
2008	18.58	25.13	11.99	6.68	7.43	0.18
2009	22.97	29.57	15.80	10.31	8.95	0.62
2010	27.24	33.10	19.07	14.31	12.41	0.46
2011	30.77	37.24	23.04	18.37	15.51	1.02
2012	35.04	41.62	27.01	23.08	20.37	1.49

Table C-3:

Percent of New LTVs With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	OUTBOARD FRONT LAP BELTS	DUAL MASTER CYLINDERS	IMPROVED DOOR LOCKS	OUTBOARD REAR LAP BELTS	CENTER FRONT LAP BELTS	CENTER REAR LAP BELTS
1960	15.00	0.00	0.00	0.00	0.00	0.00
1961	20.00	0.00	0.00	0.00	0.00	0.00
1962	30.00	9.00	9.09	7.00	6.00	5.00
1963	40.00	9.00	18.18	14.00	12.00	10.00
1964	**60.00**	7.00	27.27	21.00	18.00	15.00
1965	80.00	7.00	36.36	28.00	24.00	20.00
1966	100.00	**54.00**	45.45	35.00	30.00	25.00
1967	100.00	100.00	**54.55**	**50.00**	45.00	40.00
1968	100.00	100.00	63.64	100.00	**100.00**	**100.00**
1969	97.19	100.00	72.73	100.00	100.00	100.00
1970	96.79	100.00	81.82	100.00	100.00	100.00
1971	96.17	100.00	90.91	100.00	100.00	100.00
1972	94.49	100.00	100.00	100.00	100.00	100.00
1973	94.60	100.00	100.00	100.00	100.00	100.00
1974	59.52	100.00	100.00	100.00	100.00	100.00
1975	56.48	100.00	100.00	100.00	100.00	100.00
1976	55.28	100.00	100.00	100.00	100.00	100.00
1977	15.67	100.00	100.00	100.00	100.00	100.00
1978	14.93	100.00	100.00	100.00	100.00	100.00
1979	15.95	100.00	100.00	100.00	100.00	100.00
1980	5.72	100.00	100.00	100.00	100.00	100.00
1981	0.00	100.00	100.00	100.00	100.00	100.00
1982	0.00	100.00	100.00	100.00	100.00	100.00
1983	0.00	100.00	100.00	100.00	100.00	100.00
1984	0.00	100.00	100.00	100.00	100.00	100.00
1985	0.00	100.00	100.00	100.00	100.00	100.00
1986	0.00	100.00	100.00	100.00	100.00	100.00
1987	0.00	100.00	100.00	99.71	100.00	100.00
1988	0.00	100.00	100.00	97.16	100.00	100.00
1989	0.00	100.00	100.00	83.20	100.00	100.00
1990	0.00	100.00	100.00	79.99	100.00	100.00
1991	0.00	100.00	100.00	67.75	100.00	100.00
1992	0.00	100.00	100.00	0.00	100.00	100.00
1993	0.00	100.00	100.00	0.00	100.00	100.00
1994	0.00	100.00	100.00	0.00	100.00	100.00
1995	0.00	100.00	100.00	0.00	100.00	100.00
1996	0.00	100.00	100.00	0.00	100.00	100.00
1997	0.00	100.00	100.00	0.00	100.00	100.00
1998	0.00	100.00	100.00	0.00	100.00	99.82
1999	0.00	100.00	100.00	0.00	100.00	99.08
2000	0.00	100.00	100.00	0.00	100.00	98.26
2001	0.00	100.00	100.00	0.00	100.00	92.98
2002	0.00	100.00	100.00	0.00	100.00	78.98
2003	0.00	100.00	100.00	0.00	100.00	55.88
2004	0.00	100.00	100.00	0.00	100.00	41.08
2005	0.00	100.00	100.00	0.00	100.00	29.91
2006	0.00	100.00	100.00	0.00	100.00	22.66
2007	0.00	100.00	100.00	0.00	100.00	16.28
2008	0.00	100.00	100.00	0.00	100.00	0.00
2009	0.00	100.00	100.00	0.00	100.00	0.00
2010	0.00	100.00	100.00	0.00	100.00	0.00
2011	0.00	100.00	100.00	0.00	100.00	0.00
2012	0.00	100.00	100.00	0.00	100.00	0.00

Table C-3 (continued):

Percent of New LTVs With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	FRONT DISC BRAKES	IMPROVED INSTRUMENT PANELS	ENERGY-ABSORBING STEERING ASSEMBLY	OUTBOARD FRONT 3-POINT BELTS	ADHESIVE WINDSHIELD BONDING
1960	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00
1965	2.00	0.00	0.00	0.00	0.00
1966	3.00	0.00	0.00	0.00	0.00
1967	6.00	0.00	0.00	0.00	0.00
1968	13.00	0.00	0.00	0.00	0.00
1969	28.00	12.50	0.00	2.81	0.00
1970	41.00	25.00	3.21	3.21	0.00
1971	**63.00**	37.50	3.83	3.83	0.00
1972	74.00	**50.00**	1.81	5.51	0.00
1973	86.00	62.50	48.93	5.40	0.00
1974	84.00	75.00	49.23	40.48	0.00
1975	93.00	87.50	**50.10**	43.52	0.00
1976	99.00	100.00	53.66	44.72	0.00
1977	100.00	100.00	56.10	**84.33**	0.00
1978	100.00	100.00	55.01	85.07	20.00
1979	100.00	100.00	61.47	84.05	40.00
1980	100.00	100.00	78.22	94.28	**50.00**
1981	100.00	100.00	79.09	100.00	60.00
1982	100.00	100.00	100.00	100.00	70.00
1983	100.00	100.00	100.00	100.00	80.00
1984	100.00	100.00	100.00	100.00	90.00
1985	100.00	100.00	100.00	100.00	100.00
1986	100.00	100.00	100.00	100.00	100.00
1987	100.00	100.00	100.00	100.00	100.00
1988	100.00	100.00	100.00	100.00	100.00
1989	100.00	100.00	100.00	100.00	100.00
1990	100.00	100.00	100.00	100.00	100.00
1991	100.00	100.00	100.00	100.00	100.00
1992	100.00	100.00	100.00	100.00	100.00
1993	100.00	100.00	100.00	100.00	100.00
1994	100.00	100.00	100.00	100.00	100.00
1995	100.00	100.00	100.00	100.00	100.00
1996	100.00	100.00	100.00	100.00	100.00
1997	100.00	100.00	100.00	100.00	100.00
1998	100.00	100.00	100.00	100.00	100.00
1999	100.00	100.00	100.00	100.00	100.00
2000	100.00	100.00	100.00	100.00	100.00
2001	100.00	100.00	100.00	100.00	100.00
2002	100.00	100.00	100.00	100.00	100.00
2003	100.00	100.00	100.00	100.00	100.00
2004	100.00	100.00	100.00	100.00	100.00
2005	100.00	100.00	100.00	100.00	100.00
2006	100.00	100.00	100.00	100.00	100.00
2007	100.00	100.00	100.00	100.00	100.00
2008	100.00	100.00	100.00	100.00	100.00
2009	100.00	100.00	100.00	100.00	100.00
2010	100.00	100.00	100.00	100.00	100.00
2011	100.00	100.00	100.00	100.00	100.00
2012	100.00	100.00	100.00	100.00	100.00

Table C-3 (continued):

Percent of New LTVs With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	OUTBOARD REAR 3-POINT BELTS	SIDE DOOR BEAMS	ANY FRONTAL AIR BAGS	BARRIER-CERTIFIED FRONTAL AIR BAGS	RF PASSENGER AIR BAGS
1960	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00
1987	0.29	0.00	0.00	0.00	0.00
1988	2.84	0.00	0.00	0.00	0.00
1989	16.80	0.00	0.00	0.00	0.00
1990	20.01	0.00	0.00	0.00	0.00
1991	32.25	11.44	0.00	0.00	0.00
1992	**100.00**	12.71	13.05	13.05	0.00
1993	100.00	18.88	19.31	19.31	0.00
1994	100.00	**100.00**	32.32	32.32	7.86
1995	100.00	100.00	**82.50**	82.50	14.97
1996	100.00	100.00	96.99	96.99	41.46
1997	100.00	100.00	96.97	96.97	71.59
1998	100.00	100.00	99.74	22.62	99.64
1999	100.00	100.00	99.88	0.34	99.88
2000	100.00	100.00	100.00	0.00	100.00
2001	100.00	100.00	100.00	0.00	100.00
2002	100.00	100.00	100.00	0.00	100.00
2003	100.00	100.00	100.00	0.00	100.00
2004	100.00	100.00	100.00	0.00	100.00
2005	100.00	100.00	100.00	0.00	100.00
2006	100.00	100.00	100.00	0.00	100.00
2007	100.00	100.00	100.00	0.00	100.00
2008	100.00	100.00	100.00	0.00	100.00
2009	100.00	100.00	100.00	0.00	100.00
2010	100.00	100.00	100.00	0.00	100.00
2011	100.00	100.00	100.00	0.00	100.00
2012	100.00	100.00	100.00	0.00	100.00

Table C-3 (continued):

Percent of New LTVs With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	SLED-CERTIFIED FRONTAL AIR BAGS	FMVSS 201 HEAD IMPACT UPGRADE	PRETENSIONER AND LOAD LIMITER	CENTER REAR 3-POINT BELTS	ADVANCED FRONTAL AIR BAGS
1960	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.01	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.02	0.00	0.00
1998	77.38	0.00	3.03	0.23	0.00
1999	99.66	15.00	8.38	1.17	0.00
2000	100.00	28.22	12.64	2.22	0.00
2001	100.00	35.47	38.56	8.47	0.00
2002	100.00	**75.60**	**55.72**	24.52	0.00
2003	81.21	100.00	60.91	**51.75**	18.79
2004	66.60	100.00	68.92	67.20	33.40
2005	35.20	100.00	81.45	77.14	66.83
2006	17.20	100.00	84.53	87.30	88.70
2007	0.00	100.00	93.42	94.06	100.00
2008	0.00	100.00	100.00	100.00	100.00
2009	0.00	100.00	100.00	100.00	100.00
2010	0.00	100.00	100.00	100.00	100.00
2011	0.00	100.00	100.00	100.00	100.00
2012	0.00	100.00	100.00	100.00	100.00

Table C-3 (continued):

Percent of New LTVs With Various Safety Technologies, by Model Year, 1960-2012

MODEL YEAR	FMVSS 301 REAR IMPACT UPGRADE	ELECTRONIC STABILITY CONTROL	ANY SIDE AIR BAGS	CURTAIN PLUS TORSO BAGS	ROLLOVER CURTAINS
1960	0.00	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	2.51	0.00	0.00
1999	0.00	0.60	4.86	0.00	0.00
2000	0.00	0.67	9.19	0.05	0.00
2001	0.00	3.08	16.31	0.35	0.00
2002	0.00	4.89	27.79	0.56	1.50
2003	0.00	8.39	22.01	1.77	2.56
2004	0.00	11.92	25.84	5.93	4.22
2005	0.00	16.82	26.12	9.90	8.74
2006	18.65	30.89	29.31	17.15	15.76
2007	**64.48**	49.44	42.25	23.33	29.90
2008	85.94	**62.01**	**56.06**	32.31	46.54
2009	100.00	81.55	74.61	48.51	**56.37**
2010	100.00	88.16	91.86	69.86	78.35
2011	100.00	94.44	95.22	80.68	82.80
2012	100.00	100.00	93.93	82.97	68.62

Table C-4:

Percent of LTVs on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	OUTBOARD FRONT LAP BELTS	DUAL MASTER CYLINDERS	IMPROVED DOOR LOCKS	OUTBOARD REAR LAP BELTS	CENTER FRONT LAP BELTS	CENTER REAR LAP BELTS
1975	75.32	80.42	74.26	78.65	77.94	77.22
1976	72.14	82.31	77.17	80.64	80.00	79.35
1977	65.47	87.11	82.67	85.79	85.31	84.82
1978	58.18	89.11	85.16	87.95	87.53	87.11
1979	50.20	91.42	88.12	90.39	90.04	89.69
1980	46.56	92.64	89.73	91.76	91.46	91.16
1981	42.87	93.21	90.54	92.42	92.15	91.87
1982	40.56	93.94	91.24	93.08	92.80	92.52
1983	36.67	95.08	92.75	94.49	94.28	94.07
1984	31.73	95.36	93.40	94.79	94.58	94.38
1985	26.73	96.62	95.00	96.08	95.92	95.77
1986	23.37	97.06	95.71	96.75	96.63	96.50
1987	18.21	97.91	96.83	97.59	97.52	97.42
1988	15.78	98.30	97.27	97.70	97.92	97.84
1989	13.07	98.44	97.71	96.66	98.19	98.12
1990	11.41	98.86	98.16	95.29	98.59	98.54
1991	10.44	98.93	98.29	92.50	98.73	98.69
1992	8.91	99.08	98.52	85.69	98.90	98.86
1993	7.48	99.25	98.79	78.28	99.12	99.09
1994	6.54	99.33	98.88	69.34	99.17	99.13
1995	5.51	99.49	99.17	62.31	99.39	99.37
1996	4.37	99.59	99.32	54.63	99.51	99.49
1997	3.39	99.68	99.45	47.47	99.60	99.58
1998	2.84	99.64	99.44	42.06	99.56	99.54
1999	2.42	99.79	99.66	36.89	99.74	99.63
2000	2.04	99.82	99.73	31.65	99.79	99.40
2001	1.39	99.84	99.76	25.37	99.83	98.87
2002	1.20	99.86	99.79	20.57	99.83	97.48
2003	0.89	99.91	99.84	16.91	99.91	93.91
2004	0.68	99.93	99.89	13.95	99.93	90.12
2005	0.64	99.93	99.89	10.82	99.92	85.74
2006	0.45	99.94	99.91	9.92	99.93	81.17
2007	0.43	99.93	99.90	8.17	99.92	77.59
2008	0.29	99.97	99.94	6.87	99.96	71.70
2009	0.37	99.96	99.92	6.10	99.94	68.45
2010	0.29	99.97	99.94	5.54	99.96	64.50
2011	0.25	99.95	99.94	4.83	99.95	63.55
2012	0.22	99.94	99.92	4.61	99.93	59.39

Table C-4 (continued):

Percent of LTVs on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	FRONT DISC BRAKES	IMPROVED INSTRUMENT PANELS	ENERGY-ABSORBING STEERING ASSEMBLY	OUTBOARD FRONT 3-POINT BELTS	ADHESIVE WINDSHIELD BONDING
1975	50.01	37.65	14.62	12.66	0.00
1976	56.23	45.77	18.04	16.99	0.00
1977	64.98	55.90	26.95	26.66	0.08
1978	69.85	61.93	32.57	35.16	2.34
1979	75.51	69.09	36.54	44.72	7.47
1980	78.52	72.73	41.84	49.10	11.85
1981	80.20	74.79	43.50	53.09	15.83
1982	81.24	76.16	49.90	56.05	20.35
1983	83.89	79.14	53.66	60.51	25.41
1984	85.60	81.50	60.06	65.66	34.23
1985	88.89	85.53	66.96	71.30	43.79
1986	90.29	87.38	71.56	74.96	51.25
1987	92.71	90.45	77.01	80.61	60.06
1988	93.63	91.66	80.50	83.22	65.24
1989	94.72	93.15	83.64	86.11	70.67
1990	95.58	94.15	85.39	87.98	74.27
1991	95.95	94.62	86.53	88.91	76.53
1992	96.55	95.47	88.83	90.55	79.33
1993	97.09	96.16	90.18	92.08	81.50
1994	97.41	96.67	91.85	93.10	84.75
1995	97.96	97.27	93.26	94.23	87.07
1996	98.35	97.80	94.51	95.40	89.29
1997	98.72	98.33	95.70	96.42	91.30
1998	98.81	98.48	96.12	96.94	92.99
1999	99.15	98.86	97.04	97.46	93.99
2000	99.33	99.11	97.48	97.89	95.22
2001	99.45	99.27	98.14	98.51	96.44
2002	99.54	99.40	98.47	98.70	96.98
2003	99.63	99.52	98.76	99.06	97.65
2004	99.76	99.69	99.24	99.28	98.39
2005	99.75	99.68	99.34	99.32	98.57
2006	99.81	99.75	99.37	99.51	98.87
2007	99.79	99.75	99.48	99.54	99.00
2008	99.87	99.84	99.59	99.69	99.25
2009	99.83	99.79	99.59	99.61	99.24
2010	99.88	99.84	99.63	99.68	99.33
2011	99.87	99.83	99.68	99.72	99.48
2012	99.87	99.84	99.70	99.73	99.44

Table C-4 (continued):

Percent of LTVs on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	OUTBOARD REAR 3-POINT BELTS	SIDE DOOR BEAMS	ANY FRONTAL AIR BAGS	BARRIER-CERTIFIED FRONTAL AIR BAGS	RF PASSENGER AIR BAGS
1975	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00
1987	0.02	0.00	0.00	0.00	0.00
1988	0.30	0.00	0.00	0.00	0.00
1989	1.61	0.00	0.00	0.00	0.00
1990	3.36	0.06	0.00	0.00	0.00
1991	6.28	0.71	0.11	0.11	0.00
1992	13.25	1.52	1.47	1.47	0.00
1993	20.87	3.47	2.40	2.40	0.02
1994	29.86	11.53	5.73	5.73	0.91
1995	37.11	20.38	10.81	10.81	1.67
1996	44.90	29.21	20.24	20.24	4.85
1997	52.14	36.80	27.57	27.18	9.86
1998	57.51	43.95	34.93	28.37	18.78
1999	62.86	50.48	43.40	29.07	27.02
2000	68.15	56.89	49.77	26.07	35.84
2001	74.47	63.83	57.46	24.53	43.72
2002	79.27	69.93	64.03	23.96	51.02
2003	83.00	75.29	70.15	23.21	57.86
2004	85.98	78.79	74.13	20.87	63.43
2005	89.10	82.99	78.35	20.29	67.93
2006	90.01	84.82	80.70	17.52	72.03
2007	91.76	87.05	83.91	17.01	75.54
2008	93.09	89.19	86.04	14.76	78.59
2009	93.84	90.19	87.26	13.39	80.48
2010	94.43	91.31	88.52	12.39	82.32
2011	95.13	92.53	89.58	12.38	83.66
2012	95.33	93.14	90.99	10.84	85.56

Table C-4 (continued):

Percent of LTVs on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	SLED-CERTIFIED FRONTAL AIR BAGS	FMVSS 201 HEAD IMPACT UPGRADE	PRETENSIONER AND LOAD LIMITER	CENTER REAR 3-POINT BELTS	ADVANCED FRONTAL AIR BAGS
1975	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00
1997	0.38	0.00	0.01	0.00	0.00
1998	6.59	0.05	0.15	0.00	0.00
1999	14.27	1.31	1.06	0.12	0.00
2000	23.53	3.15	2.29	0.45	0.00
2001	32.69	7.40	5.34	1.14	0.00
2002	39.69	13.06	10.10	2.79	0.05
2003	45.23	20.33	14.03	7.10	1.35
2004	48.95	26.58	19.29	11.68	3.85
2005	50.02	33.28	24.09	16.91	7.68
2006	49.92	38.84	28.63	22.14	12.82
2007	49.22	44.08	32.33	26.33	17.45
2008	47.59	49.92	38.63	33.11	23.67
2009	48.12	52.87	42.34	36.38	25.64
2010	46.69	54.93	44.44	40.82	29.41
2011	45.87	56.71	46.48	41.84	31.22
2012	45.22	60.54	50.18	46.34	34.96

Table C-4 (continued):

Percent of LTVs on the Road With Various Safety Technologies, by Calendar Year, 1975-2012

CALENDAR YEAR	FMVSS 301 REAR IMPACT UPGRADE	ELECTRONIC STABILITY CONTROL	ANY SIDE AIR BAGS	CURTAIN PLUS TORSO BAGS	ROLLOVER CURTAINS
1975	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.01	0.00	0.00
1998	0.00	0.00	0.13	0.00	0.00
1999	0.00	0.00	0.58	0.00	0.00
2000	0.00	0.17	1.13	0.03	0.00
2001	0.00	0.50	3.00	0.05	0.00
2002	0.00	0.45	5.00	0.08	0.14
2003	0.00	1.20	6.00	0.13	0.28
2004	0.00	2.52	7.83	0.54	0.61
2005	0.16	3.44	9.23	1.13	0.85
2006	0.91	4.94	11.62	2.14	1.77
2007	3.77	6.35	13.15	3.25	3.44
2008	8.38	10.68	16.52	5.18	5.87
2009	10.34	12.70	19.59	6.61	7.81
2010	14.15	15.81	21.50	8.29	9.77
2011	16.34	17.33	23.52	10.04	11.13
2012	20.53	22.47	27.52	14.01	14.94

APPENDIX D

Computation of Fatality Risk Indices for Diseases, 1960 to 2010

The objective is to estimate the risk of dying, between the ages of 60 and 70, from any disease, from heart disease, and from cancer in 1960, 1970, 1980, 1990, 2000, and 2010 (indexed to 1960 risk = 100). The indices are graphed in Figure B of the preface to the executive summary of this report. The preface is titled "A Revolution in Safety and Health." As stated above, all three indices are 100 in 1960.

Table 9 – Cohort Probabilities of Death Within One Year (q_x) at Selected Exact Ages, by Sex and Year of Birth in *Life Tables for the United States Social Security Area, 1900-2010* lists the exact probabilities of dying within one year, from any cause, by year of birth, gender, and selected ages including 60, 65, and 70.[630] Thus, for example, the probability of a 60-year-old male in 1960 dying within one year is the table entry for birth year 1900 and age 60. The average of the following six probabilities is computed for birth years 1900, 1910, 1920, 1930, 1940, and 1950: 60-, 65-, and 70-year-old males and 60-, 65-, and 70-year-old females. These averages will be used to estimate the probability of dying between 60 and 70 in 1960, 1970, 1980, 1990, 2000, and 2010, respectively. Indexed to 1960 risk = 100, the index values for dying from any disease are 88.90 in 1970, 76.48 in 1980, 67.91 in 1990, 60.22 in 2000, and 54.80 in 2010.

The indices for heart disease and cancer are approximations, because the sources listed here do not provide death rates for specific ages, except in 2000 and 2010. *Leading Causes of Death, 1900-1998*, published by the Centers for Disease Control and Prevention and available at www.cdc.gov/nchs/data/dvs/lead1900_98.pdf , lists the death rates for the entire population (all ages), by CY, from all causes, from heart disease, and from cancer. For example, in 1960, the rates per 100,000 were 954.7, 369.0, and 149.2, respectively; while in 1970 they were 945.3, 362.0, and 162.8; and in 1980, 878.3, 336.0, and 183.9. The index for heart disease in 1970 at ages 60 to 70, for example, will be the 1970 index for all causes at ages 60 to 70 (88.90 – see above), adjusted by the change in heart disease (at all ages) from 1960 to 1970 relative to the change in all diseases (at all ages) from 1960 to 1970:

$$88.90 \times (362.0/369.0) / (945.3/954.7) = 88.08$$

The 1970 index for cancer is similarly defined. The 1980 index for heart disease is computed from the 1970 index for heart disease, the 1970 and 1980 indices for all diseases (60 to 70 years old), and the 1970 and 1980 population death rates for all diseases and for heart disease:

$$88.08 \times (76.48/88.90) \times (336.0/362.0) / (878.3/945.3) = 75.70$$

The 1980 index for cancer is computed similarly. The 1990 indices are computed from the 1980 indices the same way and the 2000 indices from the 1990 indices (but, here, the population death

[630] Bell, F. C., & Miller, M. L. (2005, August). *Life tables for the United States Social Security Area, 1900-2010*. (SSA Pub. No. 11-11536, pp. 158-159). Washington, DC: Social Security Administration. Available at www.ssa.gov/oact/NOTES/pdf_studies/study120.pdf

rates for 1998 are used to "stand in" for 2000, because the source document only goes up to 1998).

Another publication by the Centers for Disease Control and Prevention lists on p. 32 fatality rates for all diseases, for heart disease, and for cancer by 10-year age cohorts for 2000 and 2010.[631] The averages of the 55-to-64 and 65-to-74 groups will be used to estimate the probabilities of dying between 60 and 70 in 2000 and 2010. These probabilities are 1695.7 and 1363.5 for all diseases, 463.4 and 297.9 for heart disease, and 591.5 and 483.1 for cancer. The 2010 index for heart disease is computed from the 2000 index for heart disease, the already computed 2000 and 2010 indices for all diseases (60 to 70 years old), and the 2000 and 2010 population death rates (age 60 to 70) for all diseases and for heart disease:

$$48.33 \times (54.80/60.22) \times (297.9/463.4) / (1363.5/1695.7) = 35.16$$

The 2010 index for cancer is computed similarly. The risk indices graphed in Figure B in the preface to the executive summary of this report are:

	All Diseases	Heart Disease	Cancer
1960	100.0	100.0	100.0
1970	88.9	88.1	98.0
1980	76.5	75.7	102.5
1990	67.9	58.9	102.2
2000	60.2	48.3	89.3
2010	54.8	35.2	82.5

[631] Murphy, S. L., Xu, J., & Kochanek, K. D. (2013, May). Deaths: Final data for 2010. National Vital Statistics Reports, 61. Atlanta: Centers for Disease Control and Prevention. Available at www.cdc.gov/nchs/data/nvsr/nvsr61/nvsr61_04.pdf

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National Highway
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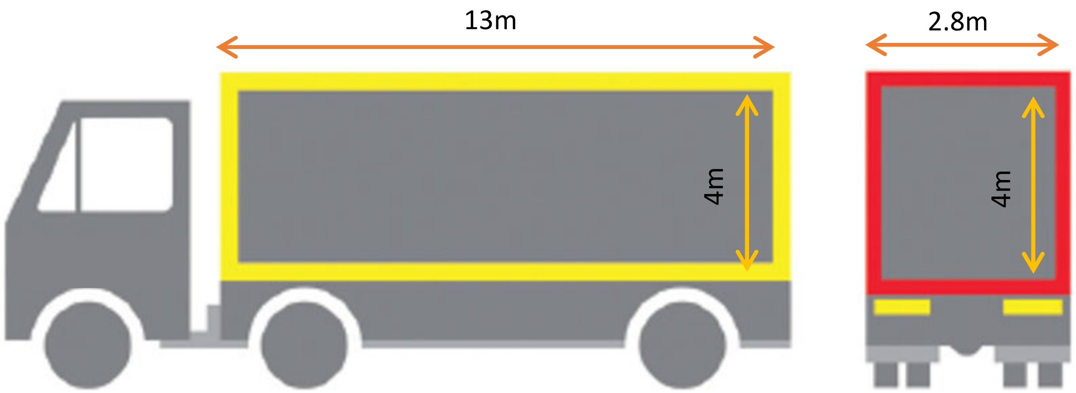
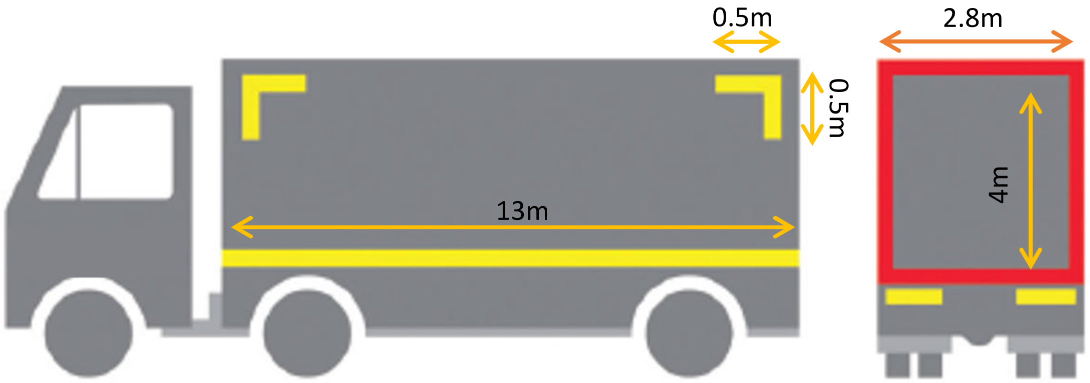
10921-012115-v3

Full Contour



Description	Lineal Metres	Cost
Lineal metres of retroreflective tape	81.6m	$400
Installation Labour Cost ($100 per hour).		$450
Total Cost		$900
Cost per annum with 7 year life expectancy		$128

Partial Contour



Description	Lineal Metres	Cost
Lineal metres of retroreflective tape	43.6m	$200
Installation Labour Cost ($100 per hour).		$300
Total Cost		$500
Cost per annum with 7 year life expectancy		$71.40

- **Cost can be dramatically reduced by owner operator installing their own retroreflective material at $28.50 per annum for a partial contour.**
- **When retroreflective tapes are applied as above, rear marker plates are not required.**

SWOV
WETENSCHAPPELIJK
ONDERZOEK VERKEERSVEILIGHEID

Invoering van contourmarkering voor het bestaande vrachtwagenpark

R-2015-2

Invoering van contourmarkering voor het bestaande vrachtwagenpark

Effecten en kosteneffectiviteit van retrofit in Nederland en in Europa

R-2015-2
Drs. W. Wijnen, dr. C.A. Bax, dr. H.L. Stipdonk, R.W.N. Wegman &
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Den Haag, 2015
Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV

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Auteur(s):	Drs. W. Wijnen, dr. C.A. Bax, dr. H.L. Stipdonk, R.W.N. Wegman & drs. N.M. Bos
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Trefwoord(en):	Vehicle marking; cost; reflectivity; lorry; visibility; safety; accident prevention; severity (accid, injury); efficiency; evaluation (assessment); cost benefit analysis; Netherlands.
Projectinhoud:	Dit rapport behandelt de kosten en baten van het retrofit invoeren van contourmarkering op vrachtauto's in Nederland. Baten zijn er in de vorm van bespaarde slachtoffers en bespaarde ongevals-kosten. Er is gekeken naar de kosteneffectiviteit voor transport-bedrijven en voor de maatschappij als geheel. Ook voor het retrofit invoeren van contourmarkering in de Europese Unie is een globale schatting gedaan van kosten en baten.
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Samenvatting

In Nederland vinden jaarlijks ongeveer 300 ongevallen plaats met vrachtauto's (bakwagens, trekkers, opleggers en aanhangers) waarbij doden of ernstig verkeersgewonden vallen. Volgens ongevallendata van de Europese Unie (CARE) vielen in 2010 5.000 doden op de EU-wegen bij ongevallen met zwaar verkeer, 75% daarvan betrof inzittenden van andere voertuigen. Ongevallen met vrachtwagens zijn over het algemeen ernstiger dan gemiddeld vanwege de omvang en massa van deze voertuigen. Een gedeelte van deze ongevallen ontstaat door zijdelingse en kop-staartbotsingen bij schemer of in het donker. Eerder SWOV-onderzoek laat zien dat contourmarkeringen op vrachtauto's een bijdrage kunnen leveren aan het voorkomen van die ongevallen. Op basis van EU-richtlijn 2007/35/EG moeten sinds 10 juli 2008 vrachtauto's met een maximummassa vanaf 7,5 ton en aanhangwagens (waaronder opleggers) vanaf 3,5 ton[1] van goedgekeurde en op de voorgeschreven manier aangebrachte retroreflecterende contourmarkering zijn voorzien om bij een typekeuring te worden goedgekeurd. Vanaf 10 juli 2011 moeten niet alleen nieuwe typen maar ook voertuigen van een ouder type die voor het eerst een kenteken krijgen, retroreflecterende contourmarkering hebben (Europese Unie, 2007a; 2007b). Voor bestaande voertuigen met een kenteken geldt deze verplichting niet.

3M is geïnteresseerd in de vraag welke inhoudelijke argumenten er kunnen worden aangedragen om in Nederland en in de Europese Unie te pleiten voor het invoeren van contourmarkering voor het bestaande wagenpark, de zogeheten retrofit, en heeft SWOV gevraagd hiernaar onderzoek te doen.

Op basis van de vraag van 3M heeft SWOV de volgende vragen opgesteld:
- Welke verkeersveiligheidseffecten zijn te verwachten van het retrofit invoeren van contourmarkering op vrachtauto's in Nederland?
- Wat zijn de maatschappelijke kosten en baten van deze maatregel en is de maatregel op maatschappelijk niveau kosteneffectief?
- Wat zijn de kosten en baten voor transportbedrijven?
- Wat is het effect van retrofit contourmarkering in de EU op het aantal doden en gewonden als gevolg van verkeersongevallen?

Om deze vragen te beantwoorden is de Nederlandse en buitenlandse literatuur bestudeerd en is een kosten-batenanalyse uitgevoerd.

Nederland

Op basis van Nederlands en buitenlands onderzoek is voor de huidige Nederlandse situatie het effect van contourmarkering geschat op maximaal 3 doden, 16 ernstig verkeersgewonden en 481 ongevallen per jaar. Deze cijfers gelden alleen in de situatie dat het hele Nederlandse wagenpark geen contourmarkering zou hebben en in één klap van contourmarkering zou worden voorzien. In werkelijkheid is dat niet zo en worden vrachtauto's vervangen als hun levensduur ten einde is. Bovendien heeft, vanwege bestaande Europese verplichtingen, een deel van het wagenpark al

[1] Voor beiden geldt: tevens breder dan 2,10 meter en/of langer dan 6 meter.

contourmarkering op 1 januari 2015 (voor het gemak van de berekening gekozen als ingangsdatum van de maatregel).

Uit CBS-cijfers valt af te leiden dat de gemiddelde levensduur van bakwagens 13 jaar is, van trucks met oplegger eveneens 13 jaar en van aanhangers 22 jaar. Geleidelijke invoer van contourmarkering zou betekenen dat het complete park van aanhangwagens gemiddeld nog 11 jaar zonder retrofit zou rondrijden, en het complete park van bakwagens en opleggers gemiddeld nog 6,5 jaar. Hier zou het effect van retrofit in één keer mee berekend kunnen worden, ware het niet dat er al wagens zijn voorzien van contourmarkering. Doordat er al vervanging heeft plaatsgevonden, is zowel de relevante parkomvang (namelijk het deel zonder retrofit) veranderd, als de gemiddelde levensduur van dat parkdeel. Er zijn verschillende manieren om die parkverandering in de berekening te verwerken. De effecten van beide factoren (omvang en levensduur) zijn volgens de berekening in dit rapport allebei evenredig van invloed op het veiligheidseffect. Het effect van deze twee factoren op de veiligheid is daarmee gelijk: het maakt bijvoorbeeld niet uit of het park halveert of de levensduur.

Indien met het bovenstaande rekening wordt gehouden, is de besparing over de totale werkingstermijn van de maatregel (dus vanaf 1 januari 2015 totdat alle vrachtauto’s voorzien zijn van contourmarkering) naar schatting:

- 8 doden
- 42 gewonden
- 1.268 ongevallen

Deze aantallen kunnen om verschillende redenen een over- of onderschatting zijn van de werkelijke effecten. In *Hoofdstuk 2* is een aantal van deze redenen genoemd.

De kosten van het retrofit invoeren van contourmarkering voor vrachtauto’s in Nederland bestaan uit de kosten voor de markering zelf en voor het aanbrengen van de markeringen. De kosten van het aanbrengen van contourmarkering zijn bepaald voor twee scenario’s: een ‘maximumscenario’ waarbij op alle vrachtauto’s de volledige contour van de zijkanten worden gemarkeerd, en een ‘minimumscenario’ waarbij alleen de onderkant en de bovenhoeken worden gemarkeerd, volgens de minimumrichtlijnen van de Europese Unie.

De ervaringen van 3M, en de minimumeisen gesteld door EU-richtlijn 2007/35/EG of UN-richtlijn ECE 48, Clause 6;21, geven aan dat men waarschijnlijk voor een groot deel van de vrachtauto’s zal kiezen voor minder/het minimum aan markering. Uit praktische overwegingen en vanwege vergelijkingsmogelijkheden, is gekozen voor zowel maximum- als minimumscenario, omdat op voorhand niet te zeggen valt om hoeveel vrachtauto’s het gaat, en omdat in de eerdere SWOV-studie naar contour-markering ook is gerekend met de maximale markering. In het minimum-scenario wordt tevens uitgegaan van lagere kosten voor het materiaal (2,00 versus 2,80 euro per meter) en voor het aanbrengen van de markering (100 versus 130 euro per vrachtwagen). In de berekening van de kosten is geen rekening gehouden met kosten voor wetgeving en voorlichting. We schatten in dat deze kosten gering zijn. De kosten voor handhaving zullen naar onze inschatting niet significant toenemen. Deze kosten vallen buiten de scope van dit onderzoek.

In totaal bedragen de kosten naar schatting 31 miljoen euro in het maximumscenario en 16 miljoen euro in het minimumscenario. Deze kosten worden volledig gedragen door de transportbedrijven. De baten van de maatregel bestaan op maatschappelijk niveau uit de bespaarde slachtoffers en ongevallen zoals hierboven aangegeven. Voor de samenleving als geheel bedragen de baten van retrofit invoering van contourmarkering 35 miljoen euro. Voor bedrijven bestaan de baten uit minder (verzekerde en onverzekerde) kosten ten gevolge van de afname van ongevallen. Deze baten worden voor bedrijven geschat op 9 miljoen euro.

De baten-kostenverhouding is daarmee voor de maatschappij 1,1 en voor individuele bedrijven 0,3 in het maximumscenario. In het minimumscenario bedraagt de baten-kostenverhouding 2,1 voor de maatschappij en 0,6 voor transportbedrijven.

	Maatschappij		**Transportbedrijven**	
	Maximumkosten*	**Minimumkosten****	**Maximumkosten***	**Minimumkosten****
Kosten	31	16	31	16
Baten	35	35	9	9
Saldo baten-kosten	3	18	-22	-7
Verhouding baten/kosten	1,1	2,1	0,3	0,6

Tabel S.1*. Kosten en baten van retrofit invoering van contourmarkering (miljoen euro, contante waarden), en saldo en verhouding van kosten en baten in Nederland. * Maximumscenario: volledige contourmarkering, prijs markering € 2,80 per meter en aanbrengkosten € 130 per vrachtwagen. ** Minimumscenario: minimaal vereiste contourmarkering, prijs markering € 2,00 per meter en aanbrengkosten € 100 per vrachtwagen.*

In het scenario met maximale kosten zijn de maatschappelijke baten iets hoger dan de kosten, en in het scenario met minimale kosten zijn de baten ongeveer twee maal zo hoog als de kosten. Dit betekent dat het ‘maatschappelijk rendement’ (licht) positief is. De ‘werkelijke’ kosten-batenverhouding zal afhangen van de hoeveelheid markering die op de zijkant wordt aangebracht en van de prijsontwikkeling van contourmarkering. Op grond van de kosten-batenanalyse, en met inachtneming van de hierboven aangegeven beperkingen, kan echter gesteld worden dat een retrofit invoering van contourmarkering vanuit een economisch perspectief waarschijnlijk een zinvolle investering is.

Voor individuele transportbedrijven geldt dat de kosten ongeveer twee tot drie maal zo hoog zijn als de baten. Dit betekent dat er voor bedrijven vanuit bedrijfseconomisch oogpunt geen stimulans is om op eigen initiatief te investeren in contourmarkering.

Doorvertaling Europese Unie

Voor het effect van retrofit invoering van contourmarkering in de Europese Unie zijn de resultaten voor Nederland eenvoudigweg doorvertaald naar een EU-totaal door te vermenigvuldigen met het totale aantal inwoners of het totale wagenpark, rekening houdend met de mortaliteit in de EU ten opzichte van die in Nederland. Daarbij is geen rekening gehouden met de verschillen per land in leeftijd van vrachtauto's, de precieze kosten van tape en belettering en de precieze kosten van schades en verlies van mensenlevens. Preciezere cijfers per EU-land vergen onevenredig meer rekenwerk, en in sommige gevallen zijn gegevens daarvoor niet voorhanden. Onderstaande tabel geeft weer welke zaken wel en niet worden meegenomen in de berekening en welke aannamen gedaan zijn voor dit rapport (kolom 2: de grove schatting). In de laatste kolom staat vermeld welke zaken in een fijne schatting nader kunnen worden uitgezocht. Dat zou kunnen in een vervolgonderzoek.

Benodigde data	**Aannamen voor grove schatting**	**Houdt wel rekening met**	**Houdt geen rekening met**	**Nodig voor fijne schatting**
Aantal slachtoffers van dit soort ongevallen in de EU?	Aantal slachtoffers in NL rekening houdend met mortaliteits-verhoudingen …	Verschil in aantal inwoners in de EU	Verschillen in aantallen doden en gewonden per 100.000 inwoners in de verschillende EU-landen	Gedetailleerder uitzoeken met CARE-data voor max. 19 landen
Verkeersmortaliteit in EU-landen	… gemiddelde mortaliteit EU t.o.v. mortaliteit in NL	Verschil in mortaliteit EU versus NL	Verschillen in mortaliteit van land tot land	Mortaliteit per land in beschouwing nemen
Hoeveel vrachtauto's zijn er in de EU en hoe lang rijden ze rond zonder contourmarkering?	Aantal vrachtauto-jaren in NL vertalen naar totale wagenpark EU	Verschil in aantal vrachtauto's per land	Verschillen in leeftijd en levensduur van vrachtauto's in de verschillende EU-landen	Kijken naar leeftijd en levensduur van vrachtauto's in de EU
Wat zijn de kosten van contourmarkering in de EU?	Kosten per vrachtauto in NL doortrekken voor aantal vrachtauto's in EU met factor 2/3 van de kosten van NL	Schatting van kosten tape en aanbrengen waarbij kosten op 2/3 van NL kosten worden geschat	Reële kosten van aanbrengen tape	Kosten van een aantal EU-landen opvragen
Wat zijn de kosten van een slachtoffer in de EU?	Kosten per slachtoffer in NL doorvertalen naar EU-aantal slachtoffers met factor 2/3 van de kosten van NL	Aantal inwoners per land	Reële kosten van een ongeval/mensenleven per land	Kosten per slachtoffer van een aantal EU-landen opvragen
Wat is het schade-bedrag per ongeval?	Kosten schadegevallen NL extrapoleren naar EU-totaal met factor 2/3 van de kosten van NL	Aantal inwoners en vrachtauto's per land	Reële kosten per schadegeval per land	Bekijken of er schade-bedragen voor bepaalde landen zijn

Tabel S.2. *Aannamen en consequenties daarvan voor berekening van de effecten van retrofit contourmarkering in de Europese Unie (exclusief Nederland).*

Omdat de rekenmethoden voor Nederland en voor de EU niet gelijk zijn, zijn het veiligheidseffect, de kosten en de baten gegeven voor de EU exclusief Nederland.

Doorvertaald naar de Europese Unie exclusief Nederland betekent retrofit invoering van contourmarkering per 1 januari 2015 een eenmalige besparing van in totaal 421 doden, 2.240 ernstig verkeersgewonden en 67.373 ongevallen over de totale werkingsperiode van de maatregel. De kosten van de maatregel bedragen in totaal 267 miljoen euro in het minimale kosten-scenario en 517 miljoen euro in het maximale kostenscenario voor de EU (minus Nederland) als geheel. Omgerekend naar geld, zijn de totale baten van de maatregel voor de EU exclusief Nederland 1.541 miljoen euro. De verhouding tussen baten en kosten komt daarmee in het maximale kostenscenario uit op 3 en in het minimale kostenscenario op 6.

Totale kosten, baten en baten-kostenverhouding voor EU inclusief Nederland

De totale kosten, baten en baten-kostenverhouding voor de gehele Europese Unie wordt berekend door de kosten en baten voor Nederland en die van de Europese Unie excl. Nederland op te tellen. Daarbij moet worden aangetekend dat de kosten en baten voor Nederland op een preciezere manier zijn berekend dan die die voor de Europese Unie: deze laatste cijfers betreffen slechts een grove schatting.

In het maximale kostenscenario tellen de kosten in de EU en Nederland op tot 548 miljoen euro, in het minimale kostenscenario bedraagt dat 283 miljoen euro. De baten tellen in beide gevallen op tot 1.576 miljoen euro. De baten-kostenratio blijft daarmee 3 voor het maximale en 6 voor het minimale kostenscenario. Ook in deze berekening van de kosten is geen rekening gehouden met kosten voor wetgeving en voorlichting en wordt verondersteld dat de kosten voor handhaving niet significant toenemen. Deze kosten vallen buiten de scope van dit onderzoek. Tot slot is geen rekening gehouden met eventuele stringentere wetgeving dan de EU-regelgeving die in enkele Europese landen reeds van kracht is. Dat geeft een lichte overschatting van het effect.

	Maatschappij	
	Maximumkosten*	**Minimumkosten****
Kosten	548	283
Baten	1.576	1.576
Saldo baten-kosten	1.028	1.293
Verhouding baten/kosten	3	6

Tabel S.3. *Kosten en baten van retrofit invoering van contourmarkering (contante waarden in miljoen euro), en saldo en verhouding van kosten en baten in de EU inclusief Nederland.*
** Maximumscenario: volledige contourmarkering, twee derde van de Nederlandse prijs (markering € 2,80 per meter en aanbrengkosten € 130 per vrachtwagen) en twee derde van de Nederlandse baten.*
*** Minimumscenario: minimaal vereiste contourmarkering, twee derde van de Nederlandse prijs (markering € 2,00 per meter, aanbrengkosten € 100 per vrachtwagen) en twee derde van de Nederlandse baten.*

Summary

Retrofit introduction of contour marking for lorries

The Netherlands has an annual number of approximately 300 fatal or serious injury crashes involving lorries (rigid lorries, articulated lorries and trailers). European Commission CARE data indicates that in 2010 around 5000 people died on EU roads in crashes involving Heavy Goods Vehicles (HGVs), and 75% of these fatalities were occupants of other vehicles. Road traffic crashes involving lorries tend to be more serious than other crashes because of the great size and mass of these vehicles. Part of these crashes are due to lateral and rear-end collisions at dusk or in the dark. Previous SWOV research has shown that contour marking on lorries can contribute to the prevention of these types of crashes. EU directive 2007/35/EC states that from 10 July 2008, lorries with a minimum weight of 7.5 tonnes and trailers from a maximum mass of 3.5 tonnes[2] must be fitted with contour marking that is approved and applied in the correct manner in order to pass the type approval test. From 10 July 2011, retroreflecting contour marking must not only be applied to new vehicle types, but also to older vehicle types that are licensed for the first time (European Union, 2007a, 2007b). The contour marking is not compulsory for existing vehicles that are already licensed. 3M wants to know which substantive arguments can be put forward to plead for introduction of contour marking for the existing vehicle park in the Netherlands and the European Union, the so-called retrofit, and asked SWOV to investigate the issue.

The 3M request resulted in the following research questions:
- What road safety effects can be expected as a result of retrofit application of contour marking on lorries in the Netherlands?
- What are the social costs and benefits of this measure and is the measure socially cost-effective?
- What are the costs and benefits for transport companies?
- What is the effect of retrofit contour marking on the number of fatalities and seriously injured in the EU due to traffic crashes?

Dutch and international literature were studied and a cost-benefit analysis was conducted to answer these questions.

The Netherlands

Based on Dutch and international research, it is estimated that in the present situation in the Netherlands, retrofit contour marking leads to an estimated maximum prevention of 3 fatalities, 16 serious road injuries and 481 crashes per year. This data is only valid for a situation in which none of the vehicles in the Dutch vehicle fleet would be fitted with contour marking and contour marking would be applied to all vehicles at the same time. This is not the actual situation and lorries are replaced when their service life has ended. In addition, due to previous European legislation, contour marking will already be applied to part of the vehicle fleet on 1 January 2015 (commencement date for the measure in our calculations).

[2] Both are required to be wider than 2.10 m and/or longer than 6 m.

Statistics Netherlands (CBS) data indicates that the average lifespan of rigid lorries and of articulated lorries is 13 years, and of trailers the average lifespan is 22 years. Gradual implementation of contour marking would imply that the entire fleet of trailers would continue to drive without retrofit for approximately 11 years, and the entire fleet of rigid lorries and articulated lorries for approximately 6,5 years. This data could be used to calculate the effect of implementing retrofit contour marking for all vehicles at once, if not for the fact that some lorries have already been fitted with contour marking. The fact that adaptations have already taken place, affects both the relevant fleet size (the share without retrofit) and the average lifespan of that share. There are various ways to include fleet changes in the calculation of the effect. The present calculations show that both factors (fleet size and lifespan) influence safety proportionally. Therefore, their effect on safety is the same, irrespective of, for example, fleet size or lifespan being half the size.

If the above is taken into account, the total savings over the period during which the measure is being introduced (i.e. from 1 January 2015 until contour marking has been applied to all lorries) amounts to:

- 8 fatalities;
- 42 serious road injuries;
- 1268 crashes.

Chapter 2 discusses the reasons for possible over- or underestimates of these numbers.

The costs of the retrofit introduction of contour marking for trucks in the Netherlands consist of the costs of the marking itself and the costs of applying the marking. The costs of applying the marking have been calculated for two different scenarios: a ‘maximum’ scenario in which full side contour markings are applied to the sides of all trucks, and a ‘minimum’ scenario in which only the bottom and the upper corners are marked, in accordance with the minimum requirements of the European Union.

Market estimates by 3M, and the minimum requirements in EU Directive 2007/35/EC or UN Directive ECE 48, Clause 6; 21, indicate that less/minimum marking will probably be chosen for many of the lorries. As it is difficult to indicate the exact number of involved lorries in advance, and as an earlier SWOV report on contour marking also made the calculations based on the maximum marking, this maximum and minimum scenario were chosen for practical reasons and comparison options. The minimum scenario is also based on lower costs for the material (2.00 versus 2.80 euros per metre) and for applying the contour marking (100 versus 130 euro per lorry). The costs for legislation and information have not been included in the calculation of the costs. We estimate these costs to be minor. In our opinion the enforcement costs will not significantly increase. These costs are outside the scope of this study.

The total estimated costs for the maximum scenario are 31 million euros and 16 million euros for the minimum scenario. As indicated above, the benefits of the measure on the social level are the casualties and crashes that are saved. For society, the benefits of retrofit introduction of contour marking amount to 35 million euros. For companies, the benefits consist of lower (insured and uninsured) costs as a result of the decrease in crashes. The benefits are estimated at 9 million euros for companies.

This means that in the maximum scenario the benefit-cost ratio is 1.1 for society and 0.3 for individual companies. In the minimum scenario the benefit-cost ratio is 2.1 for society and 0.6 for transport companies.

	Society		Transport companies	
	Maximum costs*	**Minimum costs****	**Maximum costs**	**Minimum costs**
Costs	31	16	31	16
Benefits	35	35	9	9
Balance benefits-costs	3	18	-22	-7
Benefit/cost ratio	1.1	2.1	0.3	0.6

Table S.1*. Costs and benefits of retrofit introduction of contour marking (present values in million euros), and balance and ratio of costs and benefits in the Netherlands. * Maximum scenario: full contour marking, price € 2.80 per metre and application costs €130 per lorry. ** Minimum scenario: minimum required contour marking, price €2.00 per metre and application costs €100 per lorry.*

The social benefits are slightly higher than the costs in the scenario with maximum costs, and twice as high as the costs in the scenario met minimum costs. This means that the social benefits are (slightly) positive. The 'actual' cost-benefit ratio will be determined by the amount of marking that is applied on the side of the lorry and of the price development of contour marking. However, on the basis of the cost-benefit analysis, and in compliance with the restrictions indicated above, we may conclude that a retrofit introduction of contour marking is probably a sensible investment from an economic perspective.

For individual transport companies the costs are about two to three times higher than the benefits. This means that in financial terms there is no incentive for companies to invest in contour marking on their own initiative.

Applied to the European Union

To calculate the effects of retrofit contour marking in the entire European Union, the Netherlands data was simply multiplied by the total number of inhabitants or the total vehicle fleet. The mortality in the EU as opposed to Dutch mortality was considered, not allowing for differences between countries concerning the age of lorry, the real costs of tape and lettering and the real costs of damages and human losses. More precise data per EU country requires disproportionately more calculation, and in some cases more precise data is not available. The table below shows which aspects have and which aspects have not been included in the calculation. This report uses assumptions for a rough estimation (second column). The last column indicates which aspects could be further investigated in a more precise estimate. This could be done in a follow-up study.

Required data	Assumptions for rough estimate	Takes account of	Does not take account of	Required for a more precise estimate
Number of casualties in this crash type in the EU	Number of casualties in NL, allowing for mortality ratios	Different numbers of inhabitants in the EU countries	Different numbers of fatalities/serious road injuries per 100 000 inhabitants in the EU countries	Investigate in more detail using CARE data for a maximum of 19 countries
Traffic mortality in EU countries	Average EU mortality versus NL mortality	Difference between EU mortality versus NL mortality	Differences in mortality between individual countries	Take into account the mortality in individual countries
The number of trucks in the EU and the period during which they have been driving without contour marking	Translation of the number of NL truck years into truck years for the entire EU vehicle fleet	Differences in numbers of trucks between individual countries	Differences in age and life expectancy of trucks in individual EU countries	Take into account the age and life expectancy of trucks in individual EU countries
The costs of contour marking in the EU	Translation of the costs per NL truck to the total number of EU trucks, lowering the NL costs by a factor of 2/3	Estimate of the costs of tape and application, estimating the costs at 2/3 of the NL costs	Real costs of applying contour marking	Retrieve information about the costs in a number of EU countries
The costs of a casualty in the EU	Translation of the costs per NL casualty to the number of EU casualties, lowering the NL costs by a factor of 2/3	Number of inhabitants in individual countries	Real crash costs/human losses in individual countries	Retrieve information about the costs per casualty in a number of EU countries
The damage in euros per crash	Extrapolate the costs of NL damages to EU total damages, reduced by a factor of 2/3 of the NL costs	Number of inhabitants and trucks in individual countries	Real costs of individual damages in individual countries	Investigate whether individual countries use specific damage costs

Table S.2. *Assumptions and their consequences for the calculation of the effects of retrofit contour marking in the European Union, not including the Netherlands*.

As the calculation methods for the Netherlands and the EU are not the same, the road safety effect, the costs and the benefits are given for the EU, not including the Netherlands.

Translated to the European Union not including the Netherlands, retrofit introduction of contour marking per 1 January 2015 is expected to result in a total saving of:

- 421 fatalities
- 2240 serious road injuries
- 67.373 crashes

over the period the measure is being put into effect. The costs of the measure amount to a total of 267 M€ in the minimum cost scenario and 517 M€ in the maximum cost scenario for the EU (minus the Netherlands). Converted to money, the total benefits of the measure for the EU minus the Netherlands amount to 1541 M€. Therefore the ratio between benefits and costs is 3 in the maximum cost scenario and 6 in the minimum cost scenario.

Total costs, benefits and benefit-cost ratio for the EU including the Netherlands

The total costs, benefits and benefit-cost ratio for the entire European Union are calculated by adding the costs for the Netherlands and the European Union in the previous sections. It should be noted that the costs and benefits for the Netherlands have been calculated more accurately than those for the European Union: these latest figures are only a rough estimate.

In the maximum cost scenario, the costs in the EU and in the Netherlands add up to 548 million euros, minimum cost scenario the total is 283 million euros. In both cases the benefits add up to 1576 million euros. The benefit-cost ratio therefore remains 3 for the maximum cost scenario and 6 for the minimum cost scenario. This calculation of the costs does also not take into account costs for legislation and information and costs for enforcement are assumed not to increase significantly. These costs are outside the scope of the present investigation.

	Society	
	Maximum costs*	**Minimum costs****
Costs	548	283
Benefits	1576	1576
Balance benefits-costs	1028	1293
Ratio benefits/costs	3	6

Table S.3*. Costs and benefits of retrofit introduction of contour marking (present values in million euros), and balance and ratio of costs and benefits in the EU including the Netherlands. * Maximum scenario: full contour marking, two thirds of the Dutch price (marking €2.80 per metre, application costs €130 per lorry) and two thirds of the Dutch benefits. ** Minimum scenario: minimum required contour marking, two thirds of the Dutch price (marking €2.00 per metre, application costs €100 per lorry) and two thirds of the Dutch benefits.*

Inhoud

Voorwoord

Dit rapport is uitgevoerd in opdracht van 3M Belgium en behandelt de kosten en baten van het retrofit invoeren van contourmarkering op vrachtauto's in Nederland. Ook voor retrofit invoering in de Europese Unie is een globale schatting gedaan van kosten en baten.

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1. Inleiding

In Nederland vinden jaarlijks ongeveer 300 ongevallen plaats met vrachtauto's (bakwagens, trekkers, opleggers en aanhangers)[3] waarbij doden of ernstig verkeersgewonden vallen (Mesken, Schoon & Van Duijvenvoorde, 2012). Een gedeelte van deze ongevallen ontstaat door zijdelingse en kop-staart-botsingen bij schemer of in het donker. Eerder SWOV-onderzoek (De Niet, Goldenbeld & Langeveld, 2002) laat zien dat retroreflecterende contour-markeringen op vrachtauto's een bijdrage kunnen leveren aan het voorkomen van die ongevallen. Retroreflecterend houdt in dat het licht reflecteert in dezelfde richting als de lichtbron.

Op basis van EU-richtlijn 2007/35/EG moeten sinds 10 juli 2008 vrachtauto's met een maximummassa vanaf 7,5 ton en aanhangwagens (waaronder opleggers) vanaf 3,5 ton[4] van goedgekeurde en op de voorgeschreven manier aangebrachte retroreflecterende contourmarkering zijn voorzien om bij een typekeuring te worden goedgekeurd. Vanaf 10 juli 2011 moeten niet alleen nieuwe typen maar ook voertuigen van een ouder type die voor het eerst een kenteken krijgen, retroreflecterende contourmarkering hebben (Europese Unie, 2007a; 2007b).

Voor bestaande voertuigen met een kenteken geldt bovengenoemde verplichting van retroreflecterende contourmarkering niet. 3M is geïnteresseerd in de vraag welke inhoudelijke argumenten er kunnen worden aangedragen om in Nederland en in Europa te pleiten voor het invoeren van contourmarkering voor het bestaande wagenpark, de zogenaamde retrofit, en heeft SWOV gevraagd hiernaar onderzoek te doen. Ook zou men graag willen weten welke strategieën in Nederland mogelijk zijn om de invoering van retrofit te bewerkstelligen, mocht blijken dat er positieve veiligheidseffecten van retrofit te verwachten zijn.

1.1. Vraagstelling en motivering

Op basis van de vraag van 3M heeft SWOV de volgende vragen opgesteld:

1. Welke verkeersveiligheidseffecten zijn te verwachten van het retrofit invoeren van contourmarkering op vrachtauto's in Nederland?
2. Wat zijn de maatschappelijke kosten en opbrengsten van deze maatregel en is de maatregel op maatschappelijk niveau kosteneffectief?
3. Wat zijn de kosten en opbrengsten voor transportbedrijven?
4. Wat is het effect van retrofit contourmarkering in de EU op het aantal doden en gewonden als gevolg van verkeersongevallen?
5. Wat zijn mogelijke strategieën die gebruikt kunnen worden bij het pleiten voor de invoering van de maatregel, aannemende dat de maatregel positieve veiligheidseffecten sorteert?

Het is redelijk om te stellen dat het gemakkelijker zal zijn te pleiten voor retrofit invoering bij een groter verkeersveiligheidseffect dan bij een kleiner effect. Eerder onderzoek (Morgan, 2001; De Niet, Goldenbeld & Langeveld,

[3] Wanneer we spreken over 'vrachtauto's' bedoelen we bakwagens, trekkers, opleggers en aanhangers tenzij anders aangegeven.
[4] Voor beiden geldt: tevens breder dan 2,10 meter en/of langer dan 6 meter.

2002; Schmidt-Clausen, 2001) berekende op basis van de kennis van die tijd een bescheiden positief effect van 2 tot 3 doden en 20 tot 30 ziekenhuisgewonden per jaar wanneer het hele Nederlandse wagenpark geen contourmarkering zou hebben gehad en in één klap van contourmarkering zou zijn voorzien. Het huidige onderzoek bekijkt of er inmiddels nieuwe informatie beschikbaar is. Naast de effecten zijn ook de kosten van belang, niet alleen voor de maatschappij als geheel, maar ook voor individuele bedrijven. Het huidige onderzoek bekijkt de maatschappelijke kosten en baten. Ook zijn de kosten en baten voor transportbedrijven berekend, omdat een te volgen strategie naar verwachting beïnvloed wordt door de resultaten van beide kosten-batenanalyses. Daarnaast is onderzocht hoe snel vrachtauto's vervangen worden, ook dit bepaalt mede een strategie bij een retrofit invoering.

Onderzoek naar de vijfde subvraag, de mogelijke strategieën voor het pleiten voor invoering van de maatregel, is praktisch gezien alleen nuttig indien het onderzoek inderdaad aantoont dat retrofit invoering van contourmarkering een positief effect heeft op de verkeersveiligheid en een positieve kosten-batenverhouding heeft. Daarom doet deze tussenrapportage alleen verslag van de eerste vier subvragen van het onderzoek. In overleg met 3M wordt over een eventueel vervolg met subvraag vijf beslist.

1.2. Opzet van het onderzoek

Voor de beantwoording van de eerste twee subvragen is een literatuuronderzoek uitgevoerd naar nieuwe informatie over kosten en effecten van contourmarkering (*Hoofdstuk 2*). Daarnaast zijn voor de tweede, derde en vierde subvraag nieuwe berekeningen gemaakt voor de maatschappelijke kosten en effecten van de maatregel en voor de kosten en effecten voor bedrijven (*Hoofdstuk 3*). Specifiek is gekeken naar de effecten en kosten van een *retrofit* invoering in Nederland; daarbij is de vervangingssnelheid van vrachtauto's betrokken. *Hoofdstuk 4* behandelt de (maatschappelijke) kosten en effecten van retrofit invoering van contourmarkering in de EU. *Hoofdstuk 5* behandelt de conclusies van dit onderzoek.

2. Effecten van retrofit contourmarkering

In het donker leveren grote voertuigen die stilstaan of aanzienlijk langzamer rijden dan het achteropkomende verkeer en lange voertuigen die dwars op een verkeersstroom stilstaan of langzaam rijden/manoeuvreren een risico op voor het overige verkeer als zij niet tijdig worden waargenomen en herkend. De waarneembaarheid en herkenbaarheid van deze voertuigen in de betrokken omstandigheden kunnen worden verbeterd door het aanbrengen van contourmarkering (of lijnmarkering) die retroreflecteert in de koplampen van naderende motorvoertuigen.

Op basis van EU-richtlijn 2007/35/EG moeten sinds 10 juli 2008 vrachtauto's met een maximummassa vanaf 7,5 ton en aanhangwagens (waaronder opleggers) vanaf 3,5 ton[5] van goedgekeurde en op de voorgeschreven manier aangebrachte retroreflecterende contourmarkering zijn voorzien om bij een typekeuring te worden goedgekeurd. Vanaf 10 juli 2011 moeten niet alleen nieuwe typen maar ook voertuigen van oudere typen die voor het eerst een kenteken krijgen retroreflecterende contourmarkering hebben (Europese Unie, 2007a; 2007b).

In dit hoofdstuk bepalen we welke additionele slachtofferbesparing in Nederland met retrofit van retroreflecterende contourmarkering te bereiken is ten opzichte van de geldende geleidelijke invoering door installatie op nieuwe voertuigen. Daarvoor zijn de volgende gegevens van belang:

- het aantal slachtoffers dat valt bij ongevallen in het duister/schemer waarbij een motorvoertuig tegen de zij- of achterkant van een vrachtauto of aanhanger botst;
- het aantal van die slachtoffers en ongevallen dat per jaar door de retroreflecterende contourmarkering kan worden bespaard;
- het moment waarop redelijkerwijze een verplichting tot retrofit kan ingaan;
- het aantal voertuigen dat zonder contourmarkering rijdt en hoe lang het duurt het voor deze vervangen zijn onder de huidige regelgeving.

Op basis hiervan kan een schatting worden gemaakt van het aantal slachtoffers dat per jaar extra kan worden bespaard vanaf het jaar dat met retrofit wordt begonnen en tot hoeveel dat in totaal optelt.

In *Paragraaf 2.1* bespreken we het Nederlands onderzoek naar de effecten van contourmarkering, in *Paragraaf 2.2* het buitenlands onderzoek. In *Paragraaf 2.3* komen we dan tot een vertaling van de effectcijfers naar de Nederlandse situatie.

2.1. Nederlands onderzoek in 2002

De mogelijke besparing van slachtoffers is onderwerp geweest van verschillende onderzoeken. Voor Nederland heeft SWOV (De Niet, Goldenbeld & Langeveld, 2002) hiervoor in 2002 een prognose opgesteld, gebaseerd op een groot aantal Nederlandse en buitenlandse onderzoeken en een analyse van Nederlandse ongevallencijfers uit 1998 en 1999.

[5] Voor beide geldt: tevens breder dan 2,10 meter en/of langer dan 6 meter.

Er zijn drie belangrijke veldstudies naar de effectiviteit van retroreflecterende contourmarkering, van Vector Enterprises (Burger & Smith, 1987; Morgan, 2001; Rowe, 1988; Ziedman et al., 1981, alle in De Niet, Goldenbeld & Langeveld, 2002), de National Highway Traffic Safety Administration (Morgan, 2001, in De Niet, Goldenbeld & Langeveld, 2002) en de Technische Hochschule Darmstadt (Finsterer & Schmidt-Clausen, 1992; Schmidt-Clausen, 1997; 2001; Schmidt-Clausen & Finsterer, 1989). De studies komen elk tot een andere grootte van het effect van contour-markering, en betrekken hun effect ook elk op een andere, specifieke, groep ongevallen. In de SWOV-studie van 2002 is met deze beperking voor specifieke groepen ongevallen rekening gehouden, en zijn de effecten van de verschillende studies omgerekend naar de Nederlandse situatie. Gemiddeld kwam dit voor zowel doden als ziekenhuisgewonden neer op een effectiviteit van ca. 30%. De mogelijke slachtofferbesparing kwam hiermee op 2 tot 3 doden en 20 tot 30 ziekenhuisgewonden per jaar, en tevens enkele honderden ongevallen (variërend tussen 180 en 664) met lichtgewonden of uitsluitend materiële schade (UMS).

2.2. Buitenlands onderzoek

In het SWOV-onderzoek uit 2002 is het tot dan toe uitgevoerde onderzoek in het buitenland meegenomen. Na 2002 is in Nederland geen verder onderzoek gedaan naar effectschattingen van contourmarkering. De vraag komt op of er nadien rapportages zijn verschenen van buitenlands onderzoek die aanleiding kunnen zijn om het effect van retroreflecterende contourmarkering anders in te schatten. In de afgelopen tien jaar zijn drie buitenlandse onderzoeken verschenen naar de effecten van contourmarkering.

Onderzoek uit 2004 (TÜV Rheinland group, 2004) gebruikt voor de schatting van de effectiviteit van retroreflecterende contourmarkering dezelfde studies als SWOV en komt dan ook op een zelfde effect uit.

Een uitvoerige kosten-batenstudie, vergelijkbaar met de SWOV-studie uit 2002, is die van Lawton, Richardson & Welsh (2005) voor het Britse Department for Transport. Ook in dit onderzoek wordt voor de effectiviteit gekeken naar het veldonderzoek waar ook SWOV en de TÜV zich op baseren. De basis voor de schatting van de potentiële slachtofferbesparing zijn de ongevallencijfers in het Verenigd Koninkrijk van 2003. Aanvullend is in dat onderzoek gekeken naar verschillende gewichten van vrachtauto's en zijn ook bussen en minibussen meegenomen, waardoor een beeld wordt geschetst van het mogelijke nut om ook retroreflecterende contourmarkering te verplichten op vrachtauto's onder 7,5 ton, bussen en busjes. Bij volledige uitrusting van de verschillende voertuigen met contourmarkering (of lijn-markering als contourmarkering niet mogelijk is) komt men tot een jaarlijks te besparen aantal verkeersdoden dat bij vrachtauto's vanaf 7,5 ton meer dan vijftien keer zo groot is als bij lichtere vrachtauto's en bij busjes tot en met zestien zitplaatsen; de besparing bij vrachtauto's vanaf 7,5 ton is ruim acht keer zo groot als bij grotere bussen.

Sullivan & Flannagan (2012) hebben gekeken naar de effecten van de invoering van de verplichte retroreflecterende contourmarkering in de Verenigde Staten. Voor nieuwe zware aanhangers vanaf 4,536 ton of breder dan 2,032 meter geldt in de VS vanaf december 1993 een verplichting tot contourmarkering. Met ingang van 1 juni 2001 moet ook op zware aanhangers

van vóór 1 december 1993 enige vorm van reflectie zijn aangebracht; met ingang van 1 juni 2009 moet dit volgens de normen van nieuwe aanhangers. Ten slotte geldt dat vanaf 1 juli 1997 ook op vrachtauto's retroreflecterende markering moet zijn aangebracht.
Het onderzoek van Sullivan & Flannagan (2012) richtte zich op aanrijdingen van motorvoertuigen tegen de achterkant of zijkant van een vrachtauto of aanhanger/oplegger bij duisternis en liep van 1987 tot en met 2009.
In het onderzoek wordt vastgesteld dat tussen 1987 en 2009 's nachts sprake was van een aanzienlijk grotere afname van zij- en achteraanrijdingen van lichte voertuigen tegen zware voertuigen dan overdag. Deze verandering was groter dan bij ongevallen waarbij verbetering van de opvallendheid van zware voertuigen geen rol speelde. Aangezien deze daling bij de relevante ongevallen zich afspeelde in de tijd dat geleidelijk de retroreflecterende contourmarkeringen werden ingevoerd, suggereert dit een oorzakelijk verband. Opvallend is echter dat er al sprake is van een forse daling van het aantal relevante dodelijke ongevallen tussen 1987 en 1993, nog vóórdat met contourmarkering werd begonnen. Het is dan ook onduidelijk waarom de daling in ongevallen vanaf 1987 aan markering wordt toegeschreven, terwijl de eerste zes à zeven jaar van de daling voor die markering niet relevant zijn. Gelet op de andere vormgeving van de contourmarkering, het andere voertuigpark waarop deze is aangebracht, de andere verkeersomstandigheden en de onderzoeksopzet, waardoor een overdreven effectiviteit wordt geconcludeerd, is dit onderzoek hooguit bruikbaar om te signaleren dat contourmarkering effect heeft. Het is niet gebruikt om een mate van slachtofferbesparing bij retrofit in Nederland op te baseren.

2.3. Vertaling naar de huidige Nederlandse situatie

In de inleiding van dit hoofdstuk zijn de volgende vijf gegevens van belang geacht om een inschatting te maken van de effecten van retrofit contourmarkering in de huidige Nederlandse situatie:

1. het aantal slachtoffers dat valt bij ongevallen in het duister/schemer waarbij een motorvoertuig tegen de zij- of achterkant van een vrachtauto of aanhanger botst;
2. het aantal van die slachtoffers en ongevallen dat door de retroreflecterende contourmarkering per jaar kan worden bespaard;
3. het moment waarop redelijkerwijze een verplichting tot retrofit kan ingaan;
4. het aantal voertuigen dat zonder contourmarkering rijdt en hoe lang het duurt het voor deze vervangen zijn onder de huidige regelgeving.
5. een schatting van de totale slachtoffer- en ongevallenbesparing door het retrofit invoeren van contourmarkering.

We zullen deze punten hieronder langslopen om de effectschattingen uit *Paragrafen 2.1* en *2.2* te vertalen naar de huidige Nederlandse situatie.

1. Aantal slachtoffers bij relevante ongevallen
Om het aantal mogelijk te besparen slachtoffers en ongevallen te bepalen, moeten we eerst bezien voor hoeveel ongevallen retroreflecterende contourmarkering een oplossing zou kunnen bieden. Hiervoor hebben we het gemiddeld aantal slachtoffers en ongevallen in de jaren 2005 tot en met 2009 bekeken en eenzelfde selectie gemaakt als in het SWOV-onderzoek uit 2002, namelijk ongevallen:

- met vrachtauto's, aanhangers of opleggers;

- met een motorvoertuig (fietsverlichting is veelal te zwak om profijt te hebben van retroreflectie);
- waarbij de vrachtauto de eerste of tweede botser was;
- van het type flank, kop-staart- of parkeerongeval;
- in schemer of duister;
- waarbij het aangrijppunt op de vrachtauto niet 'voor' is.

Om diverse redenen is voor de periode 2005-2009 gekozen: in deze periode was contourmarkering nog niet verplicht, en de registratiegraad van ongevallen met (licht)gewonden en met uitsluitend materiële schade (UMS) neemt na 2009 drastisch af, zodat recentere cijfers te onbetrouwbaar zijn om bovengenoemde uitsplitsingen te maken.
De geregistreerde aantallen zijn met behulp van correctiefactoren opgehoogd tot werkelijke aantallen slachtoffers en ongevallen (SWOV, 2013a; 2013b). In *Bijlage 1* zijn de tabellen met deze cijfers opgenomen.
Gemiddeld vielen er tussen 2005 en 2009 jaarlijks 10 doden en 54 ernstig verkeersgewonden bij ongevallen met bovenstaande kenmerken. In totaal, inclusief ongevallen met lichtgewonden en UMS, betreft het gemiddeld per jaar 2.124 ongevallen in de periode van 2005 tot en met 2009.

2. Te besparen aantal slachtoffers en ongevallen door contourmarkering
Als we de prognose van mogelijk te besparen slachtoffers uit het onderzoek van 2002 vertalen naar de huidige tijd op basis van de gemiddelde ongevallencijfers van 2005 tot en met 2009, dan verwachten we een slachtofferbesparing van 3 doden en 16 ernstig verkeersgewonden per jaar, en een besparing van 481 ongevallen. In *Bijlage 2* zijn de tabellen met deze cijfers opgenomen.
Bij de schatting zijn we uitgegaan van een nulsituatie en invoering van contourmarkering op alle vrachtauto's, dus vanaf 3,5 ton, en hun aanhangers en opleggers. De feitelijke invoering van retroreflecterende contourmarkering in de EU betreft vrachtauto's vanaf 7,5 ton en aanhangers vanaf 3,5 ton. In dat verband is de effectschatting dus aan de optimistische kant. De overschatting van het effect (door ook contourmarkering op vrachtwagens tussen 3,5 en 7,5 ton mee te rekenen) zal waarschijnlijk echter meevallen. De slachtofferbesparing is namelijk groter naarmate de vrachtauto's zwaarder zijn. Onderzoek uit 2004 (TÜV Rheinland group, 2004) laat bijvoorbeeld zien dat in Duitsland bij 70% van de vrachtauto-ongevallen voertuigen van meer dan 12 ton zijn betrokken, terwijl die daar 55% van het aantal vrachtauto's uitmaken.

3. Mogelijk invoeringsjaar retrofit contourmarkering
Een verplichting tot retrofit kan in principe redelijk snel worden ingevoerd, aangezien er geen langdurige wettelijk procedure voor vereist is. Er is een wijziging van de Regeling voertuigen voor nodig, een ministeriële regeling. Aangezien niet van de ene op de andere dag alle voertuigen van voor 10 juli 2011 van retroreflecterende contourmarkering kunnen worden voorzien, is een ingangsdatum van 1 januari 2015 niet realistisch, maar is voor het gemak van de berekening toch deze datum ingangsdatum gekozen. Vrachtauto's en aanhangwagens met dekzeilen zijn niet in de berekening meegenomen, aangezien geen retroreflecterende contourmarkering kan worden aangebracht op dekzeilen die al in gebruik zijn en redelijkerwijze niet verlangd kan worden dat dekzeilen vervroegd worden afgedankt terwijl ze nog in goede staat verkeren (zie ook *Bijlage 3*).

4. Aantal voertuigen zonder contourmarkering onder huidige regelgeving

De huidige regelgeving voor contourmarkering voorziet in verplichte contourmarkering voor nieuwe typen vanaf 2008, en vanaf 2011 ook voor oudere typen die voor het eerst een kenteken krijgen. Omdat vrachtauto's regelmatig vervangen worden, betekent dat dat op enig moment het gehele wagenpark voorzien zal zijn van contourmarkering. Wanneer dat precies is, verschilt per voertuigsoort, en is afhankelijk van de levensduur. Uit CBS-cijfers valt af te leiden dat de gemiddelde levensduur van bakwagens 13 jaar is, van trucks met oplegger eveneens 13 jaar en van aanhangers 22 jaar.

Geleidelijke invoer van contourmarkering zou betekenen dat het complete park van aanhangwagens gemiddeld nog 11 jaar zonder retrofit zou rondrijden, en het complete park van bakwagens en opleggers gemiddeld nog 6,5 jaar. Hier zou het effect van retrofit in één keer mee berekend kunnen worden, ware het niet dat er al wagens zijn voorzien van contourmarkering. Doordat er al vervanging heeft plaatsgevonden, is zowel de relevante parkomvang (namelijk het deel zonder retrofit) veranderd, als de gemiddelde levensduur van dat parkdeel. Er zijn verschillende manieren om die parkverandering in de berekening te verwerken. De effecten van beide factoren (omvang en levensduur) zijn, zoals we het nu berekenen (dus zonder aannamen over bijvoorbeeld een geleidelijke daling van het risico) allebei evenredig van invloed op het effect op de veiligheid. Het effect van deze twee factoren op de veiligheid is daarmee gelijk: het maakt bijvoorbeeld niet uit of het park halveert of de levensduur.

We nemen de consequenties van beide veranderingen daarom samen. Dat kan door te werken met de totale levensduur van het park in 'wagen-jaren'. De berekening houdt rekening met verschillende wagens, verschillende bouwjaren, verschillende levensduren enzovoort. In *Bijlage 3* is de berekening opgenomen. Het resultaat laat zien hoeveel wagens zonder retrofit er na 1 januari 2015 nog zouden rondrijden en hoe lang. Dat betreft 123.400 wagen-jaren voor de aanhangers, en 393.636 wagen-jaren voor de bakwagens/opleggers, opgeteld 517.076 wagen-jaren.

5. Totale schatting besparing aantal slachtoffers en ongevallen bij retrofit invoering

Het verschil tussen het gehele park voorzien van retroflectie en niets voorzien van retroflectie vertaalt zich in 3 doden en 16 ernstig verkeersgewonden per jaar en 481 ongevallen. In De Niet, Goldenbeld & Langeveld (2002) wordt geen onderscheid gemaakt naar bakwagens/opleggers en aanhangers, zij zijn samen in gelijke mate goed voor de besparing. De genoemde slachtofferbesparingen zouden behaald worden indien het gehele Nederlandse wagenpark geen contourmarkering zou hebben en in één klap contourmarkering zou krijgen. Het totale wagenpark op 1 januari 2013 bedraagt 196.164 voertuigen (zie *Tabel 3.3* en *Bijlage 3*), en we gaan ervan uit dat de omvang van het wagenpark tot 1 januari 2015 min of meer stabiel is gebleven. Per voertuig is de besparing dan $1{,}53 \cdot 10^{-5}$ dode, $8{,}16 \cdot 10^{-5}$ ernstig gewonde en $2{,}45 \cdot 10^{-3}$ ongeval per jaar.

Het totale effect op de verkeersveiligheid door retrofit invoering van contourmarkering is dan het aantal bespaarde slachtoffers en ongevallen maal het totaal aantal wagen-jaren (517.076 wagen-jaren: aantal wagens die na 1 januari 2015 nog zonder contourmarkering rondrijden, rekening houdend met de tijd dat zij nog rondrijden). Daarmee betreft de totale besparing over de totale werkingstermijn van de maatregel, dus vanaf 1 januari 2015 totdat alle vrachtauto's voorzien zijn van contourmarkering, respectievelijk:

- 8 doden,
- 42 gewonden, en
- 1.268 ongevallen.

Het hierboven berekende effect van retrofit kan enerzijds iets onderschat zijn, om de volgende redenen:

- Voertuigen uit restantvoorraden omstreeks de invoering van retroflectie voor nieuwe vrachtwagens (10 juli 2008) zijn een uitzondering. Als vrachtwagens vóór de invoering zijn geïmporteerd, maar pas ná de invoering een nieuw kenteken hebben gekregen, rekenen we ermee alsof ze retroflectie hadden, terwijl dat niet zo was. Het effect van retrofit is daarmee onderschat: ook deze vrachtwagens moeten nog worden voorzien van contourmarkering, waardoor er een extra effect van retrofit zou zijn.
- In de veldstudies die voor de schatting van het effect zijn gebruikt, was sprake van materialen met een vermoedelijk lagere opvallendheid dan die van de meer geavanceerde markeringen volgens de technische eisen van ECE R-104. Het effect van deze laatste kan wat hoger zijn.

Anderzijds kan het berekende effect van retrofit enigszins overschat zijn:

- doordat bij de berekening is uitgegaan van retroreflecterende contour-markering op alle vrachtauto's, dus ook tussen 3,5 en 7,5 ton (al zijn het overwegend ongevallen met de zwaardere vrachtauto's waarbij doden en ernstig gewonden vallen).
- door een overlap in effect met de sinds 1 januari 1998 op nieuwe vrachtauto's en aanhangers verplichte zijmarkeringslichten;
- doordat in Nederland rijdende oudere buitenlandse vrachtauto's geen retrofit zullen hebben, met uitzondering van Italiaanse, want in Italië is retrofit invoering reeds een feit;
- doordat de aantallen verkeersslachtoffers door de jaren heen ook dalen door andere maatregelen en ontwikkelingen; denk aan veiligere auto's en wegen, minder drankgebruik, meer gordelgebruik;
- door een zeer optimistische schatting van de ingangsdatum (1 januari 2015).

3. Kosteneffectiviteit voor maatschappij en bedrijf

Dit hoofdstuk gaat in op de kosten (*Paragraaf 3.1*) en baten (*Paragraaf 3.2*) van retrofit invoering van contourmarkering op vrachtauto's. Zowel de maatschappelijke kosten en baten worden berekend, als de kosten en baten voor transportbedrijven. De kosten-batenanalyse (*Paragraaf 3.3*) geeft aan of retrofit invoering vanuit economisch perspectief zinvol is, dat wil zeggen: in hoeverre wegen de baten van het aanbrengen van contourmarkering op het bestaande wagenpark (minder ongevallen en slachtoffers) op tegen de kosten daarvan.

Alle bedragen in dit hoofdstuk zijn in prijspeil 2012, tenzij anders aangegeven, en exclusief btw.[6] Conform de OEI-leidraad voor kosten-batenanalyses (CPB & NEI, 2000) hanteren we een discontovoet bij het bepalen van kosten en baten. Dit betekent dat kosten en baten een lagere waardering wordt toegekend naarmate zij zich verder in de toekomst voordoen. We hanteren een discontovoet van 5,5% zoals voorgeschreven door het ministerie van Financiën (2007), waarbij we 2013 als basisjaar hanteren.

3.1. Kosten

De kosten bestaan uit de kosten van arbeid en materiaal die benodigd zijn voor het aanbrengen van contourmarkering op het bestaande wagenpark. Volgens het Europese reglement ECE 48 moet de gehele contour van de achterkant van vrachtauto's worden gemarkeerd, en moet minimaal 80% van lengte van de zijkant worden gemarkeerd (aan de onderkant) evenals de hoeken (25 bij 25 cm, aan de bovenkant). Verwacht mag worden dat echter op een deel van de vrachtauto's (vrijwillig) de gehele contour van de zijkant gemarkeerd zal worden, maar het is op voorhand niet te zeggen in welke mate. De kosten van het aanbrengen van contourmarkering worden daarom bepaald voor twee scenario's: een 'maximumscenario' waarbij op alle vrachtauto's de volledige contour van de zijkanten worden gemarkeerd, en een 'minimumscenario' waarbij alleen de onderkant en de bovenhoeken worden gemarkeerd. Ervaringen van 3M, en de minimumeisen gesteld door EU-richtlijn 2007/35/EG of UN-richtlijn ECE 48, Clause 6;21, geven aan dat het maximumscenario erg hoog is, en dat men waarschijnlijk voor een groot deel van de vrachtauto's zal kiezen voor minder/het minimum aan markering. Uit praktische overwegingen en vanwege vergelijkingsmogelijkheden is gekozen voor zowel maximum- als minimumscenario, omdat op voorhand niet te zeggen valt om hoeveel vrachtauto's het gaat, en omdat in de eerdere SWOV-studie naar contourmarkering ook is gerekend met de maximale markering. In het minimumscenario wordt tevens uitgegaan van lagere kosten voor het materiaal en voor het aanbrengen van de markering (zie hieronder). Beide scenario's gaan ervan uit dat ook op de cabine markering wordt aangebracht.

[6] Sinds 2011 dient btw meegenomen te worden in maatschappelijke kosten-batenanalysis (Kernteam OEI, 2011). Omdat echter nog geen kengetallen voor de waardering van slachtofferreductie inclusief btw zijn vastgesteld, nemen we btw hier niet mee.

Om de kosten van retrofit invoering van contourmarkering te bepalen is informatie nodig over:

- De kosten van contourmarkering per vrachtauto, bestaande uit de kosten van de markering (materiaal) en het aanbrengen van de markering (arbeid). Om deze kosten te kunnen berekenen is informatie nodig over de afmetingen van vrachtauto's.
- Het aantal vrachtauto's waarop contourmarkering wordt aangebracht bij retrofit invoering, dat wil zeggen het aantal vrachtauto's dat zonder retrofit geen contourmarkering zou hebben.

Hieronder gaan we op deze aspecten in.

In de berekening van de kosten is geen rekening gehouden met kosten voor wetgeving en voorlichting. We schatten in dat deze kosten gering zijn. De kosten voor handhaving zullen naar onze inschatting niet significant toenemen. Deze kosten vallen buiten de scope van dit onderzoek.

3.1.1. *Kosten per vrachtauto*

De kosten van de markering en het aanbrengen daarvan baseren we op prijsopgaven van twee bedrijven die contourmarkering aanbrengen op vrachtauto's ('beletteraars' die ook reclameteksten en dergelijke aanbrengen op vrachtauto's). Volgens deze prijsopgaven bedraagt de prijs van markering 2,80 euro per meter. De kosten van het aanbrengen van markering op een vrachtauto bedragen gemiddeld circa 130 euro. Deze bedragen passen we toe in het maximumscenario. In het minimumscenario veronderstellen we dat een retrofit verplichting leidt tot een daling van de prijs (en productie-kosten) van markering, bijvoorbeeld omdat nieuwe aanbieders op de markt toetreden. We gaan in dit scenario uit van een prijs van markering van 2 euro per meter, op basis van een inschatting van 3M. Verder veronderstellen in het minimumscenario dat de kosten van het aanbrengen van markering 100 euro per vrachtauto bedragen, omdat er minder markering wordt aangebracht.

Voor de benodigde markering per vrachtauto gaan we uit van de afmetingen van een 'gemiddelde' vrachtauto, op basis van de afmetingen van enkele veel voorkomende modellen. *Tabel 3.1* geeft de afmetingen waarmee we rekenen, en de markering die per vrachtauto nodig is gegeven deze afmetingen. Op de cabine van bakwagens en op trekkers is markering niet verplicht, maar we gaan ervan uit dat markering daarop ook wordt aangebracht.

Type voertuig	**Laadruimte**			**Cabine**	**Benodigde markering**	
	Lengte	**Breedte**	**Hoogte**		**Minimum**	**Maximum**
Bakwagen	7	2,5	2,4	2	27	51
Oplegger	13	2,5	2,6	n.v.t.	33	73
Trekker	n.v.t.	n.v.t.	n.v.t.	2	4	4
Aanhanger	8	2,5	2,6	n.v.t.	25	53

Tabel 3.1. *Afmetingen vrachtauto's en benodigde markering per vrachtauto (meter).*

Tabel 3.2 geeft de kosten van de markering per vrachtauto, bestaande uit de materiaalkosten (de markering) en arbeidskosten (het aanbrengen van de markering). De materiaalkosten zijn berekend op basis van de afmetingen in *Tabel 3.1* en de genoemde prijzen van markering.

	Minimum			**Maximum**		
Type voertuig	**Markering**	**Aanbrengen**	**Totaal**	**Markering**	**Aanbrengen**	**Totaal**
Bakwagen	54	100	154	144	130	274
Oplegger	66	100	166	203	130	333
Trekker	8	100	108	11	130	141
Aanhanger	50	100	150	147	130	277

Tabel 3.2. *Kosten markering per vrachtauto (euro).*

3.1.2. *Aantal vrachtauto's*

Om de totale kosten van het aanbrengen van contourmarkering op het gehele wagenpark te berekenen is informatie nodig over het aantal vrachtauto's en over het aantal dat al voorzien is van contourmarkering op het moment dat een verplichting voor het hele wagenpark van kracht wordt. Sinds 10 juli 2011 is contourmarkering verplicht op alle bakwagens zwaarder dan 7,5 ton en op alle opleggers en aanhangers zwaarder dan 3,5 ton. Voor trekkers is contourmarkering niet verplicht. Sinds 10 oktober 2008[7] was contourmarkering alleen verplicht voor nieuwe typen bakwagens, opleggers en aanhangers. Dit betekent bijvoorbeeld dat een nieuw type vrachtauto dat vóór 10 oktober 2008 op de markt is gebracht van contourmarkering moet zijn voorzien als het na 10 juli 2011 wordt verkocht.

Voor de berekeningen gaan we ervan uit dat de retrofitverplichting wordt ingevoerd op 1 januari 2015. Het aantal vrachtauto's waarop dan contour-markering moet worden aangebracht bepalen we op basis van de volgende gegevens (zie *Tabel 3.3*):
- de omvang van het wagenpark op 1 januari 2013;
- het aantal nieuwe typen bakwagens (zwaarder dan 7,5 ton), opleggers en aanhangers (zwaarder dan 3,5 ton) dat is verkocht tussen 10 oktober 2008 en 10 juli 2011;
- het aantal nieuwe bakwagens, opleggers en aanhangers (in dezelfde gewichtscategorieën) dat is verkocht sinds 10 juli 2011;
- een schatting van de aantallen bakwagens, opleggers en aanhangers (in dezelfde gewichtscategorieën) dat zijn verkocht tussen 1 januari 2013 en 1 januari 2015.

De wagenparkcijfers en de verkoopcijfers van bakwagens zijn gebaseerd op CBS-statistieken. Verkoopcijfers van opleggers en aanhangers zijn afkomstig van RAI Vereniging. Verkoopcijfers van bakwagens en opleggers zijn echter niet uitgesplitst naar gewichtsklassen. We veronderstellen dat het aandeel

[7] De officiële ingangsdatum van de maatregel in Nederland is 10 juli 2008 (https://zoek.officielebekendmakingen.nl/stb-2008-211.html). In documentatie van 3M (3M Nederland BV, 2011) en op diverse sites van aanbieders van contourmarkering wordt verwezen naar de ingangsdatum van 10 oktober 2008. Dit betreft de ingangsdatum in de gehele EU. In dit rapport is gekozen voor een berekening met de EU-ingangsdatum.

verkochte bakwagens zwaarder dan 7,5 ton gelijk is aan het aandeel daarvan in het wagenpark. Verder gaan we ervan uit dat alle opleggers zwaarder zijn dan 3,5 ton.

Het aantal verkochte nieuwe typen vrachtauto's baseren we op gegevens van de RDW over typegoedkeuring die zijn afgegeven tussen 10 oktober 2008 en 10 juli 2011 en verkoopcijfers naar merk en model (opleggers en aanhangers alleen merk) van RAI Vereniging. Uit deze cijfers blijkt dat voor alle modellen bakwagens die zijn verkocht nieuwe typegoedkeuringen zijn afgegeven. Hoeveel nieuwe modellen bakwagen exact zijn verkocht is uit de cijfers echter niet precies af leiden. We veronderstellen dat het bij 75% van de verkochte bakwagens om nieuwe modellen gaat. Voor verkochte opleggers en aanhangers geldt dat circa 75% afkomstig is van een fabrikant (merk) die in de betreffende periode een of meer nieuwe modellen op de markt heeft gebracht. We veronderstellen dat het bij de helft daarvan (37,5%) om een nieuw model gaat waarvoor een typegoedkeuring nodig was.

Om het aantal verkochte voertuigen tussen 1 januari 2013 en 1 januari 2015 te bepalen, gaan we ervan uit dat jaarlijks ongeveer 8% van de bakwagens wordt vervangen. Dit is bepaald op basis van CBS-statistieken over de periode 2000 tot en met 2012, waaruit blijkt dat het aantal verkochte bakwagens opleggers en aanhangers ongeveer 7,5% van het wagenpark is. We gaan ervan uit dat het daarbij gaat om vervanging van oude voertuigen. De levensduur van een bakwagen is dan circa 13 jaar. Voor opleggers en aanhangers gaan we uit van een levensduur van respectievelijk 13 en 20 jaar, op basis van verkoopcijfers van RAI Vereniging en wagenparkcijfers van het CBS over de periode 2004-2012.

Het aantal voertuigen zonder contourmarkering op 1 januari 2015 bepalen we door het aantal voertuigen op 1 januari 2013 te verminderen met het aantal verkochte voertuigen waarvoor contourmarkering al verplicht is (zie *Tabel 3.3*).

Type voertuig	**Wagenpark 1-1-2013**	**Geschatte verkoop nieuwe typen 10-10-08 tot 10-07-11**	**Verkoop sinds 10-07-2011**	**Geschatte verkoop 1-1-2013 tot 1-1-2015**	**Aantal voertuigen zonder contour-markering 1-1-2015**
	(1)	**(2)**	**(3)**	**(4)**	**(1) – (2) – (3)- (4)**
Bakwagens (> 7,5 ton)	43.110	6.600	3.652	5.700	27.200
Opleggers (> 3,5 ton)	131.543	6.800	10.847	19.800	94.100
Aanhangwagens (> 3,5 ton)	21.511	900	1.182	1.900	17.600

Tabel 3.3. *Wagenpark en aantal verkocht voertuigen. Bronnen: CBS en RAI Vereniging, bewerking SWOV.*

Voor de berekening van de kosten (en effecten) gaan we ervan uit dat de verplichting niet geldt voor vrachtauto's met zeildoeken, aangezien contourmarkering niet op bestaande zeildoeken kan worden aangebracht (zie *Hoofdstuk 2*). Kosten van het aanbrengen van contourmarkering op vrachtwagens met zeildoek (20% van het wagenpark, zie *Bijlage 3*) blijven dus buiten de berekening van de kosten.

3.1.3. *Totale kosten*

De totale kosten van retrofitverplichting van contourmarkering berekenen we door het geschatte aantal vrachtauto's zonder contourmarkering te vermenigvuldigen met de kosten van het aanbrengen van contourmarkering per vrachtauto. *Tabel 3.4* geeft de totale kosten van het aanbrengen van contourmarkering op alle vrachtauto's per 1 januari 2015, die zijn berekend op basis van de kosten van contourmarkering per vrachtauto (*Tabel 3.2*) en het aantal vrachtauto's waarop contourmarkering bij een retrofitverplichting wordt aangebracht (*Tabel 3.3*). De tabel geeft de contante waarden, dat wil zeggen dat een discontovoet is toegepast (zie hierboven).

Type voertuig	Minimumkosten	Maximumkosten
Bakwagens	3	5
Opleggers	11	23
Aanhangwagens	2	3
Totaal	16	31

Tabel 3.4. *Totale kosten van retrofit contourmarkering (miljoen euro, contante waarden).*

3.2. **Baten**

De baten van retrofit invoering van contourmarkering bestaan uit de ongevalskosten (voor de maatschappij en voor transportbedrijven) die worden bespaard als er minder ongevallen zijn door contourmarkering. Om deze baten te bepalen is informatie nodig over:
- de verkeersveiligheidseffecten (reductie van het aantal slachtoffers) van verplichting van contourmarkering, en het verloop daarvan in de tijd;
- de bespaarde ongevalskosten voor de maatschappij en voor transportbedrijven.

De verkeersveiligheidseffecten zijn in het voorgaande hoofdstuk besproken. Het is onbekend of er een verschil in effect is tussen een minimale en een maximale contourmarkering. Wel is bekend dat de veldstudies die besproken zijn gebruik makten van markering die waarschijnlijk minder opvallend is dan de markering die nu verplicht is. We gaan daarom uit van de effecten die berekend zijn in het voorgaande hoofdstuk.

In deze paragraaf gaan we in op de berekening van de baten in termen van bespaarde ongevalskosten.

3.2.1. *Maatschappelijke baten*

Zoals aangegeven bestaan de maatschappelijke baten van de slachtofferreductie door retrofitverplichting van contourmarkering uit de ongevalskosten die worden bespaard. De maatschappelijke kosten van verkeersongevallen bestaan uit medische kosten, productieverlies, immateriële schade, materiële schade, afhandelingskosten en filekosten (SWOV, 2014). *Tabel 3.5* geeft een overzicht van de totale maatschappelijke kosten van verkeersongevallen in Nederland in 2009 (het meest recente jaar waarvoor deze kosten zijn bepaald).

Kostenpost	Kosten (miljoen euro)
Medische kosten	352
Materiële kosten	3.866
Afhandelingskosten	1.293
Productieverlies	924
Filekosten	300
Immateriële kosten	5.761
Totaal (afgerond)	**12.500**

Tabel 3.5. *Maatschappelijke kosten van verkeersongevallen (in miljoen euro, prijspeil 2009; De Wit & Methorst, 2012).*

De kosten per verkeersdode bedragen 2,6 miljoen euro en per ernstig verkeersgewonde 280.000 euro (De Wit & Methorst, 2012, prijspeil 2009). Op basis van de deze kosten per slachtoffer kunnen de maatschappelijke baten van contourmarkering worden bepaald. In kosten-batenanalyses wordt voor ernstig verkeersgewonden echter gerekend met een hoger bedrag (530.000 euro, prijspeil 2009) wanneer de effecten op lichter letsel en/of ongevallen met uitsluitend materiële schade (UMS) niet bekend zijn (SWOV, 2014). In dit bedrag zijn ook de kosten van lichter letsel en UMS-ongevallen inbegrepen. Bij toepassing van dit bedrag wordt aangenomen dat een maatregel (in dit geval aanbrengen van contourmarkering) het aantal slachtoffers met lichter letsel en UMS-ongevallen in dezelfde mate reduceert als het aantal ernstig verkeersgewonden. We rekenen in deze kosten-batenanalyse met 2,7 miljoen euro per dode en 550.000 euro per ernstig verkeersgewonde (bovengenoemde bedragen gecorrigeerd voor inflatie in de periode 2009-2012 op basis van prijsindexcijfers van het bruto binnenlands product, gepubliceerd door het CBS).

De totale baten berekenen we door het aantal bespaarde doden en ernstig verkeersgewonden per jaar te vermenigvuldigen met de genoemde waarden per slachtoffer (waarbij discontering wordt toegepast), en vervolgens te sommeren over de periode 2015-2032 (na 2032 zouden alle bakwagens, opleggers en aanhangers ook zonder retrofit voorzien zijn van contour-markering). De aldus berekende contante waarde van de baten bedraagt 35 miljoen euro.

3.2.2. *Baten voor transportbedrijven*

De baten voor transportbedrijven bestaan uit de kosten die transport-bedrijven besparen als zij minder betrokken zijn bij verkeersongevallen. Het gaat om besparing van materiële schade aan voertuigen en lading, letselschade, en minder uitval van voertuigen en personeel. Een deel van deze kosten is verzekerd en wordt dus door verzekeraars vergoed. Indirect komen deze kosten echter bij transportbedrijven terecht via premies. De verzekerde kosten schatten we op basis van het bedrag dat verzekeraars gemiddeld uitkeren aan een transportbedrijf bij schade ten gevolge van een verkeersongeval. We gaan uit van 7.300 euro per ongeval, gebaseerd op De Niet et al. (2002). Daarnaast zijn er niet-verzekerde kosten voor transport-bedrijven. TLN (2002) schat deze kosten op circa 2.000 euro per ongeval.

Uitgaande van de in het vorige hoofdstuk besproken ongevallenreductie, bedragen de baten voor transportbedrijven circa 9 miljoen euro (contante waarde).

3.3. Uitkomsten kosten-batenanalyse

Tabel 3.6 geeft de resultaten van de kosten-batenanalyse van retrofit invoering van contourmarkering. In het scenario met maximale kosten zijn de maatschappelijke baten iets hoger dan de kosten, en in het scenario met minimale kosten zijn de baten ongeveer twee maal zo hoog als de kosten. Dit betekent dat het ‘maatschappelijk rendement’ (licht) positief is. De ‘werkelijke’ kosten-batenverhouding zal afhangen van de hoeveelheid markering die op de zijkant wordt aangebracht en van de prijsontwikkeling van contourmarkering. Op grond van de kosten-batenanalyse kan echter gesteld worden dat een retrofit invoering van contourmarkering vanuit een economisch perspectief waarschijnlijk een zinvolle investering is.

Een kanttekening daarbij is dat er ook scenario’s denkbaar zijn waarbij de baten lager uitpakken. Een voorbeeld daarvan is een scenario waarin het effect van contourmarkering geringer is omdat het aantal ongevallen waarop contourmarkering effect heeft (verder) daalt door andere factoren. Een scenario waarbij de baten en kosten elkaar ongeveer in evenwicht houden is dan niet onrealistisch.

Voor transportbedrijven geldt dat de kosten ongeveer twee tot drie maal zo hoog zijn als de baten. Dit betekent dat er voor bedrijven vanuit bedrijfseconomisch oogpunt geen stimulans is om op eigen initiatief te investeren in contourmarkering.

	Maatschappij		Transportbedrijven	
	Maximumkosten*	**Minimumkosten****	**Maximumkosten***	**Minimumkosten****
Kosten	31	16	31	16
Baten	35	35	9	9
Saldo baten-kosten	3	18	-22	-7
Verhouding baten/kosten	1,1	2,1	0,3	0,6

Tabel 3.6. *Kosten en baten van retrofit invoering van contourmarkering (miljoen euro, contant waarden), en saldo en verhouding van kosten en baten in Nederland. *Maximumscenario: volledige contourmarkering, prijs markering € 2,80 per meter en aanbrengkosten € 130 per vrachtauto. **Minimumscenario: minimaal vereiste contourmarkering, prijs markering € 2,00 per meter en aanbrengkosten € 100 per vrachtauto.*

4. Doorvertaling slachtofferbesparing Europese Unie

Dit hoofdstuk geeft in kort bestek een mogelijke slachtofferbesparing als gevolg van retrofit invoering van contourmarkering in de Europese Unie. Dit gebeurt door de slachtofferbesparingen in Nederland grofweg 'door te vertalen'. Het hoofdstuk behandelt daarmee subvraag vier:

Wat is het effect van retrofit contourmarkering in de EU op het aantal doden en gewonden als gevolg van verkeersongevallen?

Volgens ongevallendata van de Europese Unie (CARE) vielen in 2010 5.000 doden op de EU-wegen bij ongevallen met zwaar verkeer, 75% daarvan betrof inzittenden van andere voertuigen (Pace et al., 2010).

Voor het effect van retrofit invoering van contourmarkering in de EU wordt uitgegaan van de berekening voor Nederland in de twee voorgaande hoofdstukken. Deze resultaten worden eenvoudigweg doorvertaald naar een EU-totaal door te vermenigvuldigen met het totale aantal inwoners of het totale wagenpark, rekening houdend met de mortaliteit in de EU ten opzichte van die in Nederland. Daarbij wordt bijvoorbeeld geen rekening gehouden met de verschillen per land in leeftijd van vrachtauto's, de precieze kosten van tape en belettering, en de precieze kosten van schades en verlies van mensenlevens. Ook is geen rekening gehouden met eventuele stringentere wetgeving dan de EU-regelgeving die in enkele Europese landen reeds van kracht is (dat geeft een lichte overschatting van het effect). Omdat dit een globale schatting is van de effecten en kosten van de maatregel op EU-niveau, is gewerkt met een aantal aannamen. Preciezere cijfers per EU-land vergen onevenredig meer rekenwerk, en in sommige gevallen zijn de gegevens daarvoor simpelweg niet voorhanden.

Omdat de rekenmethoden voor Nederland en voor de EU niet gelijk zijn, zullen hieronder het veiligheidseffect, de parkomvang, de kosten en de baten gegeven worden voor de EU exclusief Nederland. In *Tabel 4.1* is weergegeven welke aannamen gedaan zijn voor de berekening, en welke consequenties deze aannamen hebben. De aannamen voor de grove schatting in dit rapport staan aangegeven in kolom 2. In kolom 5 wordt weergegeven wat in een preciezere schatting nader zou kunnen worden uitgezocht. Dat zou een uitgebreider onderzoek vergen dan voor dit rapport is uitgevoerd. In onderstaande paragrafen zijn deze aannamen waar nodig nogmaals besproken.

Benodigde data	Aannamen voor grove schatting	Houdt wel rekening met	Houdt geen rekening met	Nodig voor fijne schatting
Aantal slachtoffers van dit soort ongevallen in de EU?	Aantal slachtoffers in NL rekening houdend met mortaliteits-verhoudingen …	Verschil in aantal inwoners in de EU	Verschillen in aantallen doden en gewonden per 100.000 inwoners in de verschillende EU-landen	Gedetailleerder uitzoeken met CARE-data voor max. 19 landen
Verkeersmortaliteit in EU-landen	… gemiddelde mortaliteit EU t.o.v. mortaliteit in NL	Verschil in mortaliteit EU versus NL	Verschillen in mortaliteit van land tot land	Mortaliteit per land in beschouwing nemen
Hoeveel vrachtauto's zijn er in de EU en hoe lang rijden ze rond zonder contourmarkering?	Aantal vrachtauto-jaren in NL vertalen naar totale wagenpark EU	Verschil in aantal vrachtauto's per land	Verschillen in leeftijd en levensduur van vrachtauto's in de verschillende EU-landen	Kijken naar leeftijd en levensduur van vrachtauto's in de EU
Wat zijn de kosten van contourmarkering in de EU?	Kosten per vrachtauto in NL doortrekken voor aantal vrachtauto's in EU met factor 2/3 van de kosten van NL	Schatting van kosten tape en aanbrengen waarbij kosten op 2/3 van NL kosten worden geschat	Reële kosten van aanbrengen tape	Kosten van een aantal EU-landen opvragen
Wat zijn de kosten van een slachtoffer in de EU?	Kosten per slachtoffer in NL doorvertalen naar EU-aantal slachtoffers met factor 2/3 van de kosten van NL	Aantal inwoners per land	Reële kosten van een ongeval/mensenleven per land	Kosten per slachtoffer van een aantal EU-landen opvragen
Wat is het schade-bedrag per ongeval?	Kosten schadegevallen NL extrapoleren naar EU-totaal met factor 2/3 van de kosten van NL	Aantal inwoners en vrachtauto's per land	Reële kosten per schadegeval per land	Bekijken of er schade-bedragen voor bepaalde landen zijn

Tabel 4.1. *Aannamen en consequenties daarvan voor berekening van de effecten van retrofit contourmarkering in de Europese Unie (exclusief Nederland).*

Hieronder worden achtereenvolgens het verkeersveiligheidseffect (in bespaarde doden en gewonden; *Paragraaf 4.1*), de parkomvang (*Paragraaf 4.2*) en de kosten en baten doorvertaald naar EU-niveau (exclusief Nederland; *Paragraaf 4.3*). *Paragraaf 4.4* schat de kosten en baten voor de EU inclusief Nederland.

4.1. **Verkeersveiligheidseffect op EU-niveau**

In *Hoofdstuk 2* is berekend dat er in Nederland 3 doden en 16 ernstig verkeersgewonden per jaar bespaard zouden kunnen worden. Deze aantallen gelden alleen wanneer het hele Nederlandse wagenpark geen contourmarkering zou hebben en in één klap van contourmarkering zou worden voorzien.

Deze aantallen worden als volgt vertaald naar het niveau van de Europese Unie. De berekende besparing in Nederland is gebaseerd op de periode 2005 tot en met 2009. Het totaal aantal verkeersdoden in Nederland was in deze periode gemiddeld 778 per jaar. Het aandeel bespaarde doden op het totaal bedraagt daarmee voor Nederland 0,39%. Voor de andere 27 landen in de Europese Unie betreft het totaal aantal verkeersdoden in de periode 2005 tot en met 2009 gemiddeld 40.855. Als we aannemen dat met de maatregel in de EU eenzelfde aandeel verkeersdoden kan worden bespaard als in Nederland, zou voor de EU het veiligheidseffect van het retrofit invoeren van contourmarkering uitkomen op een besparing van 158 doden per jaar (0,39% van 40.855). Ook voor dit berekende aantal geldt dat dit alleen het geval zou zijn wanneer het hele wagenpark binnen de EU geen contourmarkering zou hebben en in één klap van contourmarkering zou worden voorzien. We houden hierbij geen rekening met de mogelijkheid dat in sommige landen het ongevallenbestand er anders zou kunnen uitzien dan in Nederland, met een groter of kleiner aandeel:

- zij- of achteraanrijdingen;
- ongevallen in donker/schemer;
- ongevallen met vrachtwagens.

Voor de berekening van het aantal bespaarde ernstig verkeersgewonden bij invoering van contourmarkering ‘in één klap’ gaan we uit van de aanname dat de definitie van een ernstig verkeersgewonde dezelfde is als in Nederland (een slachtoffer dat als gevolg van een verkeersongeval opgenomen is in het ziekenhuis en een letselernst heeft van ten minste 2, uitgedrukt de Maximum Abbreviated Injury Score: MAIS). In werkelijkheid verschilt deze definitie. Ook gaan we ervan uit dat alle landen in de EU eenzelfde verhouding tussen doden en ernstig verkeersgewonden kennen als Nederland. Ook dat hoeft in werkelijkheid niet zo te zijn. *Hoofdstuk 2* laat zien dat er in Nederland door invoering van contourmarkering in één klap 16 ernstig verkeersgewonden kunnen worden bespaard. De verhouding tussen bespaarde verkeersdoden en ernstig verkeersgewonden is daarmee in Nederland 1 op 5,3. Deze zelfde verhouding passen we toe op de EU-cijfers; we komen daarmee op een mogelijke besparing van 840 gewonden per jaar.

Een zelfde methode en redenering wordt toegepast voor de doorvertaling van het aantal bespaarde ongevallen in de EU (alle ongevallen; dus ook de ongevallen met uitsluitend materiële schade). Het aantal in Nederland bespaarde aantal ongevallen werd geraamd op 481. De verhouding tussen doden en ongevallen is 1 op 160. Doorgetrokken naar de EU bedraagt het aantal bespaarde ongevallen als contourmarkering in één klap zou zijn ingevoerd 25.265.

Bovengenoemde aantallen theoretisch te besparen slachtoffers (bij invoering van contourmarkering in één klap) zijn gebruikt voor de berekening van de mogelijke besparingen bij retrofit invoering van contourmarkering vanaf 1 januari 2015. Voor vrachtauto’s in Nederland is dit aantal theoretisch te besparen slachtoffers vermenigvuldigd met het aantal wagens dat op 1 januari 2015 nog niet met contourmarkering rondrijdt, en met het aantal jaren dat zij nog zullen rondrijden (zie *Hoofdstuk 2*, het aantal wagenjaren). Voor de Europese Unie zijn niet alle gegevens uit deze berekening beschikbaar: de omvang van het wagenpark kan wel berekend worden (zie *Paragraaf 4.2*), maar het aantal jaren dat vrachtauto’s nog rondrijden zonder contourmarkering is onbekend, omdat cijfers over de levensduur van vrachtauto’s niet beschikbaar zijn. Om het aantal slachtoffers te berekenen dat in de Europese Unie (exclusief Nederland) kan worden bespaard als retrofit contourmarkering wordt ingevoerd per 1 januari 2015, wordt daarom dezelfde verhouding aangehouden voor de Europese Unie als voor Nederland voor wat betreft de theoretische slachtoffers (als contourmarkering in één klap wordt ingevoerd) en de werkelijk te besparen slachtoffers per 2015. In Nederland is deze verhouding 3 staat tot 8 doden. Doorgetrokken naar de

EU minus Nederland kunnen in de EU per 2015 in totaal 421 doden, 2.240 ernstig verkeersgewonden en 67.373 ongevallen worden voorkomen.

4.2. Omvang wagenpark

Het verkeersveiligheidseffect is in de voorgaande paragraaf berekend door het effect voor Nederland door te vertalen. Zoals gezegd had beter rekening kunnen worden gehouden met het aantal ‘wagenjaren’ dat vrachtauto’s nog zonder contourmarkering in de Europese Unie zouden rondrijden (en waarop dus retrofit contourmarkering kan worden toegepast). Voor de Europese Unie zijn echter geen gegevens beschikbaar over de levensduur van vrachtauto’s. Wel kan de omvang van het EU-wagenpark berekend worden. Deze gegevens zijn belangrijk voor het bepalen van de kosten van contourmarkering.

De omvang van het wagenpark binnen de EU is alleen bekend voor het aantal vrachtwagens en bestelwagens samen, er zijn geen cijfers bekend van enkel het aantal vrachtauto’s. De gemiddelde parkomvang in elk jaar van de periode 2005-2009 bedraagt in de EU gemiddeld 29.986.939 (bron: Eurostat). Eurostat maakt geen onderscheid tussen vracht- en bestelauto’s. In Nederland is 8% van het totaal van deze groep vrachtwagen). Uitgaande van dezelfde verhouding in de rest van de EU, betekent dit dat er binnen de EU (en na aftrek van de Nederlandse vrachtwagens) in de periode 2005-2009 gemiddeld 2.334.238 vrachtwagen zijn. Hierbij wordt geen rekening gehouden met eventuele verschillen in de verhouding tussen vracht- en bestelwagens in de verschillende EU-landen.

Ook het aantal opleggers in het EU-wagenpark is nodig voor een kostenschatting van de contourmarkering. In het wagenpark van de EU is alleen het aantal trekkers bekend, niet het aantal opleggers. Het totaal aantal trekkers in de EU (exclusief Nederland) bedraagt 1.486.887 in de periode 2005-2009. Uitgaande van de bestaande verhouding in Nederland tussen trekkers en opleggers van 1 staat tot 1,746 (gemiddeld in de betreffende jaren) (bron: CBS) komen we uit op 2.595.962 opleggers. Ook hierbij is geen rekening gehouden met eventuele verschillen in de verhouding trekkers/opleggers in de verschillende EU-landen.

In Nederland rijdt nog ongeveer 70% (70,31223%) van alle vrachtwagens nu zonder contourmarkering (138.854 wagens en opleggers die in aanmerking komen voor contourmarkering volgens *Bijlage 3*, gedeeld door het totale wagenpark volgens Eurostat (197.482 wagens en opleggers per 2014). Ervan uitgaande dat dat in EU ook zo is, komt thans circa 70% van het hier berekende aantal wagens (70,31223% van 4.930.200 voertuigen op basis van Eurostat) in aanmerking voor retrofit contourmarkering. Dit zijn 3.466.534 wagens. Met dit aantal kunnen de kosten van contourmarkering worden bepaald.

4.3. Schatting kosten en baten

Voor Nederland zijn twee kostenscenario’s berekend, een maximum- en een minimumvariant. In de maximumvariant bedragen de kosten 31 miljoen euro, in de minimumvariant 16 miljoen, volledig te dragen door de transport-bedrijven. Voor de vertaling naar EU-niveau gaan we ervan uit dat de kosten twee derde bedragen van de kosten in Nederland: in veel landen zal met name het aanbrengen van de tape (de grootste kostenpost) aanmerkelijk goedkoper zijn dan in Nederland. De schatting is gebaseerd op kennis van 3M over de kosten van tape en aanbrengen. We delen daarvoor de totale kosten in Nederland op het totaal aantal voertuigen dat in Nederland per 2015 van contourmarkering zou moeten worden voorzien. Door deze berekeningswijze wordt meteen rekening gehouden met het feit dat 20% van de voertuigen voorzien is van dekzeil dat niet geschikt is voor retrofit toepassing van contourmarkering. De kosten per wagen bedragen daarmee in het minimumscenario 77 euro per wagen, in het maximumscenario 149 euro. Het aantal wagens in de EU waarop de retrofit van toepassing is bedraagt 3.466.534. Daarmee komen de kosten in totaal uit op 267 resp. 517 miljoen euro voor de EU exclusief Nederland.

De maatschappelijke baten van de veiligheidswinst zijn in Nederland 35 miljoen euro voor bespaarde letselslachtoffers en 9 miljoen voor bespaarde materiële schade. We hanteren deze zelfde reductie-aanname voor de baten als voor de kosten: twee derde, omdat we ervan uitgaan dat zowel de kosten als de baten samenhangen met de welvaart in de EU. In beide gevallen betreft het aannamen. Rekening houdend met de verhouding tussen de bespaarde slachtoffers in Nederland en in de EU, en met de twee derde reductie, betreffen de totale baten voor de EU 1.541 miljoen euro.

De baten-kostenverhouding voor het retrofit invoeren van contourmarkering op vrachtauto's in de EU exclusief Nederland per 1 januari 2015 is daarmee als in onderstaande *Tabel 4.2*. De batenkosten-verhouding is gunstiger dan in de Nederlandse berekening, omdat relatief een groter aantal slachtoffers en ongevallen voorkomen kan worden in de EU.

	Maatschappij	
	Maximumkosten*	**Minimumkosten****
Kosten	517	267
Baten	1.541	1.541
Saldo baten-kosten	1.793	2.043
Verhouding baten/kosten	3	6

Tabel 4.2. *Kosten en baten van retrofit invoering van contourmarkering (contante waarden in miljoen euro), en saldo en verhouding van kosten en baten in de EU exclusief Nederland. * Maximumscenario: volledige contourmarkering, twee derde van de Nederlandse prijs (markering € 2,80 per meter, aanbrengkosten € 130 per vrachtwagen) en twee derde van de Nederlandse baten. ** Minimumscenario: minimaal vereiste contourmarkering, twee derde van de Nederlandse prijs (markering € 2,00 per meter, aanbrengkosten € 100 per vrachtwagen).*

4.4. Totale kosten, baten en baten-kostenverhouding voor EU inclusief Nederland

De totale kosten, baten en baten-kostenverhouding voor de gehele Europese Unie wordt berekend door de kosten en baten voor Nederland (*Hoofdstuk 3*) op te tellen bij die voor de Europese Unie excl. Nederland (*Hoofdstuk 4*). Daarbij moet worden aangetekend dat de kosten en baten voor Nederland op een preciezere manier zijn berekend dan die voor de Europese Unie: deze laatste cijfers betreffen slechts een grove schatting. Er bestaat dus een verschil in nauwkeurigheid tussen deze twee cijfers. Het totaal van de EU inclusief Nederland is daarmee ook slechts een grove schatting.

In het maximumscenario tellen de kosten in de EU (517 miljoen euro) en Nederland (31 miljoen euro) op tot 548 miljoen euro, in het minimumscenario bedraagt dat 283 miljoen euro (267 miljoen EU en 16 miljoen Nederland). De baten tellen in beide gevallen op tot 1.576 miljoen euro (1.541 miljoen euro voor de EU en 35 miljoen voor Nederland). De maatschappelijke baten-kostenratio blijft daarmee 3 bij maximale kosten en 6 in het minimale kostenscenario.

In de berekening van de kosten is geen rekening gehouden met kosten voor wetgeving en voorlichting. We schatten in dat deze kosten gering zijn. De kosten voor handhaving zullen naar onze inschatting niet significant toenemen. Deze kosten vallen buiten de scope van dit onderzoek. Tot slot is geen rekening gehouden met eventuele stringentere wetgeving dan de EU-regelgeving die in enkele Europese landen reeds van kracht is. Dat geeft een lichte overschatting van het effect.

	Maatschappij	
	Maximumkosten*	**Minimumkosten****
Kosten	548	283
Baten	1.576	1.576
Saldo baten-kosten	1.028	1.293
Verhouding baten/kosten	3	6

Tabel 4.3. *Kosten en baten van retrofit invoering van contourmarkering (contante waarden in miljoen euro), en saldo en verhouding van kosten en baten in de EU inclusief Nederland. * Maximumscenario: volledige contourmarkering, twee derde van de Nederlandse prijs (markering € 2,80 per meter, aanbrengkosten € 130 per vrachtwagen) en twee derde van de Nederlandse baten. ** Minimumscenario: minimaal vereiste contourmarkering, twee derde van de Nederlandse prijs (markering € 2,00 per meter, aanbrengkosten € 100 per vrachtwagen) en twee derde van de Nederlandse baten.*

5. Conclusie

Wat zijn de effecten van het retrofit invoeren van contourmarkering voor vrachtauto's in Nederland? Is zo'n invoering kosteneffectief voor de Nederlandse maatschappij als geheel en voor individuele bedrijven? En wat is het verkeersveiligheidseffect van de maatregel in de Europese Unie? Dat zijn de hoofdvragen van deze studie.

5.1. Nederland

Op basis van Nederlands en buitenlands onderzoek is voor de huidige Nederlandse situatie het effect van contourmarkering geschat op maximaal 3 doden, 16 ernstig verkeersgewonden en 481 ongevallen per jaar. Deze cijfers gelden alleen in de situatie dat het hele Nederlandse wagenpark geen contourmarkering zou hebben en in één klap van contourmarkering zou worden voorzien. In werkelijkheid is dat niet het geval, en worden vrachtauto's vervangen als hun levensduur ten einde is. Bovendien heeft, vanwege bestaande Europese verplichtingen, reeds een deel van het wagenpark contourmarkering op 1 januari 2015 (de voor dit onderzoek gekozen ingangsdatum van de maatregel).

Indien met bovenstaande rekening wordt gehouden, is de besparing over de totale werkingstermijn van de maatregel (dus vanaf 1 januari 2015 totdat alle vrachtauto's voorzien zijn van contourmarkering) naar schatting:

- 8 doden
- 42 gewonden
- 1.268 ongevallen.

Deze aantallen kunnen om verschillende redenen een over- of onderschatting zijn van de werkelijke effecten (zie *Hoofdstuk 2*).

De kosten van het retrofit invoeren van contourmarkering voor vrachtauto's in Nederland bestaan uit de kosten voor de markering zelf en voor het aanbrengen van de markeringen. De kosten van het aanbrengen van contourmarkering zijn bepaald voor twee scenario's: een 'maximumscenario' waarbij op alle vrachtauto's de volledige contour van de zijkanten worden gemarkeerd, en een 'minimumscenario' waarbij alleen de onderkant en de bovenhoeken worden gemarkeerd, volgens de minimumrichtlijnen van de Europese Unie.

De ervaringen van 3M, en de minimumeisen gesteld door EU-richtlijn 2007/35/EG of UN Richtlijn ECE 48, Clause 6;21, geven aan dat men waarschijnlijk voor een groot deel van de vrachtauto's zal kiezen voor minder/het minimum aan markering. Uit praktische overwegingen en vanwege vergelijkingsmogelijkheden is gekozen voor zowel maximum- als minimumscenario, omdat op voorhand niet te zeggen valt om hoeveel vrachtauto's het gaat, en omdat in de eerdere SWOV-studie naar contourmarkering ook is gerekend met de maximale markering. In het minimumscenario wordt tevens uitgegaan van lagere kosten voor het materiaal (2,00 versus 2,80 euro per meter) en voor het aanbrengen van de markering (100 versus 130 euro per vrachtwagen).

In totaal bedragen de kosten naar schatting 31 miljoen euro in het maximumscenario en 16 miljoen euro in het minimumscenario. Deze kosten worden volledig gedragen door de transportbedrijven. In de berekening van de kosten is geen rekening gehouden met kosten voor wetgeving en voorlichting. We schatten in dat deze kosten gering zijn. De kosten voor handhaving zullen naar onze inschatting niet significant toenemen. Deze kosten vallen buiten de scope van dit onderzoek.

De baten van de maatregel bestaan op maatschappelijk niveau uit de bespaarde slachtoffers en ongevallen zoals hierboven aangegeven. Voor de maatschappij als geheel bedragen de baten van retrofit invoering van contourmarkering 35 miljoen euro. Voor bedrijven bestaan de baten uit minder (verzekerde en onverzekerde) kosten ten gevolge van de afname van ongevallen. Deze baten worden voor bedrijven geschat op 9 miljoen euro.

De baten-kostenverhouding is daarmee voor de maatschappij 1,1 en voor individuele bedrijven 0,3 in het maximumscenario. In het minimumscenario bedraagt de baten-kostenverhouding 2,1 voor de maatschappij en 0,6 voor transportbedrijven.

In het scenario met maximale kosten zijn de maatschappelijke baten iets hoger dan de kosten, en in het scenario met minimale kosten zijn de baten ongeveer twee maal zo hoog als de kosten. Dit betekent dat het ‘maatschappelijk rendement’ (licht) positief is. De ‘werkelijke’ kosten-batenverhouding zal afhangen van de hoeveelheid markering die op de zijkant wordt aangebracht en van de prijsontwikkeling van contourmarkering. Op grond van de kosten-batenanalyse kan echter gesteld worden dat een retrofit invoering van contourmarkering vanuit een economisch perspectief waarschijnlijk een zinvolle investering is.

Voor transportbedrijven geldt dat de kosten ongeveer twee tot drie maal zo hoog zijn als de baten. Dit betekent dat er voor bedrijven vanuit bedrijfseconomisch oogpunt geen stimulans is om op eigen initiatief te investeren in contourmarkering.

5.2. Doorvertaling Europese Unie

Voor het effect van retrofit invoering van contourmarkering in de Europese Unie zijn de resultaten voor Nederland eenvoudigweg doorvertaald naar een EU-totaal door te vermenigvuldigen met het totale aantal inwoners of het totale wagenpark, rekening houdend met de mortaliteit in de EU ten opzichte van die in Nederland. Daarbij is geen rekening gehouden met de verschillen per land in leeftijd van vrachtauto's, de precieze kosten van tape en belettering en de precieze kosten van schades en verlies van mensenlevens. Preciezere cijfers per EU-land vergen onevenredig meer rekenwerk, en in sommige gevallen zijn gegevens daarvoor niet voorhanden. Onderstaande tabel geeft weer welke zaken wel en niet worden meegenomen in de berekening en welke aannamen gedaan zijn voor dit rapport (kolom 2: de grove schatting). In de laatste kolom staat vermeld welke zaken in een fijne schatting nader kunnen worden uitgezocht. Dat zou kunnen in een vervolgonderzoek.

Benodigde data	Aannamen voor grove schatting	Houdt wel rekening met	Houdt geen rekening met	Nodig voor fijne schatting
Aantal slachtoffers van dit soort ongevallen in de EU?	Aantal slachtoffers in NL rekening houdend met mortaliteits-verhoudingen …	Verschil in aantal inwoners in de EU	Verschillen in aantallen doden en gewonden per 100.000 inwoners in de verschillende EU-landen	Gedetailleerder uitzoeken met CARE-data voor max. 19 landen
Verkeersmortaliteit in EU-landen	… gemiddelde mortaliteit EU t.o.v. mortaliteit in NL	Verschil in mortaliteit EU versus NL	Verschillen in mortaliteit van land tot land	Mortaliteit per land in beschouwing nemen
Hoeveel vrachtauto's zijn er in de EU en hoe lang rijden ze rond zonder contourmarkering?	Aantal vrachtauto-jaren in NL vertalen naar totale wagenpark EU	Verschil in aantal vrachtauto's per land	Verschillen in leeftijd en levensduur van vrachtauto's in de verschillende EU-landen	Kijken naar leeftijd en levensduur van vrachtauto's in de EU
Wat zijn de kosten van contourmarkering in de EU?	Kosten per vrachtauto in NL doortrekken voor aantal vrachtauto's in EU met factor 2/3 van de kosten van NL	Schatting van kosten tape en aanbrengen waarbij kosten op 2/3 van NL kosten worden geschat	Reële kosten van aanbrengen tape	Kosten van een aantal EU-landen opvragen
Wat zijn de kosten van een slachtoffer in de EU?	Kosten per slachtoffer in NL doorvertalen naar EU-aantal slachtoffers met factor 2/3 van de kosten van NL	Aantal inwoners per land	Reële kosten van een ongeval/mensenleven per land	Kosten per slachtoffer van een aantal EU-landen opvragen
Wat is het schade-bedrag per ongeval?	Kosten schadegevallen NL extrapoleren naar EU-totaal met factor 2/3 van de kosten van NL	Aantal inwoners en vrachtauto's per land	Reële kosten per schadegeval per land	Bekijken of er schade-bedragen voor bepaalde landen zijn

Tabel 5.1. *Aannamen en consequenties daarvan voor berekening van de effecten van retrofit contourmarkering in de Europese Unie (exclusief Nederland).*

Omdat de rekenmethoden voor Nederland en voor de EU niet gelijk zijn, zijn het veiligheidseffect, de kosten en de baten gegeven voor de EU exclusief Nederland.

Doorvertaald naar de Europese Unie exclusief Nederland, betekent retrofit invoering van contourmarkering per 1 januari 2015 een besparing van in totaal 421 doden, 2.240 ernstig verkeersgewonden en 67.373 ongevallen. De kosten van de maatregel bedragen in totaal 267 miljoen euro in het minimale kostenscenario en 517 miljoen euro in het maximale kostenscenario voor de EU (minus Nederland) als geheel. Omgerekend naar geld, zijn de totale baten van de maatregel voor de EU exclusief Nederland 1.541 miljoen euro. De verhouding tussen baten en kosten komt daarmee in het maximale kostenscenario uit op 3 en in het minimale scenario op 6.

5.3. Totale kosten, baten en baten-kostenverhouding voor EU inclusief Nederland

De totale kosten, baten en baten-kostenverhouding voor de gehele Europese Unie wordt berekend door de kosten en baten voor Nederland en de Europese Unie excl. Nederland op te tellen. Daarbij moet worden aangetekend dat de kosten en baten voor Nederland op een preciezere manier zijn berekend dan die voor de Europese Unie: deze laatste cijfers betreffen slechts een grove schatting.

In het maximale kostenscenario tellen de kosten in de EU en Nederland op tot 548 miljoen euro, in het minimale kostenscenario bedraagt dat 283 miljoen euro. De baten tellen in beide gevallen op tot 1.576 miljoen euro. De baten-kostenratio blijft daarmee 3 voor het maximale en 6 voor het minimale kostenscenario. Ook in deze berekening van de kosten is geen rekening gehouden met kosten voor wetgeving en voorlichting en wordt verondersteld dat de kosten voor handhaving niet significant toenemen. Deze kosten vallen buiten de scope van dit onderzoek. Tot slot is geen rekening gehouden met eventuele stringentere wetgeving dan de EU-regelgeving die in enkele Europese landen reeds van kracht is. Dat geeft een lichte overschatting van het effect.

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Bijlage 1 Gemiddeld aantal relevante ongevallen en slachtoffers 2005 tot en met 2009

	Doden	Ernstig verkeersgewonden (EVG)
Gemiddeld per jaar 2005-2009 geregistreerd	10	28,8
Ophoogfactor	0	1,88
Werkelijke aantallen	10	54,4

Tabel B.1. *Gemiddelde aantal slachtoffers per jaar van 2005 tot en met 2009 van vrachtauto's/opleggers/aanhangers met een motorvoertuig, bij flank, kop-staart of parkeerongevallen in schemer of duister, waarbij de vrachtauto eerste of tweede botser was en waarbij het aangrijppunt op de vrachtwagen niet 'voor' was.*

	Ongevallen met doden en EVG	Ongevallen met lichtgewonden	UMS ongevallen	Totaal
Gemiddeld per jaar 2005-2009 geregistreerd	33,6	76,5	523,6	633,7
Ophoogfactor	1,83	3	3,5	Nvt
Werkelijke aantallen	61,4	229,5	1832,6	2123,5

Tabel B.2 *Gemiddelde aantal ongevallen van 2005 tot en met 2009 van vrachtauto's/opleggers/aanhangers met een motorvoertuig, bij flank, kop-staart of parkeerongevallen in schemer of duister, waarbij de vrachtauto eerste of tweede botser was, en waarbij het aangrijppunt op de vrachtwagen niet 'voor' was *.*

*Vanaf 2006 worden de parkeerongevallen met uitsluitend materiële schade niet meer geregistreerd als verkeersongeval, omdat blijkt dat veel eenzijdige parkeerongevallen om verzekeringstechnische redenen worden opgegeven als parkeerongevallen met een botspartner. Het gaat vermoedelijk om zeer kleine aantallen.

Bijlage 2 Te besparen aantal slachtoffers en ongevallen door contourmarkering

	Relevant in NL, gemiddeld 2002-2009	Gemiddelde reductie voor NL, gebaseerd op drie studies besproken in De Niet et al, 2002	Verwachte besparing bij totale invoering contourmarkering
Doden	10	29,33%	2,9
Ernstig verkeersgewonden*	54,4	30%*	16,3
Alle ongevallen	2123,5	22,66%	481,2

Tabel B.3 *Aantal te besparen doden, ernstig verkeersgewonden en ongevallen met contourmarkering, per jaar.*

*In De Niet et al 2002 worden de gevonden reductiefactoren in de drie buitenlandse studies toegepast op het aantal ziekenhuisgewonden in Nederland. Inmiddels werken we in Nederland met ernstig gewonden. We hebben dezelfde reductiefactoren toegepast op het aantal ernstig verkeersgewonden.

Bijlage 3 Aantal wagen-jaren zonder contourmarkering

Deze bijlage geeft het aantal trucks, aanhangers en bakwagens zonder contourmarkering na 1 januari 2015 en aantal jaar dat zij zonder contourmarkering blijven rijden als er geen retrofit invoering plaatsvindt.

Er zijn twee soorten auto's:
A Aanhangers, die na 22 jaar zijn afgeschreven.
B Bakwagens en opleggers, die na 13 jaar zijn afgeschreven.
Deze wagens zijn er in twee typen:
1. Nieuwe typen, van na 10 oktober 2008[8]
2. Oude typen, van vóór 10 oktober 2008
Deze wagens zijn er van drie verkoopmomenten
V voor 10 oktober 2008
M na 10 oktober 2008 en voor 10 juli 2011
N na 10 juli 2011

Niet alle combinaties bestaan. Alle nieuwe typen zijn van na 10 oktober 2008

De berekening van het effect van retrofit retroflectie is voor elk van die typen anders, omdat het aantal dat er op 1 januari 2015 nog van rondrijdt anders is, én de gemiddelde leeftijd van die groep anders is. En het is de gemiddelde leeftijd (of eigenlijk: de gemiddelde resterende levensduur) die er toe doet.

In onderstaande tabel is weergegeven hoeveel vrachtauto's in welk verondersteld jaar (kopregel) gebouwd rondrijden op verschillende momenten vanaf 10 oktober 2008.

[8] De officiële ingangsdatum van de maatregel in Nederland is 10 juli 2008 (https://zoek.officielebekendmakingen.nl/stb-2008-211.html). In documentatie van 3M (3M Nederland BV, 2011) en op diverse sites van aanbieders van contourmarkering wordt verwezen naar de ingangsdatum van 10 oktober 2008. Dit betreft de ingangsdatum in de gehele EU. In dit rapport is gekozen voor een berekening met de EU-ingangsdatum.

		1987	1990	1995	2000	2005	2008	2011	2013	2015	gemiddelde levensduur (jaar)	
Aanhang	V2 op 10 oktober 2008				21511							
wagens	M1 op 10 juli 2011	dit is 3/8 van het aantal verkochte wagens						900				
	M2 op 10 juli 2011	dit is 5/8 van het aantal gekochte wgens (of 5/3 van 900)						1500				
	N2 op 1 jan 2013							1182				
	N2 op 1 jan 2015								1900			
	vervangen na 10 10 2008							5482				
	V2 op 1 jan 2015				16100						8	
	M2 op 1 jan 2015							1500			17	
	totaal zonder retro in 2015				17600							10
Bakwagens +	V2 op oktober 2008				43110 + 131543							
opleggers	M1 op 10 juli 2011	dit is 75% van het aanta verkochte bakwagens en 3/8 van de verkochte opleggers						6600 + 6800				
	M2 op 10 juli 2011	dit is 25% van de bakwagens en 5/8 van de opleggers (of 5/3 van 6800)						2200 + 11333				
	N2 op 1 jan 2013								3652 + 10847			
	N2 op 1 jan 2015								5700 + 19800			
	vervangen na 10 10 2008							66932				
	V2 op 1 jan 2015					107721					3.5	
	M2 op 1 jan 2015							13533			8.5	
	totaal zonder retro in 2015					121254						5

Uit bovenstaande tabel volgt dat er 16.100 aanhangwagens (van voor 10-10 2008) nog 8 jaar rondrijden (totaal 128.800 wagen jaar), en 1.500 (van na 10 oktober 2008) nog 17 jaar (totaal 25.500 wagen jaar). Bij elkaar 154.300 wagen jaar. Als we dat betrekken op het totale park van 21.511, zou dat park nog 7 jaar zonder retroflectie rijden.

En ook zien we dat er 107.721 bakwagens en opleggers nog gemiddeld 3,5 jaar rondrijden na 1-1-2015. Totaal 377.024 wagen-jaar. De 13.533 wagens van na 10 oktober gaan nog gemiddeld 8,5 jaar mee, dus bij elkaar 115.031 wagen-jaar. Samen 492.045 wagen-jaar. Als we dat betrekken op het totale park van 174.653, zou dat park nog 2,8 jaar zonder retroreflectie rondrijden.

Voor het totale wagenpark geldt dat bakwagens, opleggers en aanhangers met dekzeilen niet beïnvloed worden door de maatregel retrofit invoering, omdat we in *Hoofdstuk 2* aannemen dat auto's met bestaande dekzeilen worden uitgezonderd van retrofit (het plakken van contourmarkering op bestaande dekzeilen is niet mogelijk). Verder gaan we ervan uit dat op nieuw aangeschafte dekzeilen vanaf 1-7-2011 contourmarkering aangebracht is. Op basis van een Europese studie (TÜV Rheinland group, 2004) gaan we ervan uit dat circa 20% van de vrachtauto's zeildoek heeft. Het totale wagenpark, 196.164 wagens (174.653 bakwagens/opleggers en 21.511 aanhangers) verminderen we daarom met 20% (= 139.722 bakwagens/opleggers en 17.209 aanhangers, totaal 156.931 wagens) en het totaal aantal wagen-jaren (492.045 wagen-jaren voor bakwagens/opleggers en 154.300 wagen-jaren voor aanhangwagens) wordt daarmee dus ook 20% verminderd tot 393.636 wagenjaren voor bakwagens/opleggers en 123.440 wagenjaren voor aanhangers, totaal 517.076 wagenjaren).

Heavy vehicle visibility

Technical Advisory Procedure

Developed by the ATA Industry Technical Council
Second edition, August 2016

About this Technical Advisory Procedure (TAP):

This Technical Advisory Procedure is published by the Australian Trucking Association Ltd (ATA) to assist the road transport industry to improve the visibility of heavy commercial trucks and trailers.

This TAP is not, nor is it intended to be, complete or without exceptions.

The Technical Advisory Procedure is a guide only and its use is entirely voluntary. Recommendations or procedures may not be suitable for or applicable to all operators. Operators should consider their own circumstances, practices and procedures when using this Technical Advisory Procedure.

Operators must comply with the Australian Design Rules (ADRs), the Australian Vehicle Standards Regulations, the Roadworthiness Guidelines and any specific information and instructions provided by manufacturers in relation to vehicle's systems and components.

No endorsement of products or services is made or intended. Brand names, where used in this Technical Advisory Procedure, are for illustrative purposes only.

Suggestions or comments about this Technical Advisory Procedure are welcome. Please write to the Industry Technical Council, Australian Trucking Association, Minter Ellison Building, 25 National Circuit, Forrest ACT 2603.

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Acknowledgement

The ATA wishes to acknowledge the Freight Transport Association of the UK for allowing the images, as noted, to be reproduced. www.fta.co.uk

Freight Transport Association
Delivering safe, efficient, sustainable logistics

Table of Contents

1) Vehicle visibility and safety

Collisions between heavy trucks and trailers with smaller, lighter vehicles can often result in severe injuries or even death to the occupants of the smaller vehicle. In many cases, these accidents may be the result of the heavy vehicle not being seen by the approaching motorist in time for the accident to be avoided, particularly in poor weather conditions or at night.

Extensive research in both the United States and Europe has shown a dramatic reduction in the frequency and intensity of such vehicle accidents with the use of retroreflective stripes and other markings that outline the contour of the vehicle.

A 2001 report by the US National Highway Traffic Safety Administration[1], reported a reduction in a range of lighting conditions by 29 to 41 percent for side and rear impacts into trailers when retroreflective tape is fitted, while in dark conditions the tape reduced side and rear impacts that resulted in fatalities or injuries to drivers of any vehicle by 44 percent. However, the Australian Design Rules mandate a higher level of lighting and reflector requirements and as a result these benefits are illustrative only and may not be fully replicated in the Australian market.

A European report detailed 1984 Bavarian accident statistics, which highlighted the potential for contour markings to improve the visibility of the combination on road.[2]

Potential for improved tuck visibility

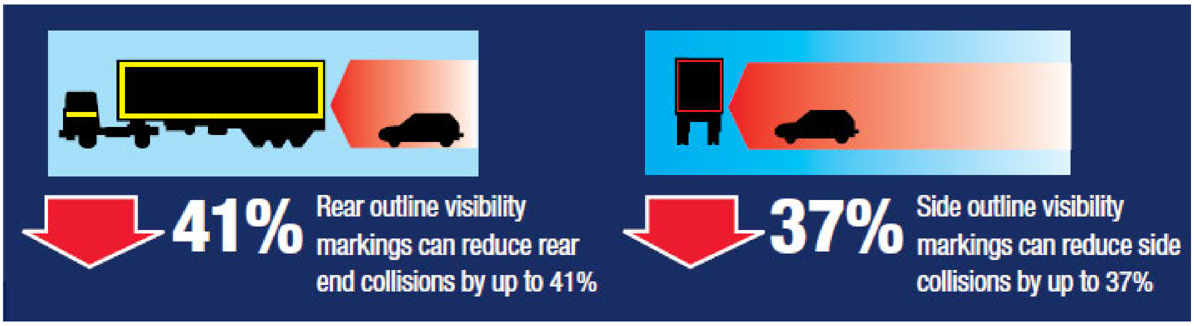

Figure 1: European report (1984 Bavarian accident statistics) for truck/passenger car accidents with injured persons for "night time/twilight" where "recognition too late" or "no recognition at all"[3]

The Australian 2015 NTI Major Accident Investigation Report[4] found that "single vehicle accidents attributed to 71.8% of losses with the balance of 28.2% involving collisions with third party vehicles. In losses with third parties, not involving fatal injury, the NTI insured heavy vehicle was liable in 59.4% of cases. In collisions involving fatalities however, the truck was not at fault on 84% of occasions". Further NTI Australian data highlights about 30% of multi vehicle crashes occur between 6 pm and 6 am overnight when traffic is at lightest and visibility is most critical. Data indicates that the vast majority of fatal accidents involving trucks and light vehicles are caused by the light vehicle. Where these accidents had resulted from a lack of truck visibility, it would be expected that there be a reduction in collisions for vehicles fitted with retro-reflective markings as experienced in the US and Europe.

In an effort to reduce accidents due to poor visibility, the ATA together with industry representatives, have developed this heavy vehicle visibility TAP, describing the methods by which increased vehicle visibility can be achieved. These requirements are based on European

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[1] US study - the effectiveness of retroreflective tape on heavy trailers - www.nhtsa.gov/cars/rules/regrev/evaluate/809222.html

[2] Contour Markings of Vehicles Final Report FO76/00. Schmidt-Clausen, 2000 Darmstadt University of Technology

[3] Contour Markings of Vehicles Final Report FO76/00. Schmidt-Clausen, 2000 Darmstadt University of Technology

[4] NTI reports can be found at www.nti.com.au. NTI is a significant insurer of heavy vehilces in Australia.

Regulation UN ECE R104 – "Uniform Provisions Concerning the Approval of Retro-Reflective Markings for Heavy and Long Vehicles and their Trailers", which define the performance, placement and material specification of the markings.

Overall, the goods transportation sector has seen an improvement in the fatal crash rates for articulated vehicles. Chart 1 illustrates that over time there has been a decline in crashes (orange line), but an almost double of the total articulated combinations in service (yellow line), which has produced a huge reduction in the fatal crash rate (green line).

Fatal crash rate per articulated vehicle, 1982 - 2015

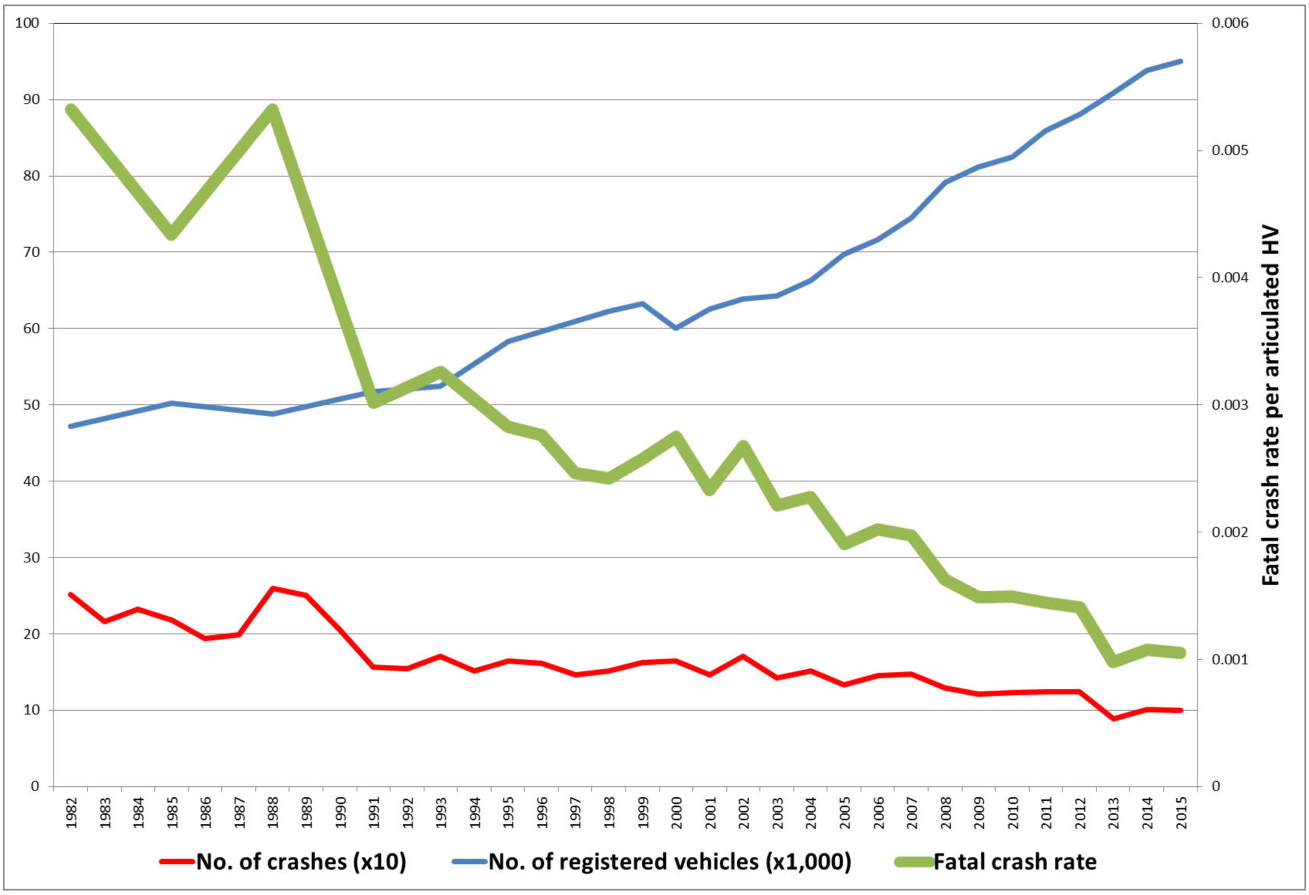


Chart 1: Fatal crash rates[5]

The risk of an accident between a truck and a car is 30 times greater when a truck does not have high visibility markings[6]. A truck with outline reflective markings is recognised much earlier than an unmarked truck because they help to define the total size of the truck to other road users. This gives drivers more time to manoeuvre safely in traffic.

Note:
This Technical Advisory Procedure is to be used in addition to and is not intended to replace existing regulations and ADR lighting or marking requirements.

[5] Adelaide University Centre for Automotive Safety Research (CASR)

[6] Prof.Dr-Ing. H.-J. Schmidt-Clausen, Laboratory Of Lighting Technology, Darmstadt University and LBI Unfallforschung Austria: Viewing Behaviour Survey/2001.

2) Contour markings

Contour markings on a heavy vehicle outlines the shape of the vehicle with retroreflective tape to give other road users visibility of the vehicle ahead and the ability to perceive their distance and closing rate. A full contour of the vehicle makes this visual perception easiest. Three levels of contour markings are acceptable:

a) Full contour – the preferred layout.

Reflective tape is applied as close as possible to the edge of the vehicle to form a continuous line depicting the outline of the vehicle. This provides maximum visibility to other road users and is best practice. This method must also be chosen if there are retro-reflective graphics on the side of the vehicle.

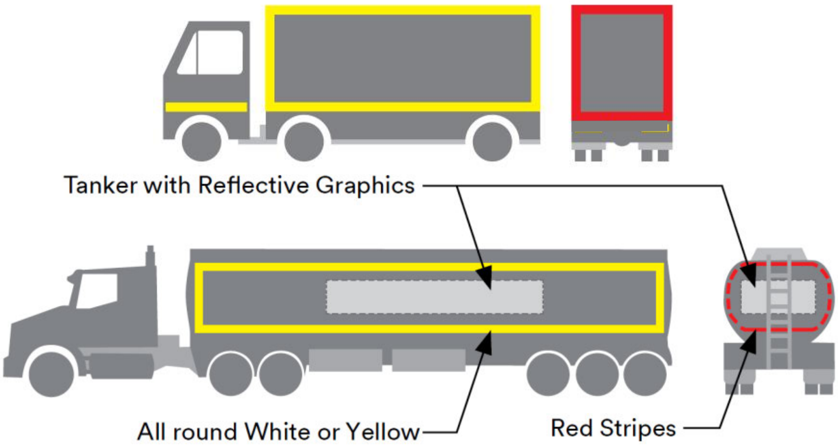


Figure 4: Full contour marking for a tanker

b) Partial contour

A single stripe of retro-reflective tape is applied along each side and rear of the body or trailer, with 'L' shape sections 0.5 m long in each corner.

Figure 5: partial contour marking

c) Stripe marking

A single stripe of retro-reflective tape is applied along each side of the vehicle and body or trailer side, and a strip across the rear. This basic layout shall only apply to those vehicles that do not utilise retro-reflective graphics or logos or have limited structure onto which tape can be applied on the upper sections of the trailer.

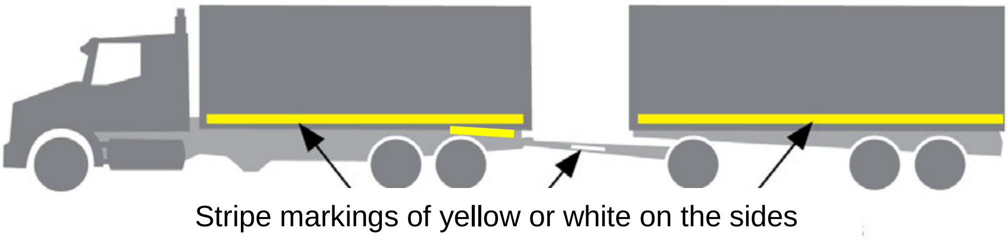


Figure 6: Stripe contour marking for truck and dog

d) Front of trailers

The UN ECE R104 does not require the forward face of the trailer to be marked, however, it is highly recommended if the trailer is regularly parked outside a secured depot, retroreflective tape should also be applied to the trailer's forward face.

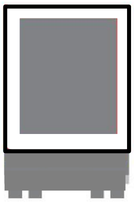


Figure 7: Stripe contour marking for the front of trailers is optional

e) Options for curtain sided vehicles

As a result of the material used for curtain sided trailers, specific retroreflective tapes must be selected. These tapes are either flexible or segmented so that they can flex as the curtain is retracted. These markings should as a minimum be applied to the lower section of the curtain, underneath the line of the straps. The placement of stripe should follow one of the three options detailed previously.

The continuous flexible tape can be applied in the same format as detailed previously, the segmented tape must be placed so that each segment is not spaced more than 50 per cent of the width of the segment apart, and covers at least 80 per cent of the vehicle length.

Figure 8: Example of segmented tape options for curtain sided trailers

3) Key material requirements

It is recommended that the retro-reflective material used for contour markings and its colour be appropriate to the location, complying with the requirements of class 1A material as specified in the UN ECE R104 regulation. Additionally, tape incorporating the European E marking (see figure 9), in accordance with Clause 5 of UN ECE R104, easily identifies that it is suitability for this application.

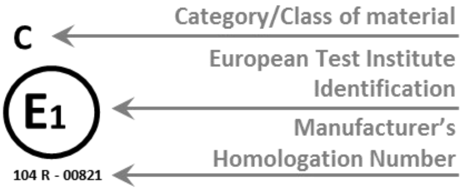


Figure 9: Example of UN ECE R104 compliant E-mark displayed on tapes

4) Key dimensional requirements

The total minimum length of the retro-reflective markings shall be at least 80 per cent of the combined length bumper to bumper (including the prime mover), and 80 percent of the width of the vehicle.

Where non-continuous stripes are used, the distance between single elements shall be as small as possible and should not exceed 50 per cent of the length of the shortest element. Such segments shall be evenly distributed.

The stripes shall be installed as close to parallel to the ground as possible, at a minimum height of 250 mm and a maximum height of 1.5 m from the ground. Where vehicle designs do not allow compliance with the 1.5 m maximum height, a 2.1 m maximum height is acceptable.

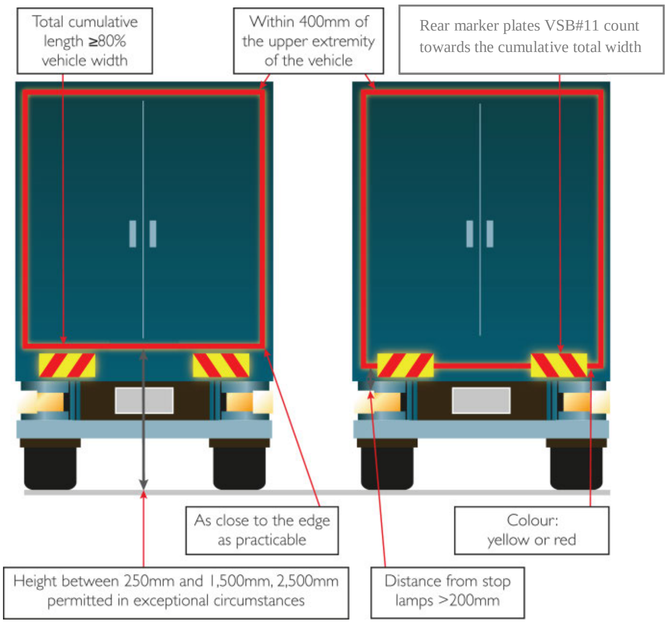
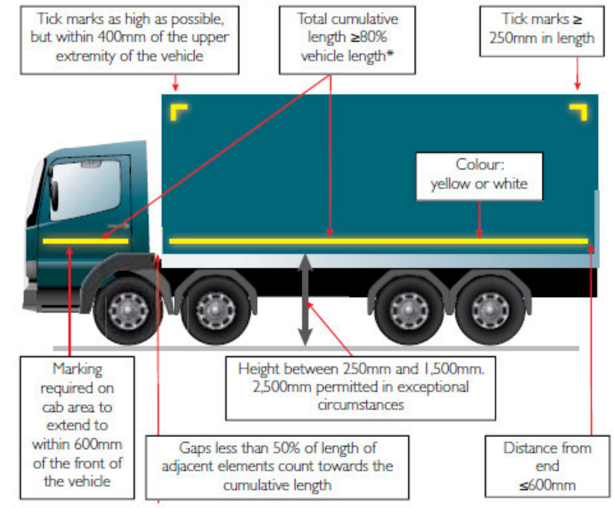


Figure 10: rear positional requirements[7]



Vehicle length excludes the cab, however the cab area must be marked to comply with the requirement to extend to within 600mm of the front of the vehicle

Figure 11: side positional requirements[5]

There are a range of suppliers and importers offering a wide range of options.
It is recommended to use tape compliant to UN ECE R104 with dimension of 50 $^{+10}_{-0}$ mm.

- Select the colour of the tape appropriate to the location and surface type.
- Select class 1A material, which has typically been E Marked for quality purposes.

[7] The ATA wishes to acknowledge the Freight Transport Association of the UK for allowing the images to be used.

5) Best practice / recommended colours

Location on vehicle	Recommended colour	Allowable optional colours, but not recommended
Front	**White**	None
Side	**Yellow**	White
Rear	**Red**	Yellow

Table 1: Permissible colours on vehicle sides

Figure 12: Sample colour swatch

The recommended colours, listed in table 1 above, have been selected to align with the typical lights used in the equivalent directions:-

- White (head lights) to the front
- Yellow (side marker lights) to the side
- Red (brake and stop lights) to the rear

Notes:-

- Refer to ADR 13/00 Installation of Lighting and Light Signalling Devices, ADR 47/00 Retroreflectors and Heavy Vehicle (Vehicle Standards) National Regulation for additional guidance. Noting that the National Heavy Vehicle Law (NHVL) for vehicle standards defers to the second or third edition ADR, if the HVNL is inconsistent with the ADR, regardless of whether or not the vehicle is required to comply with the requirement.
- Exempt vehicles, such as emergency and police vehicles, are not required to comply with this standard.

6) Applicability to vehicle types

It is recommend that high visibility markings, as detailed in this TAP, be fitted to all heavy goods vehicles with a Gross Vehicle Mass (GVM) or Gross Trailer Mass (GTM) greater than 4.5 tonne. This is in line with the UN ECE R104 requirements.

7) Issues with the use of US style red/white block stripe markings

The FMVSS 108 marking requirements have been in force in the US since December 1993. It applies to trailers over a GTM of 10,000 lbs (4,535 kilograms) and rear of prime movers. It is most visibly illustrated as the red/white block stripe pattern down the side and across the back of US trucks and trailers.

An updated version of ADR 13/00, registered 10 May 2013, is believed to be the first occasion that the optional conspicuity marking requirements were limited and that they needed to comply with the UN ECE R104 regulation. This change was not widely known within the industry and combined with an incorrect listing of the acceptable colour for side retroreflective tape detailed within ADR13/00, produced a conflict with the first edition of this TAP.

As at the date of issue of this TAP, ADR13/00 is still waiting to be updated, but it is recognised by the authorities that the colours detailed in section 4 of this TAP are approved.

This has resulted in the US style red/white block stripe conflicting with the ADR and as a result, it can no longer be used on road. The National Heavy Vehicle Inspection Manual (NHVIM) will be updated in time to clarify how these conspicuity markings will be handled for in-service vehicles.

Figure 13: US approved installation, which is NOT approved in Australia

8) Costing estimate for a full contour marking

Based on a prime mover and a single trailer combination with an overall length of 19 metre.

Figure 14: Full contour marking

Material Cost

Front (white)	11 m @ $95 per 15 m roll
Side (yellow)	68 m for the trailer and 6 m for the truck @ $95 per 15 m roll
Rear (red)	11 m @ $95 per 15 m roll

Total estimate for material cost $608 per semi-trailer combination.

Notes

- Pricing is indicative only and applicable as of July 2016.
- Retroreflective tape to suit either curved or flexible surfaces will cost about 50 per cent more than standard tape applicable to hard flat surfaces.

Labour hours for marking a prime mover and semi-trailer.

Front (trailer only)	15 minutes for a stripe marking
Side	75 minutes per side,
Rear	45 minutes
Estimated total	2 hours and 15 minutes

Notes

- Applications is dependent on access to the top of the trailer
- Skill level and the availability of suitable equipment for working at heights to apply the material will have a significant impact on the tapes fitment time.

9) Applying the tape

Instructions and application requirements can typically be found on the tape suppliers' website.

Notes

- The key is surface preparation it must be rust and dirt free.
- Clean with isopropyl alcohol (IPA) surface solution.
- Ensure air and surface temperatures are between 18 and 30 degC.

10) Application examples

Figure 15: Tanker with partial contour markings[8]

Figure 16: Skip loader with line markings[6]

Figure 17: Car carrier with partial contour markings[6]

Figure 18: Semi-trailer with tray and line markings[6]

[8] The ATA wishes to acknowledge the Freight Transport Association of the UK for allowing the images to be used.

Application examples – continued

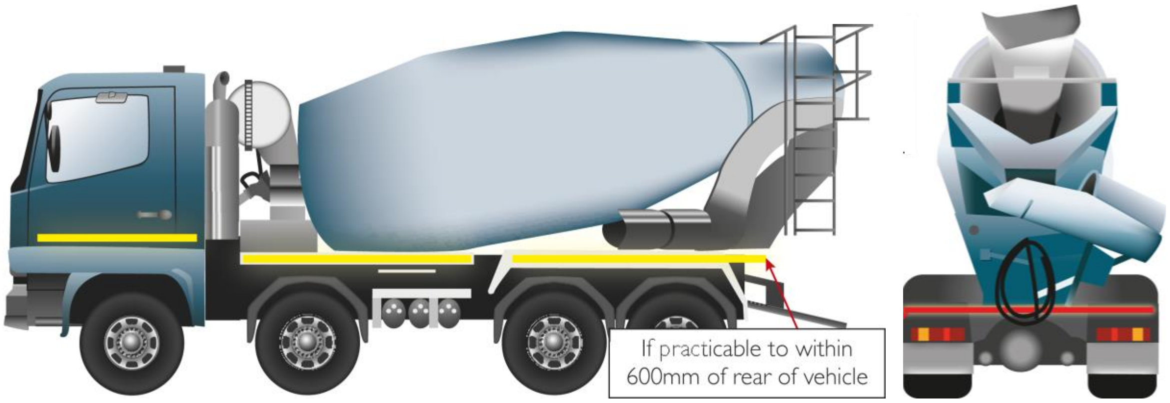


Figure 19: Concrete mixer/agitator with line markings[7]

Figure 20: Rubbish truck with partial contour markings[7]

Many rubbish trucks will not be able to take a full line or contour marking due to the equipment being fitted. In these cases, it is acceptable to retain rear marker plates with conspicuity markings fitted to the fullest extent practicable.

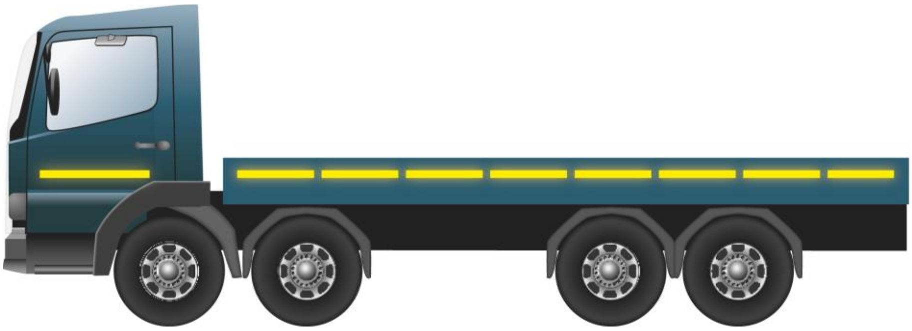


Figure 21: Rigid with tray and line markings[9]

[9] The ATA wishes to acknowledge the Freight Transport Association of the UK for allowing the images to be used.

Application examples – continued.

Semi-trailer combination with full contour marking

B-double tanker combination with stripe marking

The retroreflective tape should be applied along widest segment of the tanker to have maximum visibility effect for other road users, which is usually the vertical surface. This may place the tape more than 1.5 m above the road surface as required by UN ECE R104, but the enhanced visibility of the tape is preferred.

Application examples – continued

Rubbish truck full contour marking

Tray and flatbed truck: (mark the best profile you can for the vehicle).

B-double tanker trailers

TAP development process, history and validation

The process

The ITC will approve the need for the creation of a new TAP or the triennial routine review of an existing TAP. The nominated editor(s), who are listed below, with support of the ITC and specialist industry technical members as required, will agree on the TAP content with approval by an ITC member majority vote. A suitably qualified and experience ATA appointed peer reviewer will further review the publication and if necessary, recommended changes. These changes will then be reviewed and approved again by an ITC member majority vote before the document is released.

Document version control

Edition	Date	Nature of change / comment	Editor(s)
First	July 2003	Initial issue	David Coonan, ATA National Manager - Policy
Second	July 2016	General update and rewrite to bring the document in line with current practices with additional illustrative pictures.	Chris Loose, ATA, Senior Adviser Engineering

The next review is expected on or before August 2020.

Drafting committee, first edition

Member	Organisation	Title / Qualification
Pippa Batchelor	3M Australia	Technical and Regulatory BDM, 3M ANZ. Engineering
Mark Gorman	3M Australia	ANZ Business Development Manager - Markings

Peer review, second edition

Edition	Date	Peer Reviewer	Organisation / Qualifications
Second	July 2016	Ivan Babic	Manager Signs and Delineation Assets - RMS NSW, Bachelor of Engineering and Chair of Standards Australia working group ME-053 Motor Vehicles - Rear Marker Plates

INDUSTRY TECHNICAL COUNCIL

About the ATA Industry Technical Council:

The Industry Technical Council (ITC) is a standing committee of the Australian Trucking Association (ATA). The ITC's mission is to improve trucking equipment, its maintenance and maintenance management. The ITC was established in 1995.

As a group, the ITC provides the ATA with robust professional advice on technical matters to help underpin ATA policymaking. It is concerned with raising technical and maintenance standards, improving the operational safety of the heavy vehicle sector, and the development of guidelines and standards for technical matters.

ITC performs a unique service in the Australian trucking industry by bringing operators, suppliers, engineers and other specialists together in a long-term discussion forum. Its members provide expert and independent advice in the field to inform the work of the ITC. The outcomes from ITC benefit all ITC stakeholders and the industry at large.

The ITC operates under the Australian Trucking Association's Council, which formulates industry policy for the implement by the organisation.