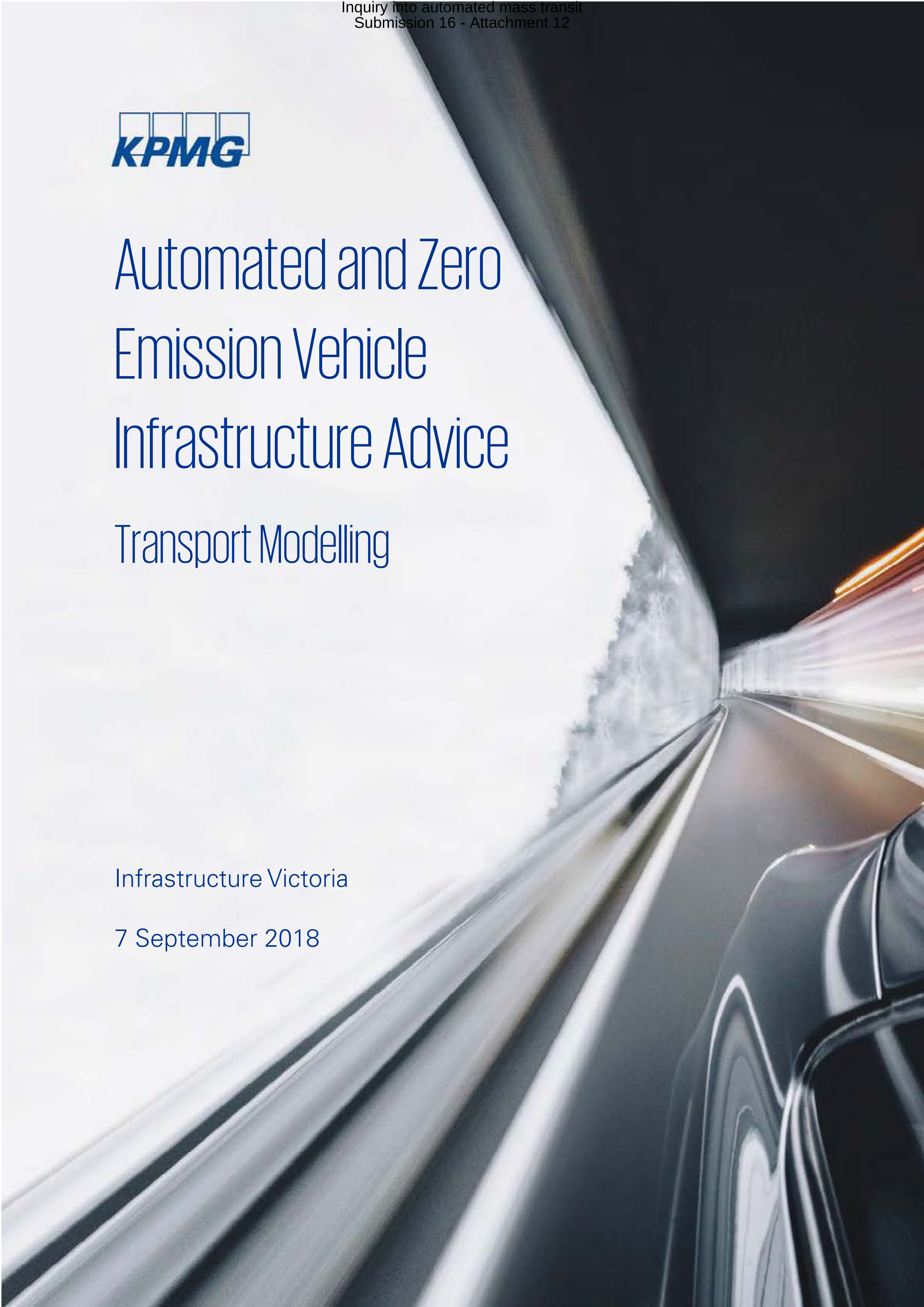

Automated and Zero Emission Vehicle Infrastructure Advice

Transport Modelling

Infrastructure Victoria

7 September 2018

Contents

Disclaimer and limitations

Inherent limitations

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Model outputs are always an approximation of what can be expected in the real environment. The MABM is a strategic planning tools that is best at representing strategic level demands and patterns at a network wide and corridor level, rather than individual links within a transport network. Notwithstanding this, there will usually be differences between forecasts or projected and actual results, because events and circumstances frequently do not occur as expected or predicted, and those differences may be material. KPMG does not make any confirmation or assessment of the commercial merits, technical feasibility or compliance with any applicable legislation or regulation of the transport policy reforms, technology interventions and/ or major transport projects described in this report.

Outputs need to be interpreted with an understanding of the above general limitations as well as the specific strengths and weaknesses of the MABM as described in the MABM Calibration and Validation Report[1] and the 2046 Reference Scenario and AZEVIA Model Development Report[2].

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[1] KPMG and Arup (2017), Model Calibration and Validation Report, Available from https://goo.gl/dZdfwJ.
[2] KPMG (2018), 2046 Reference Scenario and AZEVIA Model Development Report.

Glossary

AV	Automated Vehicle
AZEVIA	Automated and Zero Emission Vehicle Infrastructure Advice
CDV	Conventionally Driven Vehicle
DRT	Demand Responsive Transport
ICE	Internal Combustion Engine
IV	Infrastructure Victoria
MABM	Melbourne Activity and Agent Based Model
MATSim	Multi-Agent Transport Simulation
MCG	Melbourne Cricket Ground
MUTT	Marginal Utility of Travel Time (i.e. value of travel time savings)
TUB	Technical University of Berlin
VITM	Victorian Integrated Transport Model
VOC	Vehicle Operating Costs
VHT	Vehicle Hours Travelled
VKT	Vehicle Kilometres Travelled
V2I	Vehicle to infrastructure (refers to communication technology)
V2V	Vehicle to vehicle (refers to communication technology)
ZEV	Zero Emission Vehicles

Executive Summary

We are entering a new era in transport

This report considers the impacts of three emerging transport technologies and their potential outcomes for Melbourne. These technological changes could have profound and long-lasting impacts on how Victoria's cities and towns look, feel and function.

Automated vehicles

Today, the cars we are accustomed to are conventionally driven vehicles (CDVs), meaning we need people to drive them. The most significant change we expect to see in cars over the next few decades is the emergence of automated vehicles (AVs).

For the purpose of this report, AVs refer to Level 4 and Level 5 automation, as defined by the Society of Automotive Engineers[3]. Level 4 vehicles are highly automated, meaning they can drive by themselves in certain areas without any human input (e.g. on sealed roads only). Level 5 vehicles are fully automated – they can drive anywhere a CDV can drive, without any need for a human driver.

Vehicles on demand

'Vehicles on demand' is a service that we already enjoy in Melbourne. Through taxi and ridesharing services, we can request a ride when we want it and use it to access destinations. Right now, these services are relatively expensive compared to private vehicles, and so are only used for a small fraction of trips across Melbourne. However, if AVs were used in these services, we estimate that the cost of vehicles on demand could go down to about one-third of the current cost without the need to pay a driver. This could be cheaper than private car ownership on an annual basis, saving consumers money in the long term.

There is significant potential for using vehicles on demand for more trips – or even as a complete replacement for private cars (which cost owners financing, registration, insurance and servicing), when AVs become available.

Zero emission vehicles

Zero emission vehicles (ZEVs) do not emit any tailpipe or source emissions as they drive. In addition, the running cost of electric vehicles is likely to be lower than traditional internal combustion engine (ICE) vehicles (please note this is not necessarily the case for hydrogen vehicles). The introduction of zero emission vehicles reduces the monetary cost of driving to individuals, as well as the cost of cars in the form of damage to our environment.

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[3] SAE International (2016), *SAE International Standard J3016 – Automated Driving*. Summary available from https://goo.gl/jpn8D3.

Melbourne has many possible transport futures

Melbourne is growing and evolving. The future of Melbourne's transport system is shaped by numerous factors relating to our people and our transport system. Changes in demographics, employment patterns and the timing and frequency of travel of Melbourne's residents are key influencers of demand and causes of potential strain on our transport system.

Infrastructure Victoria has chosen a few key illustrative scenarios to demonstrate the potential transport futures for Melbourne in 2046. Each scenario is an exploration into the effect of one particular way that transport technology could unfold. The impact of these scenarios have been explored using the Melbourne Activity and Agent Based Model (MABM)[4]. It should be noted that in reality, Melbourne's future is more likely to be a combination of these scenarios and technologies, rather than any one extreme. The purpose of the scenarios is to explore the disparate impacts of different transport futures, not to accurately represent a likely future state.

The table below summarises the main scenarios modelled in the MABM. Variants of each scenario have been modelled to explore how different assumptions and/or responses affect Melbourne's illustrative futures.

Scenario	Description	*Automated Vehicles*	*Vehicles on demand*	*Zero emission vehicles*
Dead end	This is the no change, 'business as usual' scenario. None of the technologies are taken up by 2046. The fleet is entirely composed of traditional CDVs which are privately owned. This forms a reference scenario in that it is similar to existing fleet composition and ownership models.	✗	✗	✗
Private drive	All vehicles are automated, but are privately owned (i.e. no vehicles on demand). The AVs are zero emission – they are powered by electricity, not fossil fuels.	✓	✗	✓
Hydrogen highway	All vehicles are privately owned and automated. The cars are powered by hydrogen fuel cell vehicles rather than fossil fuels.	✓	✗	✓
Electric avenue	The fleet is entirely composed of electric vehicles (but vehicles are not automated) and are privately owned.	✗	✗	✓
Fleet street	All vehicles are automated, and operate as on-demand vehicles. This means that all car travel is undertaken via a fleet of shared, on-demand automated taxis. All vehicles are automated and are powered by electricity, not fossil fuels.	✓	✓	✓
High speed	This scenario is equivalent to Fleet street, except the change happens more rapidly, and a full shift to automated, electric vehicles as an on-demand service occurs by 2031.	✓	✓	✓
Slow lane	Half of the population uses a vehicle on demand model (like the Fleet street scenario), and the other half of the population use privately owned CDVs (like Dead end).	✓ ✗	✓ ✗	✓ ✗
Mix of scenarios	On-demand AVs, private AVs and zero emission CDVs all co-exist. This represents a mix of electric avenue (zero emission CDVs), Private drive (private AVs) and Fleet street (on-demand AVs).	✓ ✗	✓ ✗	✓

Source: Infrastructure Victoria

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[4] KPMG and Arup (2017), *MABM Fact Sheet*. Available from https://goo.gl/9yXD7D

How do we measure success?

In order to assess the illustrative scenarios, we need a meaningful set of metrics. The following measures of success are important aspects of Melbourne's transport experience that we can quantify and assess in our scenarios. Demand and crowding on public transport is not a measure in its own right, though it is considered in detail for each scenario, and impacts on each of the measures of success. While improved road safety is also an important measure, we have not included it here because it is not explicitly modelled in the MABM.

Road congestion

Road congestion is a by-product of excess demand, with road networks becoming more crowded for longer periods of the day as demand exceeds capacity. We measure congestion by average delay (seconds/km) and average speed of the network (km/h). Lower average delays and a higher average network speed implies less congestion and a better outcome. As congestion improves, travellers save time and running costs (e.g. fuel or electricity costs).

The vehicle fleet

The vehicle fleet in this context refers to the entire stock of passenger vehicles in Melbourne used on a typical weekday (excluding public transport vehicles and freight vehicles). We measure the size and efficiency of Melbourne's vehicle fleet by the number of vehicles, and their average utilisation (i.e. percentage of the day in which the average vehicle is being used). A lower number of vehicles and higher utilisation of vehicles represents a better outcome. This is because we get more from each individual vehicle, reducing the overhead costs of our fleet, such as depreciation, insurance, registration and servicing. When more of the vehicle fleet is run using an on-demand model rather than private ownership, the overhead costs of using a vehicle are lower per person, because these costs are shared among a large cohort of people using on-demand services. It also saves on costs, such as the land and monetary cost of storing parked cars, as the vehicles spend more time moving and less time parked. Reducing the vehicle fleet also saves on labour, raw materials and energy used in the construction of vehicles.

Physical activity

An important measure of transport outcomes is the distance people walk as part of their daily travel (km/person/day). Physical activity is integral to good health and walking is the most accessible and universal form of physical activity. Public transport use makes for longer walking distances because people walk to and from public transport stops, rather than driving directly from their origin to their destination. People may also walk directly between origins and destinations rather than using motorised modes such as car and public transport. In this analysis, we have excluded walking as an activity in its own right (e.g. walking for exercise, driving to a hiking trail and then walking it) – as this activity would not necessarily change under any of the scenarios examined in this report.

Accessibility

Accessibility is defined as how easily and conveniently people can access their chosen activities. This varies from person to person, with activities spanning work, study, leisure and other commitments. We measure accessibility based on estimates of a person's 'satisfaction' of their day – including how much time they can spend at their preferred activities rather than stuck in traffic or on crowded public transport services. The cheaper, quicker and easier a transport option is, the more time spent doing activities and the lower likelihood of being late, the more satisfied the person is and the higher their accessibility is. Accessibility is an important measure because it quantifies how easily people can fulfil their needs, including accessing jobs, education, healthcare, social, shopping and other activities.

What are some potential outcomes in 2046?

The table below summarises the difference between the main scenarios modelled in the MABM, compared to the Dead end (i.e. business as usual) scenario. The Dead end scenario, where no new vehicle technologies are introduced by 2046, is characterised by a large number of cars (3.5 million) which are idle over 95% of the time, double the walking distance per person compared with 2015, and morning peak delays which are 24% worse than in 2015.

◉	⭕	-	○	●
Much worse	Slightly worse	Similar	Slightly better	Much better

Scenario	Comments	Road congestion	Fleet	Physical activity	Accessibility
Private drive	- Congestion reduces with platooning[5] but is negatively impacted by empty running - Lower public transport usage eases rail crowding - AV popularity increases the vehicle fleet by 7%, but vehicles spend most of the day idle - Walking distance is 15% lower than Dead end - Accessibility rises as congestion and vehicle operating costs fall	○	-	⭕	●
Hydrogen highway	- Average delays per km reduce by 78% due to platooning[5] - AV popularity increases the fleet by 7% but vehicle utilisation falls to just 3.6% - Physical activity reduces by 17% as people move away from public transport - Accessibility increases by 7%	●	-	⭕	●
Electric avenue	- Congestion worsens because lower operating costs compared to Dead end lure more people onto the roads - Cheaper electric cars improve accessibility by 7%	⭕	-	-	○
Fleet street	- More public transport trips occur (as people avoid on-demand fares) and road congestion is almost eliminated - The vehicle fleet collapses from 3.5 million to 260,000 and utilisation rises from 5% to 36% - The average person walks 2.5 km per day as part of their travel, compared with 2.1 km in Dead end - On-demand AV fares and wait times reduce accessibility by 11%	●	●	●	◉
High speed	- Impacts are similar to the Fleet street scenario described above - The estimated vehicle fleet size is 210,000	●	●	●	◉
Slow lane	- A mixed fleet dilutes the impacts of AVs relative to Fleet street - Delays are 76% lower than in Dead end - The vehicle fleet falls from 3.5 to 2.0 million - Physical activity increases by 7-8% - On-demand AV fares and wait times reduce accessibility slightly	○	●	○	⭕
Mix of scenarios	- Mix of private AVs, private zero emission CDVs and on-demand AVs creates results between Fleet street and Private drive for most metrics	●	○	○	-

Source: MABM & KPMG Analysis

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[5] Platooning is the ability of AVs to drive with short distances between cars via electronic coupling.

What if we have different patterns of urban development?

Some of the scenarios we tested have major impacts on travel behaviour. While our main scenarios assume a baseline pattern of urban development, these changes could influence where Melburnians choose to live, work and undertake other activities. We tested some scenarios that have Melbourne's land use patterns evolving in a different way between 2015 and 2046 – an 'expanded low density' city, and a 'centralised high density' city. These land use scenarios were developed by Infrastructure Australia[6]. We ran these variants against the Private drive and Mix of scenarios.

The outcomes of those scenarios relative to the baseline urban development patterns are described below. Generally, the impacts of the land use scenarios we tested are minor relative to the much larger impacts of automated vehicle technology and on-demand AVs. The extent of changes to land use that these technologies could generate is unknown – the horse and cart, passenger rail and automobile all had fundamental impacts on how our cities are shaped, and new transport technologies could similarly have fundamental impacts.

	Private drive	Mix of scenarios
Expanded low density city	People shift modestly towards car use and away from public transport, although most people use private cars regardless.	People shift modestly towards private cars and public transport as people in outer areas look to avoid using on-demand AVs due to high fares and wait times.
Centralised high density city	There is a significant shift away from private cars and towards public transport due to higher public transport service levels in the inner city.	Private car use stays about the same, but people shift modestly from on-demand AVs to public transport which provides a cheaper alternative to on-demand AVs.

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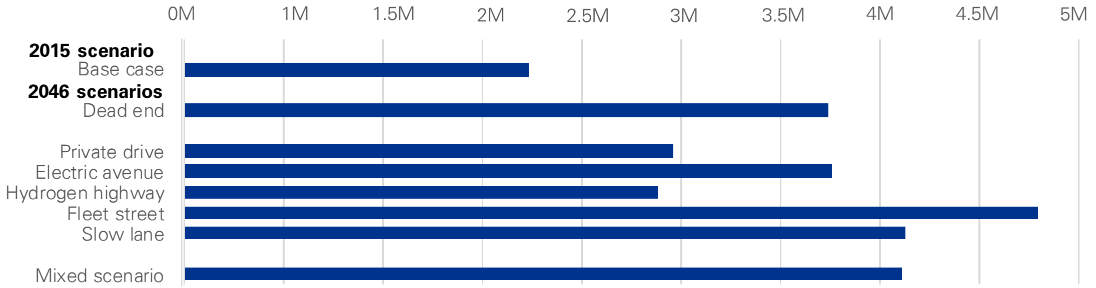
[6] Infrastructure Australia (2018), Future Cities: Planning for our growing population, Available from https://goo.gl/gLTMkB.

What happens with public transport?

Public transport patronage grows strongly in all the main scenarios

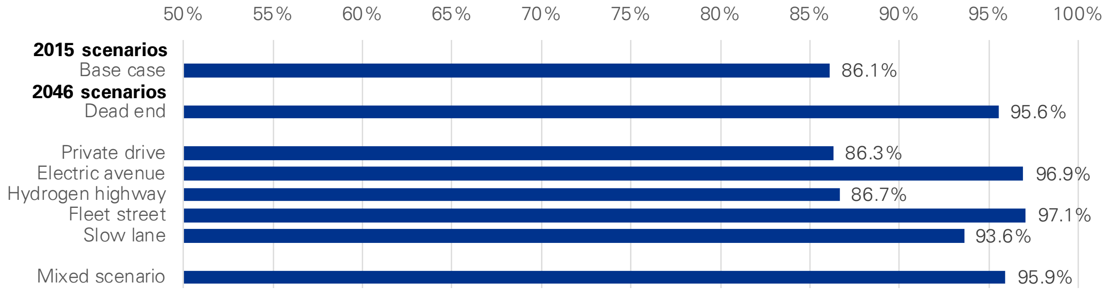
One thing that all the future scenarios have in common is that they have much higher levels of public transport patronage than today. Even the scenario with the lowest usage (Private drive) has more than double today's patronage, and the scenario with the highest usage (Fleet street) has over four times today's patronage.



Source: MABM

All the main scenarios have significant crowding on heavy rail

All of the main scenarios have heavy rail crowding of at least the 2015 level, and some (Fleet street, Slow lane, Electric avenue) are significantly higher than the 2015 level. The figure below shows average crowding for inbound morning peak rail services as a proportion of the design standard for crowding.



Source: MABM

Buses and trams are particularly important for Fleet street

While there is an increase in use of all public transport modes in the Fleet street scenario, the largest increases are on buses, and to a lesser extent trams. This is because users switch to public transport to save money by avoiding on-demand AV fares. The Fleet street scenario has more usage of public transport for a broader range of everyday activities (beyond just commuting), and these diverse locations are better served by buses and trams than trains. Other scenario variants consider replacing buses with demand responsive transport vehicles. This considerably improves accessibility, particularly in outer areas.

What influences the outcomes?

The following table summarises how key influences behind traveller behaviours impact the measures of success for Melbourne's transport futures.

🔴	⭕	-	○	🟢
Much worse	Slightly worse	Similar	Slightly better	Much better

Influence	Comments	*Road congestion*	*Vehicle fleet*	*Physical activity*	*Accessibility*
More comfort and convenience of driving	AVs allow occupants to undertake activities such as reading, sleeping, watching movies or participating in work activities. Therefore, AV users are likely to care somewhat less about travel times, and will be happy to spend longer times in an AV compared to a CDV. The more that people value this comfort and convenience over time savings, the more popular AVs become. This leads to more congestion, a higher fleet size, and less walking due to less public transport use. The additional comfort increases people's accessibility (satisfaction), despite the extra congestion.	🔴	⭕	⭕	○
Mass take-up of vehicles on demand	AVs on demand would allow consumers to forego private ownership altogether, and instead rely on on-demand vehicles which are much cheaper and more convenient than today's taxis. This is because no driver needs to be paid and fixed costs are split between many users. Mass take-up would also reduce the wait times and create economies of scale and network effects. The vehicle fleet could be reduced by around 90%.	⭕	🟢	⭕	⭕
Less 'sunk' travel costs	AVs on demand may be paid with a fare (including a time and distance component). While this fare would be much lower than today's taxis, it would still be greater than the per-trip running cost of a private car. This is because most costs of vehicle ownership are 'sunk', such as financing and maintenance, and are not perceived by travellers on a trip-by-trip basis. This means travellers are less likely to use cars and more likely to use public transport. It also decreases accessibility.	🟢	○	🟢	🔴
Higher effective road capacity	AVs are not restricted by the limits of human spatial awareness and reaction times. This means that AVs can operate safely with much smaller gaps between vehicles. The ability of AVs to travel in tight groups of vehicles is called platooning.	🟢	-	⭕	🟢
Empty running	AVs can travel without any occupant. This means that AVs do not need to park at the location of their owners' activity. This ability of private AVs to undertake empty running might benefit the owner, but also cause additional congestion, since the vehicle is travelling more on the network. AVs on-demand also run empty in between dropping off one passenger and picking up the next.	🔴	⭕	⭕	⭕

Source: MABM & KPMG Analysis

How should we respond?

New transport technologies will have major influences on the way our cities and towns look, feel and function. The future of transport technologies is rapidly changing and is subject to considerable uncertainty. Techniques, such as scenario analysis (as used in this report) and real options analysis for dealing with uncertainty in long term planning for infrastructure, will be needed to navigate this uncertainty. New transport technologies present opportunities to realise major economic, social, environmental and liveability benefits, but they also come with threats of potential negative impacts if not appropriately managed. Some of these opportunities and threats are summarised below.

Opportunities

- Reduce the size of the fleet
- Get more from our existing road infrastructure
- Improve amenity and liveability
- Make transport pricing fairer
- Reduce transport disadvantage

Threats

- Congestion due to optional empty running of private AVs
- Congestion due to comfort and convenience
- Congestion due to empty running of on-demand vehicles
- Delays getting in and out of on-demand vehicles
- Congestion due to urban sprawl
- Poor accessibility and equity outcomes
- Reduced productivity of our CBD and inner core

Government will need to respond in various ways to ensure Victorians are able to enjoy the full benefits of these technologies. A select number of potential responses designed to help maximise the opportunities and mitigate the threats are summarised below.

Non-build responses

- Create an integrated transport pricing strategy
- Address coverage and fares for vehicles on demand
- Plan for population growth in inner and middle suburbs
- Re-evaluate the road hierarchy

Build responses

- Build communications infrastructure to enable platooning
- Invest in high quality alternatives to driving
- Invest in high capacity trunk public transport
- Provide parking and drop-off/pick-up locations for AVs

1 Introduction

1.1 Background and context

1.1.1 Automated and Zero Emission Vehicle Infrastructure Advice

In October 2017, Victoria's Special Minister of State Gavin Jennings requested that Infrastructure Victoria (IV) provide written advice to the Victorian Government on Victoria's Infrastructure Requirements to "enable the implementation of automated and zero emission vehicles"[7]. IV's advice is referred to as Automated and Zero Emission Vehicle Infrastructure Advice (AZEVIA). The scope of IV's advice is to advise the Victorian Government on the infrastructure requirements that:

a) Enable the operation of highly Automated Vehicles (AVs) (otherwise referred to as autonomous vehicles, driverless vehicles or self-driving vehicles);
b) Respond to new ownership and market models which may arise from AVs; and
c) Respond to the eventuality of Zero Emission Vehicles (ZEVs) as a high proportion of the Victorian fleet.

In the context of this work, AV refers to vehicles operating at Levels 4 and 5 of automation (High Automation, Full Automation) as described by SAE international[8]. This means that the vehicle is able to automate all aspects of the dynamic driving task without human intervention.

ZEVs are defined as vehicles which produce no tailpipe or source emissions. These vehicles have the potential to reduce or eliminate greenhouse and local air and noise pollution impacts. ZEVs is an umbrella term for Electric Vehicles (EVs) and Hydrogen Vehicles (HVs).

The term "fleet" in the context of this report is a broad term which encompasses all private passenger vehicles and taxis registered and operated in the State of Victoria on a typical weekday.

1.1.2 Melbourne Activity and Agent Based Model

In 2017, KPMG worked with IV to develop a new strategic activity and agent based transport model for Melbourne. The model is called the Melbourne Activity and Agent Based Model (MABM)[9]. The purpose of a strategic transport model is to test the impacts of a variety of different infrastructure and policy scenarios and model the impacts on transport system performance, as well as the fairness and equity impacts of those scenarios. The modelling is intended to form part of the evidence base to inform the public debate relating to transport policy and investment.

The MABM builds on the theoretical framework and software platform called "Multi-Agent Transport Simulation" (MATSim). The MATSim theoretical framework represents leading practice in strategic transport modelling.

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[7] Gavin Jennings (25 October 2017), *Terms of Reference – Advice from Infrastructure Victoria on automated and zero emission vehicle infrastructure*. Available from https://goo.gl/drFfgY.

[8] SAE International (2016), *SAE International Standard J3016 – Automated Driving*. Summary available from https://goo.gl/jpn8D3.

[9] Infrastructure Victoria (2017), *Managing Transport Demand*. See summary and attachments at https://goo.gl/SmzNNy.

KPMG applied the MATSim framework and modified it to suit local conditions in Melbourne. The MABM has several advantages over traditional modelling approaches[10], including:

- It puts the customer at the centre, being person-based rather than trip-based – this means it is more suited to modelling the fairness and equity impacts of different infrastructure and policy scenarios;
- It focusses on plans and activities rather than journeys – this means it can take into account constraints that are unique to individuals – for example if a person needs to take a car to work so they can pick a child up from school after work;
- It is able to consider peak spreading impacts – this means that it is more suited to understanding the circumstances in which people change their travel times to earlier or later in the day, and for understanding policy scenarios in which policy or pricing settings vary during peak and off-peak times; and
- It is able to produce rich visualisations – this means it is easier for modellers to communicate findings to a broader audience, and it also improves the transparency of modelling.

In addition to these advances over traditional modelling techniques, the MABM provides a strong foundation for modelling of the AV and ZEV scenarios described in Section 3.1 of this report. MATSim has been used to undertake scenario modelling for AV and ZEV scenarios in other parts of the world, including Berlin (Germany), San Francisco (USA) and Braunschweig/Wolfsburg (Germany)[11].

The MABM was validated in 2017 to a base model year of 2015[12]. A 2031 reference scenario was also created in 2017[13]. A 2046 reference scenario was created in 2018, and a number of AV and ZEV modules were also introduced in 2018[14]. The baseline MABM is a simulation of a typical weekday (i.e. a Tuesday in August during the school term, and with no public holidays occurring in that week).

1.2 Our scope

The main objective of this report is to provide the evidence base as part of IV's AZEVIA project described in Section 1.1.1 of this report. The scope of KPMG's work described in this report is to:

- Run the scenarios as agreed with IV and defined in Appendix A using MABM;
- Report on the key findings arising from those scenarios, including opportunities and threats, and implications for Victoria; and
- Provide recommendations that may help maximise the benefits of the technological changes and mitigate potential negative consequences for consideration by IV.

The scope of this report is limited to analysis of travel behaviour and transport system impacts (transport modelling). Other elements of the AZEVIA project are part of separate work packages and therefore out of scope for this report. As a result, this report does not include discussion relating to these areas. Out of scope areas include:

- Land use impacts of automated and zero emissions vehicles;
- Energy impacts;
- Socio-economic impacts;

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[10] KPMG and Arup (2017), *MABM Fact Sheet*. Available from https://goo.gl/9yXD7D.
[11] A list of recent publications by the Technical University of Berlin can be found at this link: https://goo.gl/TGSwZY.
[12] KPMG and Arup (2017), *Model Calibration and Validation Report*, Available from https://goo.gl/dZdfwJ.
[13] KPMG and Arup (2017), *Travel Demand and Movement Patterns Report*, Available from https://goo.gl/HBVmZC.
[14] KPMG (2018), *2046 Reference Scenario and AZEVIA Model Development Report*.

- Review of international markets;
- Financial impacts to Government;
- Information and Communications Technologies;
- Transport Engineering;
- Environmental and health impacts; and
- Urban design.

As the model used for this analysis (MABM) only covers the Melbourne metropolitan area, this report discusses the key outcomes for Melbourne. Additional analysis was also undertaken using a trip-based model (VITM) for the remainder of Victoria, as described in Appendix G. This was provided for use by separate work packages (e.g. land use), but the model functionality was not available to explore the impacts and outcomes in detail for regional areas. The Statewide VITM methodology is described in Appendix G.

1.3 Our approach

We are entering a new era in transport. This report considers three emerging technologies – automated vehicles, zero emission vehicles and automated vehicles on demand. Any or all of these could have major impacts on how our cities look, feel and function.

1.3.1 We explore the impacts of new technologies using scenario analysis

Using the MABM, we ran a number of transport scenarios to explore the effects of new vehicle technologies on Melbourne’s travellers and transport system.

IV have chosen a few key illustrative scenarios to demonstrate the potential transport futures of Melbourne in 2046. Each scenario represents the effect of one particular way that transport technologies could unfold, using the MABM. It should be noted that, in reality, Melbourne’s future is more likely to be a combination of these scenarios and technologies, rather than any one extreme. The purpose of the scenarios is to explore the disparate impacts of different transport futures, not to accurately represent a likely future state.

The modelled scenarios are described in Sections 5-10 of this report. The Dead end scenario assumes no new vehicle technology is introduced in Melbourne between 2015 and 2046 (a ‘business as usual’ scenario) and forms the basis for comparison. The other scenarios explore how different technologies may impact our travellers and transport system in 2046.

1.3.2 We assess the impacts by defining measures of success

Each new vehicle technology has a range of potential impacts on Melbourne’s transport system and travellers. We identified four key measures of success (congestion, the vehicle fleet, physical activity and accessibility) and assessed the modelled scenario outcomes against these measures. The measures of success are described in more detail in Section 4, and the potential outcomes for each scenario are described in Sections 5 through 10 .

1.3.3 We identify opportunities, threats and potential responses

We know what could happen, so what’s next? By identifying key opportunities and threats of Melbourne’s possible transport futures, we lay out some potential strategies and responses that can help maximise the benefits of new transport technologies, while minimising any potential downsides. The opportunities, threats and potential responses to the future needs of Melbourne’s travellers and transport system are summarised in Section 12.

1.4 How to use this report

This report is underpinned by MABM results. Summary results can be found in Appendix A. This report also includes numerous charts, maps and graphics in the Appendices. These are referenced throughout the report using hyperlinks. If you are reading this report as a PDF, you can go into greater detail on a subject whenever you see a box like the one below. All you need to do is click on the link to access the information. When you're done, you can press Alt-left (hold down the alt key and press the left arrow key on your keyboard) to return to where you were reading. You can practise on the one below.

➡ Hyperlinks appear in boxes like this one. Try clicking on **this example**. When you're done, you can return here using the Alt-left command.

Following this introductory section, the remainder of this report is structured as follows:

We are entering a new era in transport
A summary of the new transport technologies that are incorporated into our scenario modelling.

Melbourne has many possible futures
A summary of our approach to identify the key outcomes of Melbourne's transport future using scenario modelling of key new technologies.

How do we measure success?
An outline of the key measures of success we are measuring for Melbourne's transport future.

What are the potential outcomes?
An analysis of the performance of Melbourne's transport system under the modelled scenarios is split into six Sections. The Sections include an overview of potential outcomes (Section 5), potential effects of private AVs (Section 6), potential effects of on-demand AVs (Section 7), effects of these two technologies co-existing (Section 8), effects of different land use patterns (Section 9), and public transport impacts and possibilities (Section 10).

What influences the outcomes?
An exploration of the key factors behind Melbourne's potential transport outcomes.

How should we respond?
An identification of opportunities and threats involved in Melbourne's potential transport futures, and possible responses to maximise the benefits and minimise the downsides of new transport technologies.

Appendices

Detailed information on the scenario modelling results, including plots of changes in accessibility, volume capacity ratios, changes in flow and changes in speed across the various scenarios.

➡ Infrastructure Victoria commissioned KPMG, Arup and Jacobs to undertake some analysis of automated and zero emission vehicles as part of the 30-year infrastructure strategy in 2016. That work is described in a report that can be found here: **https://goo.gl/TBvfJ6**. That work used traditional trip-based models, including the Victorian Integrated Transport Model and the Outline Transport Model. That work found that increases in capacity (from platooning) led to major reductions in congestion and improvements in accessibility, despite extra demand for car trips caused by AVs. Those findings are consistent with the findings in this report. The work described in this report builds on the earlier work by testing a broader array of potential outcomes. The use of the MABM also allows simulation of on-demand AVs – an important potential part of everyday travel in automated vehicle scenarios which trip-based models have limited ability to model.

2 We are entering a new era in transport

This report considers three emerging technologies. Any or all of these could have major impacts on how our cities look, feel and function.

2.1 Automated vehicles

Today, the cars we are accustomed to are conventionally driven vehicles (CDVs), meaning we need people to drive them. The most significant change we expect to see in cars over the next few decades is the emergence of AVs.

For the purpose of this report, AVs refer to Level 4 and Level 5 automation, as defined by the Society of Automotive Engineers[15]. Level 4 vehicles are highly automated, meaning they can drive by themselves in certain areas without any human input (e.g. on sealed roads only). Level 5 vehicles are fully automated – they can drive anywhere a CDV can drive, without any need for people to get involved.

2.2 Vehicles on demand

'Vehicles on demand' is a service that we already enjoy in Melbourne. Through taxi and ridesharing services, we can request a ride or vehicle when we want it and use it to access destinations. Right now, these services are relatively expensive and inconvenient[16] compared to private vehicles, and so are only used for a small fraction of trips across Melbourne. We estimate that the cost of vehicles on demand could go down to about one-third of what it is now without the need to pay a driver. This could be cheaper than private car ownership on an annual basis, saving consumers money in the long term.

There is significant potential for using vehicles on demand for more trips – or even as a complete replacement for private cars (which cost owners financing, registration, insurance and servicing), when AVs become available.

2.3 Zero emission vehicles

Zero emission vehicles (ZEVs) do not emit any tailpipe or source emissions as they drive. In addition, the running cost of electric vehicles is likely to be lower than traditional internal combustion engine (ICE) vehicles (please note this is not necessarily the case for hydrogen vehicles). The introduction of zero emission vehicles reduces the monetary cost of driving to individuals, as well as the cost of cars in the form of damage to our environment.

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[15] SAE International (2016), *SAE International Standard J3016 – Automated Driving*. Summary available from https://goo.gl/jpn8D3.

[16] Inconveniences of using on-demand vehicles include the need to wait, uncertainty of wait times, uncertainty of fares (if surge pricing is applicable) and inconvenience of using or unavailability of special equipment such as baby seats or roof racks.

3 Melbourne has many possible futures

Melbourne is constantly growing and evolving. The future of Melbourne's transport system is shaped by a number of factors relating to our people and our transport system. Changes in demographics, employment patterns and travel needs of people in Melbourne are key influencers of demand and causes of potential strain on our transport system.

3.1 We use scenarios to explore Melbourne's possible futures

Infrastructure Victoria has chosen a few key illustrative scenarios to demonstrate the potential transport futures of Melbourne in 2046. Each scenario aims to represent the effect of one particular way that transport technologies could unfold, using the MABM. It should be noted that, in reality, Melbourne's future is more likely to be a combination of these scenarios and technologies, rather than any one extreme. The purpose of the scenarios is to explore the disparate impacts of different transport futures, not to accurately represent a likely future state. Table 1 summarises the main scenarios explored in this report.

Table 1: Scenarios – Melbourne's many possible transport futures

Scenario	Description	*Automated Vehicles*	*Vehicles on demand*	*Zero emission vehicles*
Dead end	This is the no change, 'business as usual' scenario. None of the technologies are taken up by 2046. The fleet is entirely composed of traditional CDVs which are privately owned. This forms a reference scenario in that it is similar to today.	✗	✗	✗
Private drive	All vehicles are automated, but are privately owned (i.e. no vehicles on demand). The AVs are zero emission – they are powered by electricity, not fossil fuels.	✓	✗	✓
Hydrogen highway	All vehicles are privately owned and automated (as in Private drive), but the cars are powered by hydrogen fuel cells.	✓	✗	✓
Electric avenue	The fleet is entirely composed of electric vehicles (but vehicles are not automated) and are privately owned.	✗	✗	✓
Fleet street	All vehicles are automated, and operate as on-demand vehicles. This means that all car travel is undertaken via a fleet of shared, on-demand automated taxis[17]. All vehicles are powered by electricity, not fossil fuels.	✓	✓	✓
High speed	This scenario is equivalent to Fleet street, except the change happens more rapidly, and a full shift to automated, electric vehicles as an on-demand service[17] occurs by 2031.	✓	✓	✓
Slow lane	Half of the population uses a vehicle on-demand model (as in Fleet street), and the other half of the population use privately owned CDVs (as in the Dead end scenario).	✓ ✗	✓ ✗	✓ ✗
Mix of scenarios	On-demand AVs, private AVs and zero emission (electric) CDVs all co-exist. This represents a mix of electric avenue (zero emission CDVs), Private drive (private AVs) and Fleet street (on-demand AVs).	✓ ✗	✓ ✗	✓

Source: Infrastructure Victoria

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[17] This does not include commercial carpooling, however more than one passenger can take an on-demand AV from the same pick-up location to the same drop-off location (e.g. a family travelling together to a restaurant).

3.2 We model the scenarios by setting key assumptions

In order to model the scenarios, we need to make some key assumptions. Table 2 summarises the key variables that we vary in order to model the scenarios. Each scenario represents a different combination of new vehicle technologies and key variables in the model.

Table 2: Scenario variables

Variable	Definition	Application
Mode share	Share of trips taken by private CDV, private AV, on-demand AV, public transport and walking.	In most scenarios, the mode share is determined by the model. In "No mode shift" runs, the mode share in the run is fixed to the mode share of the Dead end scenario. This allows us to understand outcomes within a mode, in isolation of any shifts between modes.
Marginal utility of travel time (MUTT)	Travellers in MABM can make trade-offs between slower, cheaper travel options and faster but more expensive options. The MUTT is the perceived value that travellers place on their travel time to make those decisions.	MUTT is lowered in scenarios of Private drive, Fleet street and Slow lane, to test how traveller behaviour changes when time is perceived to be less important. Low MUTT scenarios assume that time is valued at half the rate in AVs compared to CDVs. This means that people in an AV are twice as happy to spend time in an AV compared to a CDV, because they are more comfortable and can undertake activities in the AV.
Share of vehicles	The proportion of private CDVs, private AVs and on-demand AVs.	This input determines what kind of cars are available for travellers. This is the main variable that changes between scenarios.
Fleet size	The total number of vehicles used on the modelled typical weekday, whether they be privately owned or on-demand.	The fleet size of on-demand AVs relates to the Fleet street and Slow lane scenarios. It determines the available supply of vehicles for people who want to use on-demand AVs. The corresponding value for scenarios with private ownership is the size of the private fleet.
AV flow factor	This measures the effectiveness of AVs in platooning. If the AV flow factor is 2.0, then twice as many AVs can flow along a road as CDVs, due to their more efficient behaviour.	Most scenarios assume that AVs flow 75% more efficiently than CDVs. To test the sensitivity of AV efficiency, low flow runs reduce the change in efficiency between AVs and CDVs, so that AVs flow only 25% more efficiently.
Empty running	The ability of privately owned AVs to make trips without people. This might include dropping a traveller at a destination, then allowing the empty car to drive home. On-demand AVs also do empty running between fares.	This input is used as a variation of scenarios with Private AVs, to explore the impacts of empty running as a way for people to avoid paying for parking. Vehicles on demand always have empty running, in order to meet travellers at pick-up locations. The main scenarios of Private drive, Hydrogen highway and Mix of scenarios allow empty running of private AVs to avoid parking charges.

3.3 We model variants of scenarios to test assumptions

In order to test the effects of our variables and assumptions, we created multiple versions of each scenario. These scenarios are summarised in Table 3. Please note that there are no variants of the Dead end, Electric avenue or Hydrogen highway scenarios.

Table 3: Variants of the scenarios – key scenarios

Variation	Definition	Application
No mode shift	Mode share stays the same as in Dead end. This means travellers are not able to change their transport mode choice when new technologies arrive. They are still able to change their time of travel and their route or choice of public transport service.	Used to isolate the effects of new technologies before induced demand dilutes the impacts. For example, this helps to determine what fleet size is required in a Fleet street scenario to service the same demand as private CDVs in the Dead end scenario.
Low MUTT	The perceived value of time is lowered. This means travellers are not as concerned about the time of travel, as they are in other scenarios. This may occur for AVs if people are able to sleep, read or consume entertainment in private while travelling.	Used to test the sensitivity of the MUTT assumption. Given the uncertainty of MUTT for AVs in future, these sensitivities allow us to understand the range of potential implications of this factor. Low MUTT scenarios halve the value that people place on travel time.
Low flow	The AV flow factor is lowered. This means AVs are still more efficient than CDVs in terms of road capacity, but by a smaller margin.	Used to test the sensitivity of the AV flow factor assumption. Given the uncertainty of the extent to which platooning will affect road capacity for AVs in future, these sensitivities allow us to understand the range of potential impacts. Low flow scenarios use a flow factor of 1.25 for AVs rather than 1.75.
Empty Running	Private AVs are allowed to make trips without occupants (to drop travellers at a destination then return home, for example).	Used to test the effects of allowing private AVs to drive with or without people. For example, congestion may be worse if empty running is allowed in Private drive as people send their cars away to avoid parking charges. This assumption is relevant to all scenarios with private AVs (e.g. Hydrogen highway, Private drive, Mix of scenarios, where main scenarios include empty running and some variants do not).
Vehicle operating cost	This is the per kilometre cost of running a vehicle and is determined by the fuel or energy costs.	This input is used to distinguish the cost of running CDVs compared to zero emission AVs. For example, the vehicle operating cost is the only difference between the Electric avenue scenario and the Dead end scenario.

3.4 We explore other factors to test their impacts

Once we have modelled the key scenarios and tested their assumptions using variants, the next step in our approach is to explore how non-technology factors such as policy and pricing affect Melbourne’s transport futures. Table 4 outlines alternative runs to Private drive and Fleet street, which test the effects of potential policies and commercial responses to AVs and ZEVs.

Table 4: Private vehicle scenario variants for assessing potential responses to Melbourne’s transport system performance

Response	Definition	Parameters
Expanded markets *(see page 27)*	Automated vehicles allow the possibility of car usage for those who are currently not able to operate a car due to age, disability or lack of a driver license.	People who usually would not have access to cars (such as children, unlicensed adults and people with disabilities) are allowed to access AVs as ‘drivers’. In this scenario, 25% of children aged 5-11, 50% of children aged 12-17, and 75% of adults who do not otherwise have access to private vehicles are granted this option.
Area based road pricing *(see page 27)*	Any private vehicle trip that uses a road in Inner Melbourne (within approximately 5km of the CBD) pays a price. The area covered by the charge extends to Maribyrnong Road in the North, the Maribyrnong River in the West, Fitzroy Street/Dandenong Road in the South, and Orrong Road and the Yarra River in the East.	Vehicles travelling on any road within the area during the peak periods (7am-9am and 3pm-6pm) pay $5, and vehicles travelling outside the peak periods (9am-3pm or 6pm-7am) pay $2.50. Drivers could pay up to four times per day if they drive in the area in all periods. This is intended to mitigate the additional congestion created by drivers who send their automated vehicles home to avoid inner city parking charges.
Distance based road pricing *(see page 28)*	Drivers are charged a flat rate for every kilometre they drive, irrespective of the time and location of the trip.	Every kilometre travelled in a private vehicle is subject to a 12.6c charge. This is designed to compensate for the lack of fuel excise paid by drivers of electric vehicles.
Freight to night *(see page 28)*	This scenario is designed to test the potential effects of allowing zero emission freight vehicles to operate at night (which is currently highly regulated by a number of local councils across Victoria, due to noise and other factors relating to traditional freight vehicles).	A proportion of freight that travels during the day in the Private drive scenario travels at night instead. Of the freight trips that take place between the hours of 7am and 7pm, 50% take place in the night time hours between 7pm and 7am compared to around 20% in the Private drive scenario.
Slow lane with private AVs *(see page 45)*	This scenario is a variant of the Slow lane scenario, where the population uses private AVs and private CDVs, rather than on-demand AVs and CDVs. It tests the effects of allowing the first users of AV technologies to own the vehicles privately.	Half of the population in this scenario variant have access to private CDVs, whereas half have access to private AVs. This is compared with half of the population having access to CDVs and half having access to on-demand AVs in the main Slow lane scenario.
Private drive, station drop-off and pick-up *(see page 61)*	This scenario is a variant of the Private drive scenario where park and ride capacities are unconstrained. This is because private AVs can drop an owner at a train station and park elsewhere, nearby or at home.	All train station car park facilities become effectively unconstrained in terms of capacity to simulate AV station drop-off and pick-up.

Table 5: On-demand vehicle scenario variants for assessing potential responses to Melbourne’s transport system performance

Response	Definition	Parameters
On-demand vehicle subscription pricing *(see page 35)*	The price of taking a trip in an on-demand AV comprises a flagfall price (i.e. fixed price per trip), as well as a price per kilometre and price per minute. In this scenario, users pay an upfront subscription, e.g. a quarterly fee to access the service in exchange for a significantly lower rate per trip.	Under the Subscription scenario, the perceived cost of each trip is substantially reduced, as the upfront subscription is perceived as a ‘sunk’ cost, similar to many of the costs of private vehicle ownership. Each trip is subject to a reduced flagfall and per km rate of 50c and 5c respectively.
Calibrated fleet street *(see page 35)*	This scenario is a variant of Fleet street with fewer available on-demand AVs. It tests the effectiveness of a vehicle on-demand model with a more limited number of vehicles. Wait times and traveller behaviour are reduced in this calibrated scenario.	Under the main Fleet street scenario, Melbourne travellers have access to a significant available fleet of on-demand AVs for their travel. They utilise approximately 256,490 of these AVs on a typical weekday. The calibration scenario limits the total number of cars to around this fleet size, so that there are no on-demand AVs that are expected to be idle during a typical weekday. Please note that fleet sizes in this report refer only to vehicles that are used in a typical weekday.
No new (pre-construction) major road projects *(see page 37)*	This scenario is a variant of Fleet street with lower investment in major road projects. This variant assumes that no major road projects beyond those already under construction are built between now and 2046. The variant scenario is designed to test the hypothesis that using a smaller, on-demand only AV fleet reduces the need for new freeways.	In this scenario, no new freeways other than the ones already under construction at the time of this report are included in Melbourne’s road network in 2046. This gives on-demand AVs less roads to choose from when taking trips.

Table 6: Scenario variants for assessing potential public transport options for Melbourne’s future

Response	Definition	Parameters
Buses replaced by DRT in Fleet street *(see page 60)*	Bus services are replaced by a demand responsive transport (DRT) service as a complement to the Fleet street scenario. Users pay a reduced rate to access these on-demand AVs which can do up to four pickup/drop-offs per trip. This scenario is designed to test the effectiveness of DRT travel as a replacement for buses in a future with on-demand AV technology.	Users who take the bus in the Fleet street no mode shift scenario are instead assigned to a pooled on-demand service. These users pay the standard public transport fare (which is significantly lower than the standard on-demand AV fare) but may be made to share the vehicle with up to three other riders.

4 How do we measure success?

In order to assess the possible transport futures of Melbourne that we are modelling, we need a meaningful set of metrics to assess them against. The following measures of success are important aspects of Melbourne's transport experience that we can quantify and assess in our scenarios. While improved road safety is also an important measure, we have not included it here because it is not explicitly modelled in the MABM.

4.1 We identify key, quantifiable measures of success

The four measures of success are described below. Only measures directly related to the transport system are included. Other impacts are considered in separate work packages, as described in Section 1.2. An important feature of these measures is that they are unambiguously positive or negative impacts. For example, all else being equal, less congestion is always better than more congestion.

Road congestion

Road congestion is a by-product of excess demand, with road networks becoming more crowded for longer periods of the day as demand exceeds capacity. We measure congestion by average delay (seconds/km) and average speed of the network (km/h). Lower average delays and a higher average network speed implies less congestion and a better outcome. As congestion improves, travellers save time and running costs (e.g. fuel or electricity costs).

The vehicle fleet

The vehicle fleet in this context refers to the entire stock of passenger vehicles in Melbourne used on a typical weekday (excluding public transport vehicles and freight vehicles). We measure the size and efficiency of Melbourne's vehicle fleet by the number of vehicles, and their average utilisation (i.e. percentage of the day in which the average vehicle is being used).

A lower number of vehicles and higher utilisation of vehicles represents a better outcome. This is because we get more from each individual vehicle, reducing the overhead costs of our fleet such as depreciation, insurance, registration and servicing. When more of the vehicle fleet is run using an on-demand model rather than private ownership, the overhead costs of using a vehicle are lower per person, because these costs are shared among a large cohort of people using on-demand services.

It also saves on costs such as the land and monetary cost of storing parked cars, as the vehicles spend more time moving and less time parked. Reducing the vehicle fleet also saves on labour, raw materials and energy used in the construction of vehicles.

Physical activity

An important measure of transport outcomes is the distance people walk as part of their daily travel (km/person/day). Physical activity is integral to good health and walking is the most accessible and universal form of physical activity. Public transport use makes for longer walking distances because people walk to and from public transport stops, rather than driving directly from their origin to their destination. People may also walk directly between origins and destinations rather than using motorised modes such as car and public transport. In this analysis we have excluded walking as an activity in its own right (e.g. walking for exercise, driving to a hiking trail and then walking it) – as this activity would not necessarily change under any of the scenarios examined in this report.

Accessibility

Accessibility is defined as how easily and conveniently people can access their chosen activities. This varies from person to person, with activities spanning work, study, leisure and other commitments. We measure accessibility based on estimates of a person’s ’satisfaction‘ of their day – including how much time they are able to spend at their preferred activities rather than stuck in traffic or on crowded public transport services. The cheaper, quicker and easier a transport option is, the more time spent doing activities and the lower likelihood of being late for important activities like work, the more satisfied the person is and the higher their accessibility is. Accessibility is an important measure because it quantifies how easily people can fulfil their needs, including accessing jobs, education, healthcare, social, shopping and other activities.

4.1.1 What about public transport?

While public transport usage has direct and significant impacts on the four measures of success, it is not included as a measure of success in its own right. The general relationship between public transport usage and the measures of success are discussed in Table 7.

Table 7: The relationship between public transport usage and the measures of success

Measure of success	Relationship with public transport usage
Road congestion	Public transport usage has a **positive impact** on road congestion. This is because the more people that use high capacity public transport services, the fewer drivers there are to generate congestion on the road network. Because of the non-linear nature of traffic congestion, even moving a small percentage of road users to public transport can have a significant beneficial impact on congestion.
The vehicle fleet	Public transport usage has a **mixed impact** on the vehicle fleet. Higher public transport usage makes people less likely to purchase cars, meaning more public transport usage would be expected to have a modest downward impact on the overall fleet size. However, public transport usage also has the effect of making the fleet less utilised, as people are more likely to leave their cars at home, idle.
Physical activity	Public transport usage has a **positive impact** on physical activity. Walking is the most common and accessible form of physical activity for Melburnians, and public transport usage directly leads to more walking, as people walk to and from bus and tram stops and train stations.
Accessibility	Public transport usage has a **positive impact** on accessibility. There are a few main reasons for this. Public transport usage reduces congestion (as described in the first row of this table), which directly improves people's accessibility. In addition, public transport allows people to avoid the inconvenience and cost of parking, especially in inner areas, saving them money and improving their overall satisfaction with their travel options for many people. Finally, public transport provides an alternative option to driving, and for accessibility, more options is always better than fewer options. When public transport provision is insufficient for the level of demand, this causes crowding and delays, which reduces accessibility. More discussion of this is included overleaf.

Source: KPMG Analysis

Crowding on public transport is an important aspect of the performance of the public transport system. Excessive crowding leads to poor accessibility outcomes, and is a marker of insufficient public transport investment.

Of the potential future scenarios described in Section 3, **all scenarios have major projected increases in public transport usage compared to 2015**. This is true in terms of absolute levels of usage, the share of travel that occurs by public transport (mode share) and the levels of crowding. This suggests that we will need to continue to invest heavily in Victoria's public transport system to support Victoria's rapid projected population growth. For more detail about the modelled performance of the public transport system under each of the scenarios, please refer to **Section 10**.

When you're done, you can return here using the Alt-left command.

4.2 We use MABM to assess outcomes against those measures

The MABM provides a number of outputs related to traveller behaviour and the demands on Melbourne's road network. Table 8 summarises some key outputs of the model, and how we use the outputs to assess how well Melbourne's transport system accommodates the needs of its travellers.

Table 8: Model output metrics for measures of success

Measure	Metric	Relationship between metric and measure of success
Road congestion	– Average delay on the roads (seconds/km) – Average network speed (km/h)	Lower average delays and a higher average network speed implies less congestion and a better outcome. As congestion improves, travellers save time and running costs (e.g. fuel or energy costs).
Vehicle fleet	– Size of vehicle fleet – Vehicle utilisation (% of time that a vehicle is in use on average) – Daily travel distance per vehicle (km) – Empty running (km)	The size of the fleet is important because if there are less cars but the same transport task, we get more benefit out of each vehicle. This saves on overhead costs such as parking, depreciation, insurance, registration and servicing. The vehicle utilisation is a measure of how efficiently each car is being used, as opposed to sitting idle and taking up valuable land in parking.
Physical activity	– Daily walking distance for the average person (km/person/day) – Public transport mode share (%)	The more that the average person walks per day, the better Melbourne's transport system is for the physical health of Melbourne. This is largely determined by the share of trips that are taken on public transport, because people walk to and from public transport.
Accessibility	– Accessibility index (overall) – Accessibility by type of traveller – Accessibility by region – Wait time (minutes)	We measure accessibility based on estimates of a person's 'satisfaction' of their transport options. The cheaper, quicker and easier a transport option is, the more satisfied the person is, the more time and money they have to do what they want to do, and therefore the higher their accessibility is.

Other key outputs of the model give us a sense of travel demand and traveller behaviour, as well as transport system performance. This is useful for background and context, as well as for analysing the key influences behind our measures of success. Table 9 summarises some of the key background model outputs.

Table 9: Background model outputs used to analyse potential transport outcomes

Metric type	Metric	Relationship between metric and measures of success
Road	– Total travel distance (km) – Percentage of trips by car	Road network outputs are closely related to congestion. By understanding the total distance that our travellers are undertaking by road, as well as the share of travel undertaken by car, we can understand how travel behaviours are affecting Melbourne's road network. This is particularly important for congestion.
Public transport	– Train station entries – Tram boardings – Bus boardings – Public transport crowding (patronage as a percentage of load standard during the morning peak)[18]	Public transport demand is closely related to congestion outcomes. The more we use public transport, the fewer cars we need on the road on any given day. Increased use of public transport also encourages walking. By enabling ancillary physical activity, it helps contribute to better health outcomes. All else being equal, more and better public transport options has a positive impact on all four of the measures of success. Public transport crowding is an important measure of the required public transport investment for the future.

→ A summary of outcomes for all scenarios can be found in **Appendix A**. When you're done, you can return here using the Alt-left command.

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[18] Crowding statistics are presented as the number of passengers as a percentage of the 'load standard' of inbound trains during the morning peak. The load standard is defined as the desired maximum capacity of a train service, based on Public Transport Victoria guidance. The maximum number of people that can physically fit on a train is known as the 'crush load', and is higher than the load standard. Rail vehicle load standards are defined as 85% utilisation of the seated capacity of the vehicle plus an average of four passengers per square metre over 90% of the usable standing area. Rail loading to capacity ratios greater than 100% indicate heavy crowding and difficulty boarding or alighting from services, causing significant levels of passenger discomfort. Rail loads above the crush load make passengers unable to board services.

5 What are the potential outcomes?

This section describes the potential outcomes of each vehicle technology scenario for 2046. The Dead end scenario, which assumes that no new vehicle technologies are introduced, is used as a benchmark case against which other scenarios can be compared. There are many variants of some of the main scenarios, but this section provides an outline of the key results and outcomes for the main version of each scenario. Table 10 provides an overview of the results for each scenario compared to the Dead end scenario.

Table 10: Scenario outcomes

🔴	⭕	-	○	🟢
Much worse	Slightly worse	Similar	Slightly better	Much better

Scenario	Comments	Road congestion	Fleet	Physical Activity	Accessibility
Dead end	Population growth increases travel demand	-	-	-	-
Private drive	Private AVs increase accessibility but reduce public transport and walking.	○	-	⭕	🟢
Hydrogen highway	Similar outcome to Private drive, but vehicles are slightly more expensive to run, so more people use public transport, reducing congestion relative to Private drive.	○	-	⭕	🟢
Electric avenue	Congestion worsens as cars become cheaper to run.	⭕	-	-	○
Fleet street	On-demand AVs lead to fewer cars and almost eliminate road congestion as people look to avoid on-demand AV fares by using public transport instead.	🟢	🟢	🟢	🔴
High speed	The impacts of Fleet street are realised earlier, in 2031 rather than 2046.	🟢	🟢	🟢	🔴
Slow lane	The impacts of on-demand AVs are diluted when CDVs are also on the roads.	○	🟢	○	⭕
Mix of scenarios	Mix of private AVs, private CDVs and on-demand AVs creates results between Fleet street and Private drive for most metrics.	🟢	○	○	-

Source: MABM & KPMG Analysis

Many of the key scenarios listed in Table 10 have several variants in order to test assumptions and the effects of key policy and behavioural changes in response to new vehicle technologies. Scenarios with no additional variants (Hydrogen highway, Electric avenue and High speed) can be compared against the Dead end scenario in Section 5.2.1.

5.1 A closer look at business as usual for Melbourne's future

Melbourne's population is projected to be 65% larger in 2046 than 2015

According to Victoria in Future 2015 projections, there will be 65% more people in Melbourne in 2046 compared to 2015. This means more demand for travel, and potentially significant impacts on Melbourne's transport system.

We assume that our transport networks will be significantly expanded

Increases in road capacity are expected to partially accommodate the extra demand for transport. Assumed road network improvements include the Outer Metropolitan Ring Road, the North East Link, the West Gate Tunnel, the East-West Link (Eastern section) and additional lanes for the M80, Monash Freeway and Calder Freeway.

Higher mode share for public transport (19% of motorised trips in 2046 compared to 10% in 2015) is also projected to mitigate road congestion. Assumed public transport improvements to accommodate this higher take up include the Melbourne Metro Rail Tunnel, the Mernda Line extension, Melton electrification, Wallan electrification, Wyndham Vale extension, Doncaster Bus Rapid Transit, Melbourne Airport Rail Link, Rowville Rail extension, Clyde Rail extension and Melbourne Metro 2.

But Melbourne's traffic is still projected to grow, mostly in outer areas

Car and truck traffic, measured by kilometres travelled, is projected to increase by 62% in outer suburban areas, driven by urban expansion and outer suburban road investments. This contrasts with traffic increases of 36% in middle suburbs and 11% in inner suburbs, where there are fewer opportunities to increase road capacity due to physical constraints.

We'll move slower in peak periods but faster in off-peak periods

Travel demand is projected to increase between 2015 and 2046 across the day. However, road based travel is projected to increase more during non-peak periods (46%) than during peak periods (41%). This is largely due to travel in inner areas, where growth in road capacity is constrained, but where major increases in public transport capacity are planned. In contrast, travel during non-peak periods is less focused on the CBD and inner areas, and consists of more cross-town travel, where there is projected to be major increases in road capacity. As a consequence, the average travel speeds during the peak periods are projected to decrease by 4%, while the average speeds during the non-peak periods are projected to increase by 4%.

Without new technology, we hit a Dead end

Under the Dead end scenario, no new transport technologies are introduced between 2015 and 2046. A more detailed account of the business as usual 2046 future is available in a separate report[19].

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[19] KPMG (2018), *2046 Reference Scenario and AZEVIA Model Development Report*.

5.1.1 Key results: Business as usual for Melbourne's transport future

Scenario assumptions

The Dead end scenario has the assumption that no new vehicle technologies (such as AVs, electric vehicles or hydrogen vehicles) are in use by 2046 in Melbourne. These scenarios show the projections of Melbourne's travel demand and road network performance over time, with the same underlying assumptions as the Dead end scenario.

- Scenarios show the results of "business as usual" projections, meaning no new technologies are introduced.
- All scenarios use population and employment projections from Victoria in Future 2015.
- All cars in these scenarios are private CDVs. Taxis are included in the model, but are not considered as an option for most day-to-day travel.

Scenarios

2015
Base case

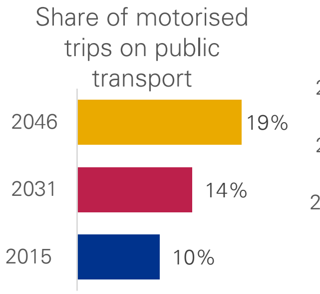
2031
Base case

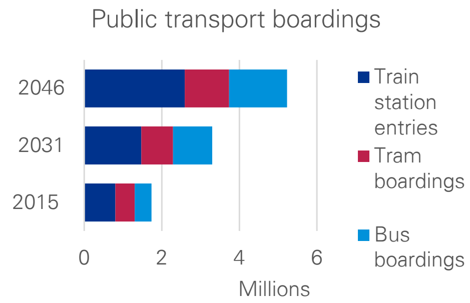
2046
Dead end

Travel demand by mode

Melbourne travellers are projected to make a higher portion of their trips on public transport over time.

In particular, train use is projected to increase over time.

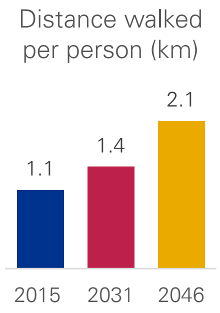

Share of motorised trips on public transport

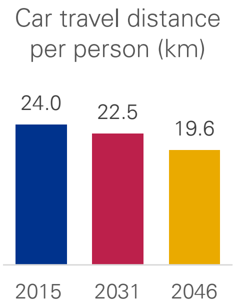

Public transport boardings

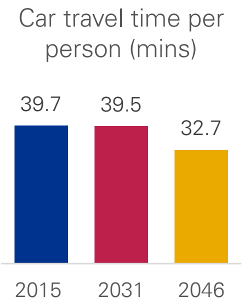
Travel distance and time

Walking distance is expected to increase over time, to almost double in 2046 compared to 2015 due to more public transport usage.

However, average travel distance is projected to decline over time as the city becomes denser.


Distance walked per person (km)

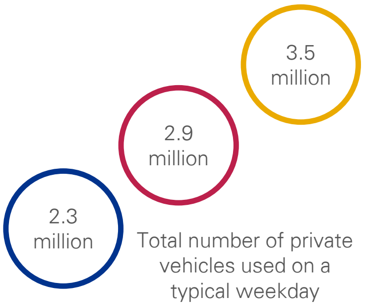

Car travel distance per person (km)


Car travel time per person (mins)

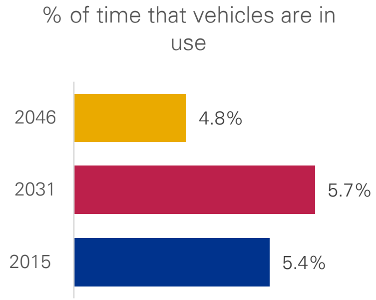
Vehicle fleet

The vehicle fleet is projected to rise by 52.5% between 2015 and 2046 due to population growth.

The average car is expected to spend less time on the roads in 2046 than other time periods. However, cars are projected to mostly sit idle.

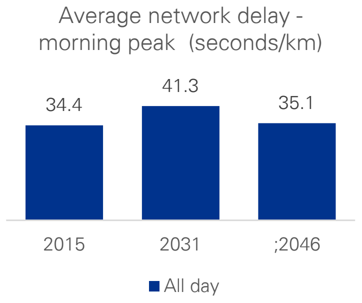


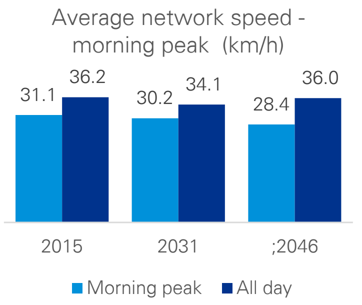
Total number of private vehicles used on a typical weekday


% of time that vehicles are in use

Road network

Congestion is projected to reach its worst point in 2031, before assumed road capacity improvements ease the strain on Melbourne's road network by 2046. However, morning peak congestion is projected to worsen over time.


Average network delay - morning peak (seconds/km)


Average network speed - morning peak (km/h)

5.2 If no new technologies are introduced, we hit a Dead end

Under the Dead end scenario, no new transport technologies are introduced between 2015 and 2046.

Congestion doesn’t get much worse on average, but delays in the morning peak are projected to get 24% worse

A typical weekday in the 2046 Dead end scenario is projected to have similar average congestion as 2015 (with only 1-2% longer delays). However, the average morning peak driver would bear the brunt of population growth. For every kilometre driven, the delay of a morning peak driver would be 24% longer in 2046 than 2015 (not the total driving time). The average speed of cars across the network would be 8% lower than in 2015 during the morning peak. Crowding on public transport is also projected to significantly worsen, despite major increases in capacity between 2015 and 2046. During the morning peak period, congestion on rail services entering the CBD is projected to grow from 86% to 96% between 2015 and 2046[20].

The vehicle fleet expands almost 1:1 with population but spends over 95% of the time idle

Melbourne’s daily vehicle use is projected to rise almost 1:1 with population growth, with projected growth of 52% between 2015 and 2046. Private vehicles in 2046 are projected to spend even less time being used on average than private vehicles in 2015, with an average time in use of 4.8% of the day. This low utilisation rate creates inefficiencies in terms of the costs of buying, maintaining, storing and using vehicles.

The average walking distance per person per day rises by one km

Due to the projected increase in average land use density across Melbourne between 2015 and 2046, as well as the increase in public transport use, the average person is expected to walk more as part of their travel. Melbourne travellers are projected to walk 15.3 million km in 2046, tripling the total from 2015. This translates to an 88% increase in walking per person, from 1.1 km per person per day to 2.1 km – a positive given the significant health challenges anticipated due to the increasingly sedentary lifestyles of many Melbourne residents.

The Dead end scenario is the benchmark for accessibility

The less time and money a travel option takes, the higher its accessibility score. A higher score means that people can do what they want more easily, conveniently and cheaply, having better access to opportunities they want to access and improve their circumstances and personal wellbeing. For the purpose of this study, the accessibility for the 2046 Dead end scenario is indexed at 100 and all other scenarios are then compared to this baseline result.

➡ For more information on accessibility and our method for calculating it, please go to Appendix B. When you’re done, you can return here using the Alt-left command.

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[20] Please refer to Section 8.3for more information on how public transport crowding is measured.

5.2.1 Key results: Dead end versus other scenarios

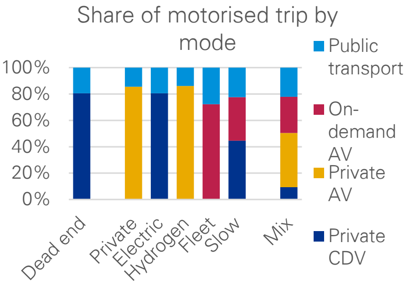
Scenario assumptions

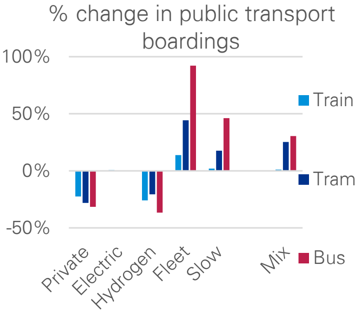
- Dead end and Electric avenue do not include AVs. In Dead end, vehicles are powered by fossil fuels, whereas in Electric avenue, vehicles are powered by electricity.
- Private drive and Hydrogen highway include AVs, which are all privately owned. In Private drive, AVs are electric and in Hydrogen highway, they are powered by hydrogen fuel cells.
- Fleet street includes AVs that perform customer trips on demand (not privately owned).
- In Slow lane, half the population has the option of using on-demand electric AVs and half the population use people-driven cars powered by fossil fuels. In the Mix of scenarios, private CDVs, private Avs and on-demand Avs co-exist.
- In all scenarios, AVs are 75% more efficient on roads than CDVs due to platooning, mode shares are estimated by MABM, and private AVs can perform empty runs (i.e. trips without passengers)

Travel demand by mode

In Fleet street, travellers do not have the option of a private vehicle, so they are more likely to use public transport.

Scenarios with private AVs have the lowest public transport use.

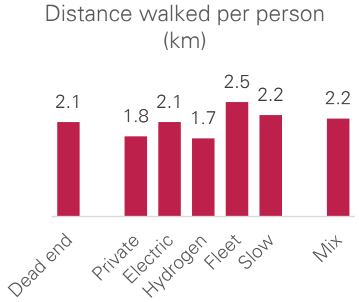


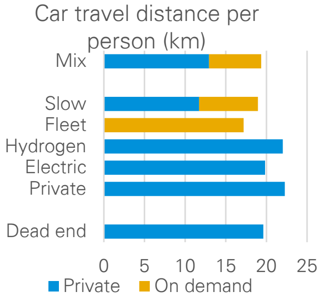


Travel distance

Scenarios with more public transport use have higher walking distances, because travellers walk to and from public transport stops.

Total travel distance by car is highest in private AV scenarios.

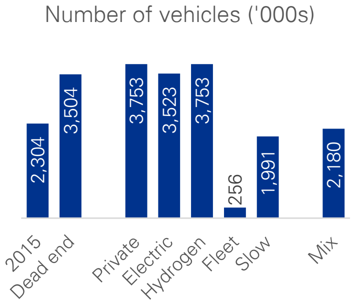


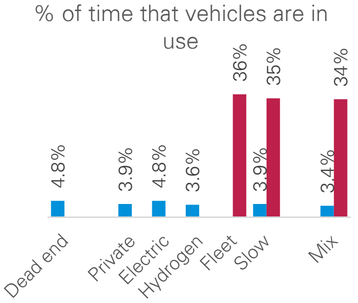


Vehicle fleet

Vehicles are highly utilised in the Fleet street scenario, due to a smaller fleet shared between many travellers.

When Melburnians use on-demand AVs for day-to-day travel, far fewer vehicles are required to service the road task.

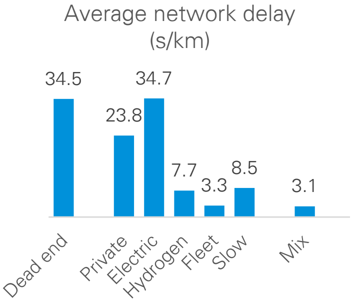


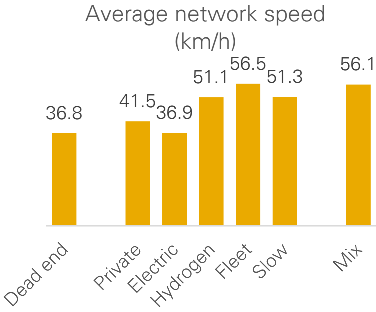


Road network

Congestion is dramatically reduced with the introduction of new technologies, except electric vehicles.

Reductions in delay and increases in speed are caused primarily by 'platooning' of AVs and mode shift to public transport.





5.2.2 Beneficiaries

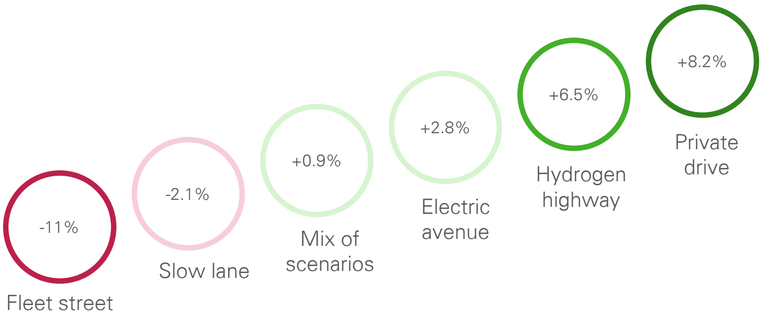
Scenario accessibility by user profile

- Dead end is the reference case for accessibility – meaning that the other scenarios are compared against it.
- The following charts show the changes between Dead end accessibility, and the accessibility scores of the main scenarios, for different groups of people.
- Accessibility scores are based on factors such as the time it takes for travellers to reach their destinations, the cost of travel, the comfort of travel, the likelihood of reaching their activities on time and the amount of time that travellers have to conduct activities away from home.

Overall accessibility

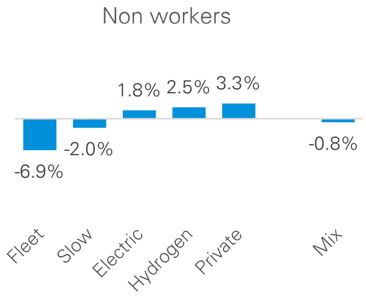
Private drive has the highest improvement in Accessibility, as congestion is relatively low and people have their own, comfortable AVs.

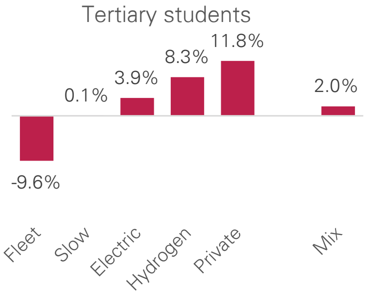
Scenarios with on-demand AVs have the worst accessibility scores due to wait times and fares for on-demand AVs.



Workers and non workers

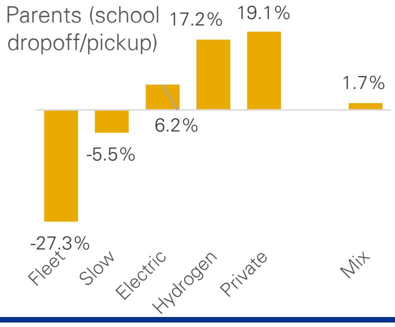
Worker accessibility is more significantly affected by different AV scenarios than non worker accessibility, as they travel the most and furthest.

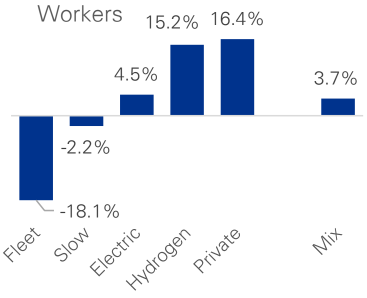




Parents and students

Parents are also affected strongly by different AV scenarios – this is because they are often workers, they travel the most frequently and are most likely to live in middle and outer suburbs.

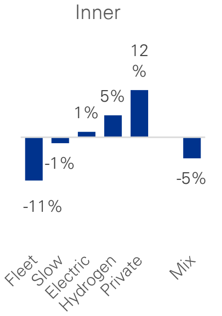


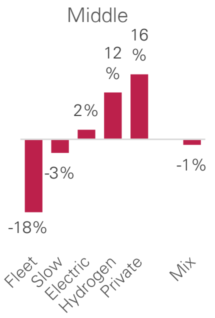


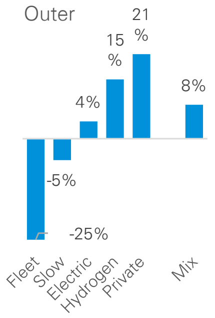
By region

The inner areas are less impacted by change than middle and outer areas.

This is because inner areas have more disposable income, more alternatives to car available (public transport, walking and cycling) and lower wait times in on-demand AV scenarios.







5.3 Electric avenue: zero emissions technology without automation

Congestion	Vehicle fleet	Physical activity	Accessibility
○	-	-	○

What is Electric avenue?

The Electric avenue scenario assumes that all private vehicles are replaced by electric vehicles. Because electric vehicles are cheaper to run than traditional ICE cars (based on the assumed price difference of electricity and petrol), cars in the Electric avenue scenario operate with substantially lower operating costs than existing private vehicles.

Operating costs fall but congestion remains

There are projected to be slight increases in speeds and slight reductions in congestion as lower operating costs incentivise vehicles to travel longer distances to avoid slow parts of the network. There is projected to be a very minor shift in travel towards public transport compared to the Dead end scenario.

The vehicle fleet is unchanged from Dead end at around 3.5 million

The Electric avenue scenario is projected to have no material impact on the vehicle fleet size or utilisation rate, compared to the Dead end scenario.

Accessibility is a little better with cheaper electric vehicles

Due to the reduction in vehicle operating costs, the Electric avenue scenario is projected to produce increases in overall accessibility compared to the Dead end scenario of 2.8%, with increases of accessibility of 4.3% for workers and 1.8% for non-workers. These lower costs slightly improve the satisfaction people have with their travel options.

No significant geographic or peak time effects

The Electric avenue scenario did not show any significant change from the Dead end scenario with respect to the geographic or peak time traffic impacts. There is projected to be a slight decrease in average travel speeds of 3% in the inner suburbs and a projected increase in speeds of 2% for outer suburbs.

➡ Volume capacity ratios for the Electric avenue scenario can be found at the following links in Appendix D for the morning peak (**page D.5**) and afternoon peak (**page D.36**).
You can also compare Electric avenue with Dead end at the following links: accessibility (**page C.4**), morning peak flow (**page E.4**), afternoon peak flow (**page E.34**), morning peak speed (**page F.4**) and afternoon peak speed (**page F.34**). When you're done, you can return using the Alt-left command.

6 What if we own private automated cars?

This Section provides an overview of the potential effects of new technologies in scenarios in which people continue to own private vehicles. Table 11 summarises the outcomes from the main scenarios outlined in this Section relative to Dead end.

Table 11: Private vehicle scenario outcomes

🔴	⭕	-	○	🟢
Much worse	Slightly worse	Similar	Slightly better	Much better

	Comments	Road congestion	Fleet	Physical Activity	Accessibility
Private drive	Private AVs increase accessibility but reduce public transport and walking.	○	-	⭕	🟢
Hydrogen highway	Outcomes are similar to the Private drive scenario.	○	-	⭕	🟢

A number of variants of private AV scenarios were tested to explore the assumptions which underpin the outcomes. Table 12 summarises the variants of private AV scenarios.

Table 12: Private drive scenario variants

Variant	Description
Low flow	'Platooning'[21] means that AVs flow 25% more efficiently than CDVs, rather than 75% more efficiently in the main Private drive scenario.
Low MUTT	AV users are more willing to accept longer travel times, due to the increased comfort and convenience of AV travel.
No empty running	Private AVs are barred from making trips with no passengers.
No mode shift	Everyone travels the same way as the Dead end scenario. This is to demonstrate the effects of private automated vehicle technology on network performance, before taking into account the impacts of induced demand.
Extending AVs to all passengers	Rather than restricting private AV use to licensed drivers, all travellers can be AV passengers, including children and unlicensed adults.
Area-based charge	Private AVs are charged a fee to drive on roads in the inner city.
Distance charge	Private AVs pay a distance-based road price of 12.6 c/km.
Freight at night	Half of freight vehicles travel at night, between 7pm and 7am.

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[21] Platooning is the ability of AVs to drive with short distances between cars via electronic coupling.

6.1 Private drive

Congestion	Vehicle fleet	Physical activity	Accessibility
○	-	○	●

What is Private drive?

The Private drive scenario assumes that private AVs replace private CDVs. AVs are not restricted by the limits of human spatial awareness and reaction times. This means that AVs can operate safely with much smaller gaps between vehicles. The ability of AVs to travel in tight groups of vehicles is referred to as platooning. Due to the ability to operate without a human occupant, private AVs also have the ability to return home or another location to avoid paying a parking charge, as long as there is enough time and it is cheaper to do so.

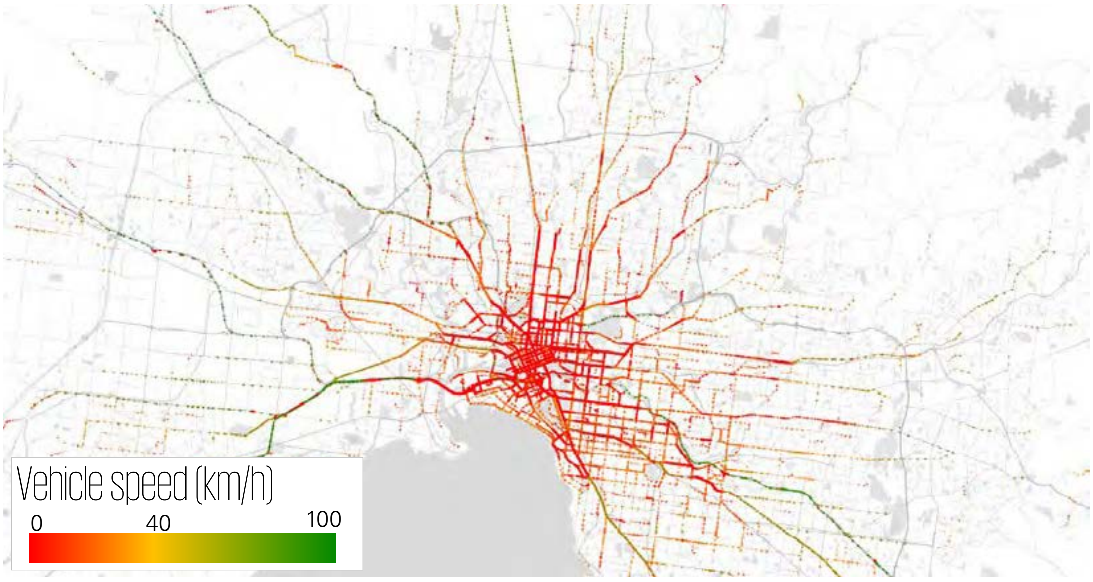
Congestion reduces with platooning but is affected by empty running

In Private drive, road network delays are reduced by 31% on average, compared to the Dead end scenario. Particular improvements in delays occur in the morning peak period, where delays are 36% lower than in the Dead end scenario. The average speed of the network is 13% higher in Private drive throughout the day.

Inner city roads bear the brunt of empty running

Inner city roads tend to be more congested in the Private drive scenario relative to the Dead end scenario. The projected increase in inner area traffic reduces average speeds by 29%. A snapshot of empty vehicles during the morning peak is shown in Figure 1. This contrasts with the increase in average speeds of 31% for middle suburbs and 39% for outer suburbs, which is projected to occur due to the increase in road capacity enabled by vehicle platooning.

Figure 1: Private AVs with no occupants by vehicle speed, 8am



Source: MABM

Lower use of public transport shifts crowding on rail to congestion on roads

The Private drive scenario is characterised by a significant shift away from public transport towards private AVs (19% of motorised trips in Dead end compared with 14% in Private drive). The shift in travel away from public transport reduces the projected crowding on the rail network by 10% compared to the Dead end scenario, from 96% to 86%.

AV popularity increases the vehicle fleet by 8%, but vehicles are even less utilised than in Dead end

The projected increase in the vehicle fleet size compared to the Dead end scenario is 250,000 vehicles, or 8%. There is also a reduction in the utilisation of the vehicle fleet. This is driven by less congestion and shorter travel times – less time travelling means the vehicles spend a greater proportion of the day idle. Vehicles are in use only 3.9% of a typical weekday, compared to 4.8% for the Dead end scenario.

Public transport and walking distance are 15% lower than Dead end

The Private drive scenario has a projected reduction in walking distance per person per day compared to the Dead end scenario (-15%), from 2.1 km to 1.8 km. This is driven by lower usage of public transport.

Accessibility increases as congestion falls, especially in the peak

The introduction of private AVs is projected to lead to an 8% increase in accessibility compared to the Dead end scenario. The increase in accessibility for workers (16%) is projected to be greater than for non-workers (3%), as they travel primarily during peak periods, where much of the congestion reduction benefits are realised.

➡ Volume capacity ratios for the Private drive scenario can be found at the following links in Appendix D for the morning peak (**page D.2**) and afternoon peak (**page D.33**).

You can also compare Private drive with Dead end at the following links: accessibility (**page C.1**), morning peak flow (**page E.1**), afternoon peak flow (**page E.31**), morning peak speed (**page F.1**) and afternoon peak speed (**page F.31**). Similar maps for all of the variants of Private drive can also be found in Appendices **C**, **E** and **F**. You can find an index of all runs and variants in **Appendix A**.

When you're done, you can return using the Alt-left command.

6.1.1 Key results: Private drive scenarios

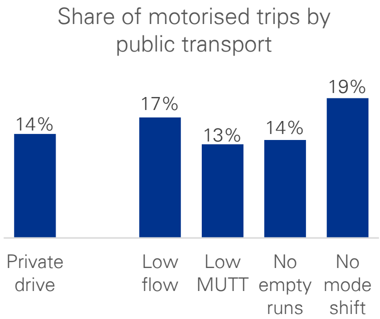
Scenario assumptions

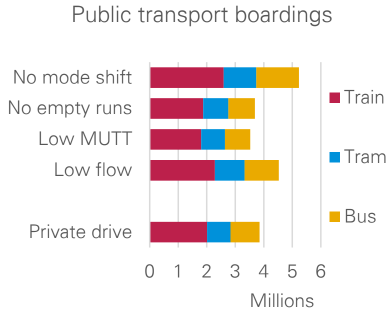
- Private drive includes only AVs which are all privately owned. There are no on-demand AVs or people-driven cars (i.e. CDVs).
- The No empty running model run does not allow people to send their AVs home to avoid parking charges.
- The Low MUTT model run assumes that travellers value time at a lower rate than in the rest of the scenarios due to the increased comfort and convenience of AVs compared to CDVs.
- The Low flow model run assumes that the platooning factor for AVs is 1.25, rather than 1.75 in other scenarios. This means AVs flow only 25% more efficiently than CDVs (due to platooning), rather than 75%.
- The No Mode Shift model assumes that travellers choose the same mode of travel as they would in the Dead end. scenario.

Public transport

Low flow and No mode shift have the highest levels of public transport usage.

All Private drive scenarios have lower public transport usage than the Dead end scenario, at 13-17% of trips.

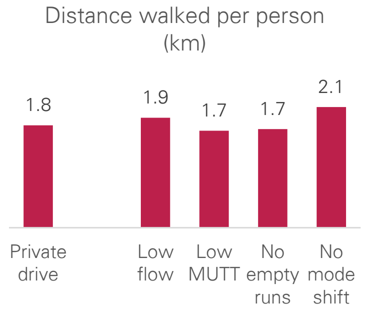

Share of motorised trips by public transport

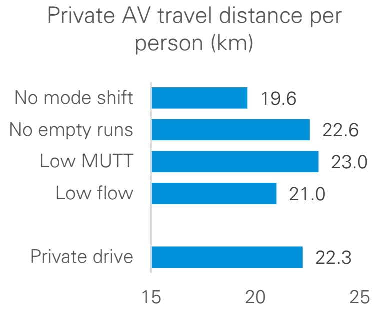

Public transport boardings

Travel distance

Private drive scenarios have a low average distance walked, at 1.7 – 1.9 km per person.

Low flow and Empty running scenarios have higher walking distances due to more public transport usage.

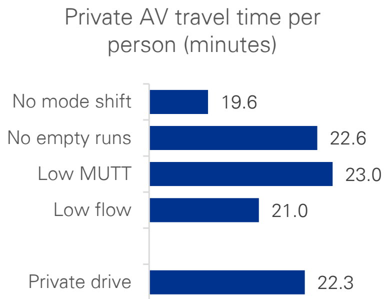

Distance walked per person (km)

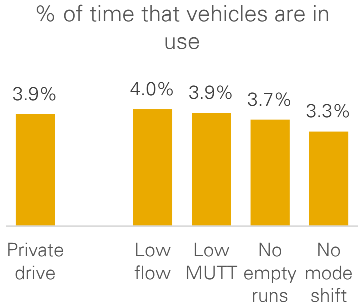

Private AV travel distance per person (km)

AV utilisation

Empty running has the highest travel distance per person due to extra trips where vehicle owners are not in the car.

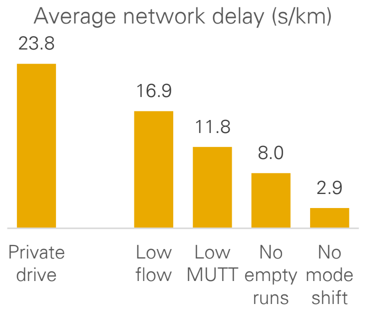
Low flow has the lowest travel distance due to more public transport usage.

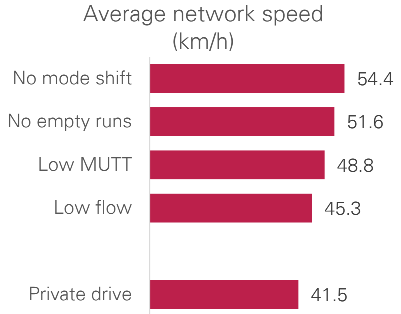

Private AV travel time per person (minutes)


% of time that vehicles are in use

Road network

Average speeds are lowest with Empty running due to the extra congestion from empty trips. Delays are nearly tripled with Empty running.


Average network delay (s/km)


Average network speed (km/h)

6.2 Other variants of Private drive

6.2.1 Extending AV use to all passengers

More cars and kilometres travelled when anyone can “drive” an AV

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion is similar to Private drive without empty running, since this scenario also has no empty running.	Vehicle fleet is 7-8% higher than in Private drive and 15% higher than in Dead end.	Physical activity is the same as in Private drive, no empty running.	Accessibility increases among all groups.

In the main Private drive scenario, only licensed drivers have access to AV travel. Under this scenario, anyone can be the “driver” of an AV, including children, adults without licenses, or adults with disabilities that would otherwise prevent them from being able to operate a vehicle. The scenario assumes that 25% of children aged 5-11, 50% of children aged 12-17, and 75% of adults who do not otherwise have access to a driver license are granted this option. Universal access and social inclusion objectives of the Victorian Government would be furthered if policy allowed these segments of the community to “drive” AVs.

Because more people have access to AV travel as the “driver”, the fleet size and total vehicle kilometres travelled is higher in this scenario compared with Private drive. The additional traffic generates little change in congestion in terms of network speed or delay, which both increase less than 1% compared to Private drive without empty running. Despite the opportunity that AVs present to those who previously did not have the ability to drive, the overall effect on the population is minimal. However, this scenario assumes that people’s daily plans do not change as a result of their ability to drive. In practice, trip rates for these segments of the population may increase due to improved mobility.

6.2.2 Area-based charge in the inner city

An area-based charge in the inner city increases public transport use and reduces delays

Congestion	Vehicle fleet	Physical activity	Accessibility
Delays in the morning peak are reduced, as empty running is mitigated.	Charging a fee to enter the inner city does not significantly affect the vehicle fleet.	Physical activity is similar.	Accessibility is similar in aggregate, but is redistributed.

Under this scenario, private drivers must pay a charge of $2.50 to drive in the inner city, with an additional $2.50 charge applied during peak times (7am-9am and 3pm and 6pm). The charge disincentives people from making private AV trips into the inner city, which has a positive effect on congestion. As a result, average network speed rises by 2 km per hour compared to Private drive, and average delay falls by 5 seconds per km. Although tolls and charges tend to negatively impact some individuals’ accessibility, the aggregate effect is negligible. This suggests that an area-based charge may be an effective way to mitigate the congestion caused by empty running.

What’s the evidence? The area-based road pricing scenario has negligible impact on accessibility for all measured demographic groups and residential locations. You can find a map of the accessibility change between this scenario and Private Drive on **page C.10**. When you’re done you can return here using the Alt-left command.

6.2.3 Distance-based road pricing

A distance-based road price benefits inner city residents but hurts the outer suburbs

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion improves because people have a disincentive to drive.	The vehicle fleet is similar.	Physical activity is similar.	Accessibility is lower for all types of travellers.

Under this scenario, a distance based charge applies a monetary cost to every kilometre driven. This means that people who drive further are charged more than people who drive shorter distances. In this scenario, a charge of 12.6c per km is applied to all private vehicle trips.

Applying an additional cost to driving reduces the size of the private AV fleet and the number of kilometres driven relative to the Private drive scenario. However, the effects of the charge have a strong geographic component, with the strongest impact in the areas furthest from the city centre. Those who live further from the city generally driver longer distances and are more car dependent than people who live in the inner city. These people are the most negatively impacted by a distance-based charge and try to reduce their car travel in response.

In contrast, people in the inner city enjoy the benefits of less traffic generated from people driving into the city from outer areas. A reduction in congestion in inner areas, combined with a tendency to perform shorter trips, actually leads to a slight increase in car trips overall.

What's the evidence? A distance-based pricing scheme disadvantages people who live further from the city and advantages those who live in inner areas. You can find a plot of the accessibility change between this scenario and Private Drive on **page C.11**, which demonstrates the geographic distribution of beneficiaries in this scenario. When you're done you can return here using the Alt-left command.

6.2.4 Allowing zero emission freight vehicles to travel at night

Moving half of daytime freight to night makes little difference to outcomes when there is little daytime congestion.

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion is similar because Private drive congestion is already low.	The vehicle fleet is similar.	Physical activity is similar.	Accessibility is similar across all traveller types.

Freight vehicles are often subject to curfews which prevent them from operating during the night hours. This is primarily due to the noise that heavy vehicles generate in residential areas. Zero emission freight vehicles may be quieter than today's freight vehicles, and it may become acceptable for them to operate at night.

This scenario tested the impacts of moving freight to night, so that 50% of all freight is moved in the night-time hours (defined as 7pm to 7am) compared to about 20% in the Private drive scenario. This made little different to the accessibility and congestion outcomes due to the small amount of road congestion in the Private drive scenario.

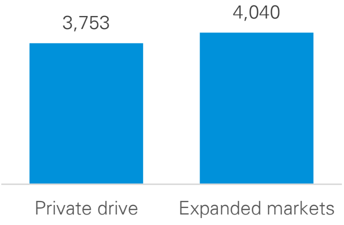
6.2.5 Key results: other variants of Private drive

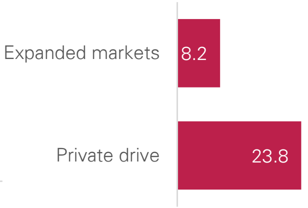
Scenario assumptions

- The following scenarios are variants of Private drive, which take consider non-technology changes to Melbourne's transport system.
- The expanded markets section assumes that children, the elderly, adults with disabilities and other adults with no access to a driver license can "drive" an AV.
- The area based road pricing scenario assumes that entry into an inner cordon (within about 5km of the CBD) attracts a charge to private car travellers of $5 during the peaks (7am-9am and 3pm-6pm) and $2.50 outside the peaks.
- Distance based road pricing assumes that travellers in private cars pay a fee for each kilometre driven in Melbourne.
- The freight to night scenario assumes that regulations on night freight travel are relaxed due to the increased safety, reduced noise and improvement of other factors for automated heavy vehicles.

Expanded markets

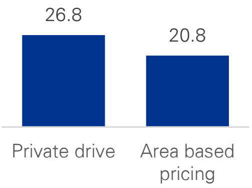
Congestion and fleet size rise slightly while public transport usage falls when there are no restrictions on who can operate an AV.

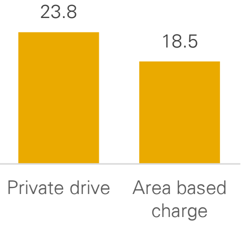

Number of vehicles ('000s)


Average total network delay (s/km)

Area based road pricing

When travellers are charged a fee for entering the inner city, peak time delays in the inner city are reduced.


Average inner city network delay – morning peak (s/km)


Average total network delay (s/km)

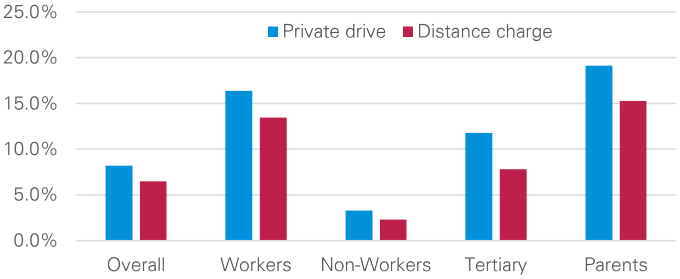
0% change
Overall average accessibility is not affected by adding an area-based charge

Distance based road pricing

Congestion improves because people have a disincentive to drive.

Accessibility is lower across the city. Tertiary students are affected the most due to their lower incomes and long driving distances, followed by Parents and Workers.

Accessibility increase compared to Dead end



Freight to night

Moving half of daytime freight trips to night has little effect on key road network performance metrics.

This is because platooning of AVs means there is little congestion in the Private drive, and only a low proportion of freight is moved during the peaks.

+0.3%
Average network speed

-1.3%
Average delay

6.3 Hydrogen highway

Congestion	Vehicle fleet	Physical activity	Accessibility
○	-	○	●

What is Hydrogen highway?

In the Hydrogen highway scenario, private AVs powered by hydrogen replace traditional cars. Hydrogen powered AVs are assumed to operate at a similar cost to today's cars. Private AVs also have the ability to return home or another location to avoid paying a parking charge. A variant of Hydrogen highway without empty running was also run.

Congestion reduces with platooning

Vehicle platooning is projected to reduce average delay from 35 seconds per kilometre in Dead end to 16 seconds per kilometre in Hydrogen highway. Network wide average speed increases from 37 km/h in Dead end to 45 km/h in Hydrogen highway.

AV popularity increases the fleet by 7% but vehicle utilisation is low

The Hydrogen highway scenario is projected to increase the vehicle fleet size compared to the Dead end scenario as AV use becomes more popular. The average utilisation of vehicles is projected to decrease to just 3.6%, from 4.8% in the Dead end scenario and 5.4% in 2015.

Physical activity reduces by 15% as people forgo public transport

The Hydrogen highway scenario is projected to reduce walking from 2.1 km in the Dead end scenario to just 1.8 km. This is because travellers are using public transport for a smaller proportion of trips, and so do not need to walk as much as part of their daily travel.

Accessibility increases by 6.5% as congestion reduces

Accessibility in the Hydrogen highway scenario is 6.5% higher than in the Dead end scenario because vehicle platooning lowers congestion and improves travel times. Accessibility is 13% higher for workers and 2.3% higher for non-workers.

Empty running creates congestion in inner areas

The Hydrogen highway scenario is projected to include 14% more vehicle kilometres travelled compared to the Dead end scenario. This is due to empty running trips and a lower share of public transport trips (14% compared to 19% for the Dead end scenario). The negative effect of empty running reduces inner area speeds by 12% on average, while speeds in middle and outer suburbs increase by 37-38%.

➡ Volume capacity ratios for the Hydrogen highway scenario can be found at the following links in Appendix D for the morning peak (**page D.6**) and afternoon peak (**page D.37**).

You can also compare Hydrogen highway with Dead end at the following links: accessibility (**page C.5**), morning peak flow (**page E.5**), afternoon peak flow (**page E.35**), morning peak speed (**page F.5**) and afternoon peak speed (**page F.35**). When you're done, you can return using the Alt-left command.

7 What if we use vehicles on demand?

This Section provides an overview of the potential effects of new technologies if all AVs were to operate using a vehicles on-demand model, with no private ownership. Table 13 summarises the outcomes of the main scenarios described in this Section relative to Dead end.

Table 13: Vehicles on demand - scenario outcomes

🔴	⭕	-	○	🟢
Much worse	Slightly worse	Similar	Slightly better	Much better

	Comments	Road congestion	Fleet	Physical Activity	Accessibility
Fleet street	On-demand AVs lead to fewer cars and almost eliminate road congestion as people look to avoid on-demand AV fares by using public transport instead.	🟢	🟢	🟢	🔴
High speed	The impacts of Fleet street are realised earlier, in 2031, not 2046.	🟢	🟢	🟢	🔴

Table 14 summarises the variants of on-demand AV scenarios that were tested to explore the assumptions which underpin the outcomes of the main Fleet street scenario.

Table 14: Fleet street scenario variants

Variant	Description
Low flow	'Platooning'[22] means that AVs flow 25% more efficiently than CDVs, rather than 75% more efficiently in the main Fleet street scenario.
Low MUTT	AV users are more willing to accept longer travel times, due to the increased comfort and convenience of AV travel.
No mode shift	Everyone travels the same way as the Dead end scenario. This is to demonstrate the effects of on-demand AVs on network performance, before taking into account the impacts of induced demand.
Subscription fares for on-demand AVs	On-demand AV users pay a subscription to use the service, reducing the per-trip cost of using a vehicle on demand.
No new (pre-construction) major road projects	No major road projects are built beyond those presently under construction.
Calibrated Fleet street	Fewer fleet vehicles are available to test realistic wait times and service metrics.
DRTs replace buses	Buses are replaced with on-demand carpooling (DRTs). This variant is described in Section 10.

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[22] Platooning is the ability of AVs to drive with short distances between cars via electronic coupling.

7.1 Fleet street

Congestion	Vehicle fleet	Physical activity	Accessibility
🟢	🟢	🟢	🔴

What is Fleet street?

The Fleet street scenario assumes that all private vehicles are replaced with shared automated vehicles, otherwise referred to as on-demand vehicles. On-demand vehicles can platoon, increasing the number of vehicles that can travel on a road link before it becomes congested. Users are charged a fare with a flagfall, time and distance component to use the vehicles on demand, similar to a taxi.

A much smaller fleet, but little change in vehicle kilometres

In the Fleet street scenario, 28% of all motorised trips are taken on public transport, compared to 19% for the Dead end scenario. This significantly eases congestion. However, on-demand AVs run empty between dropping off one passenger and picking up the next – once this is accounted for, the total vehicle kilometres travelled is projected to increase by 0.4% relative to the Dead end scenario. Empty kilometres account for around 13% of all vehicle kilometres undertaken by on-demand AVs in this scenario.

Congestion and peak time delays are almost eliminated, but empty running keeps traffic volumes up

The replacement of private CDVs with on-demand AVs almost eliminates road congestion across the network. Average network delays across the day are reduced by 90%, while morning peak delays are reduced by 93% compared to Dead end. On average, peak time speeds increase by 74% across the network.

Public transport gets crowded when nobody owns a car

The projected shift in travel towards public transport compared to the Dead end scenario increases the projected congestion on the rail network by 1.5%, to 97%. However, it is the bus network that is projected to experience the biggest increase in patronage, with 2.9 million bus boardings per day, almost double the boardings of the Dead end scenario. The main cause of this is the fares of on-demand AVs – people are incentivised to use public transport to avoid these fares.

Lower costs overall, but higher perceived costs for each individual trip

The annual cost of using on-demand AVs for everyday travel is likely to be lower than the annual cost of car ownership[23]. However, much of the cost of private vehicles is 'sunk', and not considered when deciding whether to make each individual trip. The high 'perceived' cost of on-demand AVs could be a barrier to adoption, and could limit the significant benefits available with a shift to shared ownership.

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[23] Refer to Section 4.3 of the separate report KPMG (2018), *Vehicles advice – financial analysis*.

Higher speeds across the network

Average road speeds for the Fleet street scenario are projected to be 54% faster than the Dead end scenario. This is due to vehicle platooning, with increases in speed projected to occur across Melbourne. The biggest gains are projected to be for the inner and middle suburbs (64% and 62% respectively), with average speeds in outer suburbs projected to increase by 43%.

The vehicle fleet collapses from 3.5 million to 260,000

The Fleet street scenario has a major impact on the total number of vehicles required to meet demand. A 93% reduction in the required number of vehicles is projected compared to the Dead end scenario. This is achieved by significantly increasing the utilisation of the vehicles by allowing them to be shared. Under this scenario, each vehicle is being utilised for 36% of the day on average, compared to just 4.8% in the Dead end scenario.

Physical activity increases along with public transport use

The Fleet street scenario is projected to lead to a 21% increase in walking kilometres travelled compared to the Dead end scenario. This increase comprises walking to public transport services as well as walking directly to destinations. This measure excludes walking as an activity in itself (e.g. hiking or leisure walking).

Accessibility declines in outer areas as fares increase travel costs

Due to the increase in travel costs associated with the shared AV fares, the Fleet street scenario is projected to produce decreases in overall accessibility compared to the Dead end scenario of 11%. The decrease in accessibility for workers (-22%) is projected to be greater than for non-workers (-7%), as they are more reliant on the public transport system to access their main activity – travelling furthest on average. The outer suburbs are the most affected by accessibility reductions – and this could be generalised to regional areas of Victoria as well. This is because people in outer and regional areas would need to wait longer for on-demand AVs and pay higher fares due to longer average trip lengths. On-demand AVs are most viable in dense, inner city areas.

➡ Volume capacity ratios for the Fleet street scenario can be found at the following links in Appendix D for the morning peak (**page D.3**) and afternoon peak (**page D.34**).

You can also compare Fleet street with Dead end at the following links: accessibility (**page C.2**), morning peak flow (**page E.2**), afternoon peak flow (**page E.32**), morning peak speed (**page F.2**) and afternoon peak speed (**page F.32**). Similar maps for all of the variants of Private drive can also be found in Appendices **C**, **E** and **F**. You can find an index of all runs and variants in **Appendix A**. When you're done, you can return using the Alt-left command.

7.1.1 Key results: Fleet street scenarios

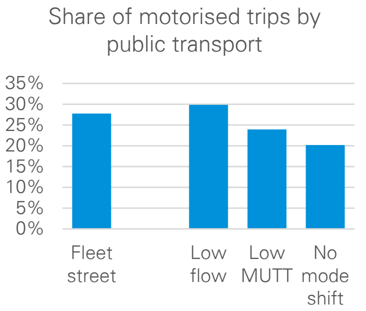
Scenario assumptions

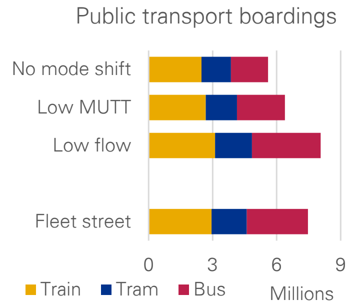
- Fleet street includes AVs, which are all used through an on-demand service model (i.e. not privately owned).
- The Low MUTT run assumes that travellers value time at a lower rate than in the rest of the scenarios due to the increased comfort and convenience of AVs compared to CDVs.
- The Low flow model run assumes that the platooning factor for AVs is 1.25, rather than 1.75 in other scenarios. This means AVs flow only 25% more efficiently than CDVs (due to platooning), rather than 75%.
- The No mode shift model assumes that travellers choose the same mode of travel as they would in the Dead end scenario.

Public transport

When all AVs are on-demand, public transport usage is high. This is because travellers look to avoid on-demand fares.

When on-demand AVs are only 25% more efficient than CDVs, public transport usage is at its highest.

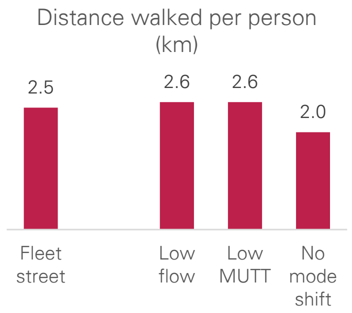

Share of motorised trips by public transport

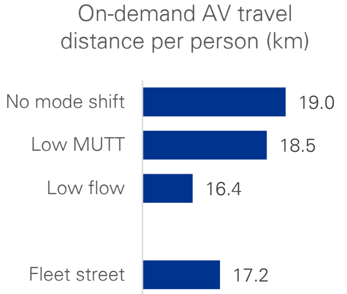

Public transport boardings

Travel distance

Walking distances are high in Fleet street scenarios due to widespread public transport use.

There is less vehicle travel demand when AV flow improvements compared to CDVs are smaller and more when comfort is more important.

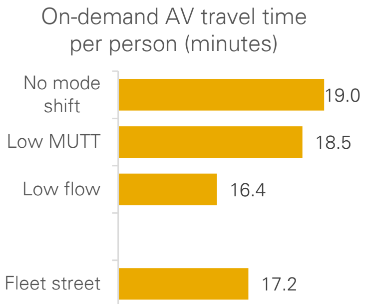

Distance walked per person (km)

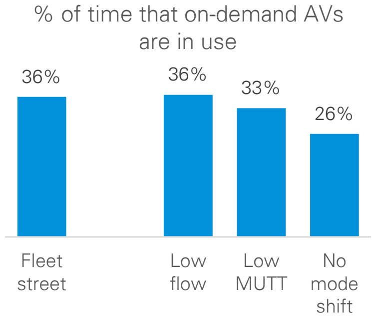

On-demand AV travel distance per person (km)

On-demand AV utilisation

Vehicles are in use approximately half the time when the efficiency of AV is diluted (i.e. Low flow).

Travel time per person improves when more people use public transport, because it reduces congestion.

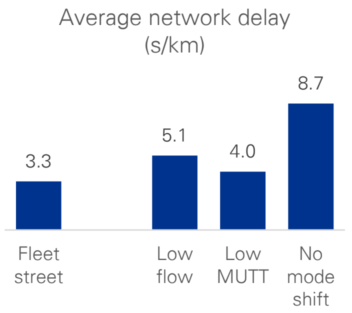

On-demand AV travel time per person (minutes)

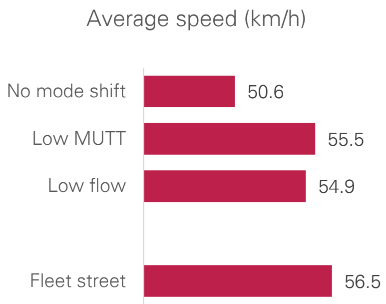

% of time that on-demand AVs are in use

Road network

Congestion is worst in the No mode shift model run because of relatively low public transport use.

Low flow has somewhat higher delays than the default scenario due to the reduced flow improvements of AVs.


Average network delay (s/km)


Average speed (km/h)

7.2 Other variants of Fleet Street

7.2.1 Subscription fares for on-demand AVs

A subscription fare model mitigates the poor accessibility outcomes of Fleet Street

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion is marginally higher compared to Fleet street, as there is more demand for AV travel.	The vehicle fleet is 40% higher than Fleet street, but still 90% lower than Dead end.	Physical activity is lower than in the Fleet street scenario.	Accessibility increases among all groups.

In this scenario, users of on-demand AVs pay a subscription quarterly or annually, and pay only an incremental fare for each trip. This subscription is perceived as a 'sunk' cost. This means that when considering travel options on a particular day, an individual will not take the cost of the subscription into account. This is similar to many of the costs of private vehicle ownership. When choosing whether to make a particular trip by car, an individual might consider the cost of fuel but usually would not usually consider the 'sunk' costs associated with buying, registering and insuring their vehicle. Similarly, in this scenario individuals do perceive the per trip fare, but do not perceive the cost of their subscription.

Each individual trip is only charged at a small incremental fare of 50c per trip and 5c per kilometre. We assume that every person has a subscription. This has a large impact on behaviour since all on demand vehicle trips become less costly compared to the Fleet street scenario. Platooning also means travel times are lower than Dead end. This improves people's satisfaction with their travel options, as they can take advantage of the speed and convenience of on-demand AVs, but do not feel restricted by the high perceived per-trip costs.

➡ **What's the evidence?** Significant accessibility improvements were seen in the subscription fare scenario relative to the Fleet street scenario. These improvements apply to all demographic groups. People in outer areas were the greatest beneficiaries as they tend to travel the longest distances, and therefore benefit the most from the perceived reduction in fares in the Fleet street scenario (see **page C.14**). When you're done, you can return using the Alt-left command.

7.2.2 Calibrated fleet street scenario

The calibrated Fleet street scenario provides realistic estimates of wait times and other on-demand AV behaviour, by limiting the fleet size for vehicles on demand.

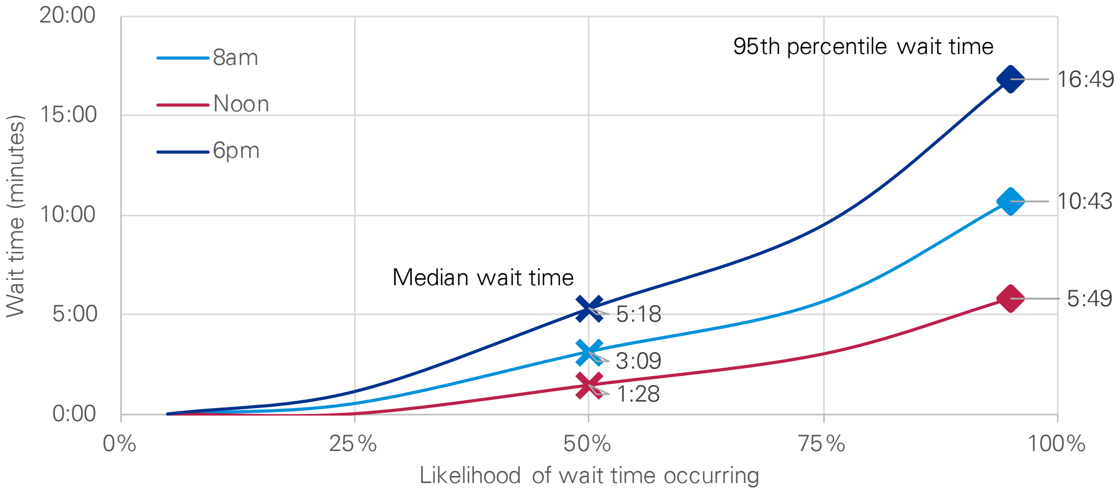
Congestion	Vehicle fleet	Physical activity	Accessibility
Less congestion in the peak period and overall due to higher public transport usage.	This scenario assumes a much smaller fleet of 260,000 on-demand AVs.	Significantly more walking due to high public transport usage (2.8km per person compared to 2.5km in Fleet street).	Slightly lower accessibility overall, with people in outer areas hit worst due to increases in wait times for on-demand AVs.

The main Fleet street scenario required a peak of around 260,000 shared vehicles for Melbourne in 2046 on a typical weekday. The Calibrated fleet street scenario takes the same assumptions as Fleet street, but assumes only 260,000 on-demand AVs exist. This means that the shared fleet is optimised to maximise revenue for operators, as no surplus vehicles exist.

Assuming an efficient fleet size of on-demand AVs allows the model to produce realistic metrics such as wait times for on-demand AVs. The average wait time for an on-demand vehicle in this scenario is 3:26, compared to 2:43 in the Fleet street scenario. This scenario also had a greater percentage of on-demand AV kilometres being run empty, increasing from 13% to 16% across a typical weekday and from 16% to 23% during the morning peak.

Figure 2 summarises the waiting time distribution for on-demand AVs in the Calibrated fleet street scenario. The median wait time across the day is 1 minute 52 seconds. The median wait time is 5 minutes 18 seconds in the afternoon peak, 3 minutes 9 seconds during the morning peak, and 1 minute 28 seconds in the middle of the day. Longer wait times disproportionately affect residents of outer suburbs, where waiting times are more sensitive to fleet size.

Figure 2: Waiting time (minutes) for an on-demand AV – cumulative distribution



Source: MABM

When wait times are longer, public transport becomes more popular as an alternative transport mode. The Calibrated fleet street scenario included more public transport usage relative to Fleet street, with public transport mode share rising from 28% to 32% at the expense of on-demand AVs.

What's the evidence? Waiting times and accessibility for residents of outer suburbs are more sensitive to changes in fleet size than waiting times in the inner city.

When there is a smaller fleet size, the same number of travellers share fewer on-demand AVs. This means wait times rise, and the advantages of on-demand AVs compared to public transport become smaller. As a result, some residents choose to switch to public transport, which partially offsets the rise in waiting time from the smaller fleet size.

Residents of the inner city are more likely to switch to public transport than residents of the outer suburbs when waiting times rise. This is because public transport options are more limited in the outer suburbs, and less immediately available for the average outer suburb resident. Because outer suburb residents do not as readily switch to public transport, the waiting times of on-demand AVs are not offset as much as they are in the inner city.

In essence, waiting times change more in the outer suburbs when the fleet size decreases, because a smaller fleet is servicing a similar amount of trips, whereas in the inner city, the smaller fleet size is servicing a smaller amount of trips. This is demonstrated in the change in accessibility between the Calibrated fleet street and Fleet street scenarios on **page C.19**. When you're done, you can return using the Alt-left command.

7.2.3 No new (pre-construction) major road projects

Less investment in freeways has little effect when all vehicles are on-demand AVs.

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion is marginally higher compared to Fleet street, as there is slightly less road capacity.	Vehicle fleet is the same.	Physical activity is similar.	Accessibility is slightly lower, due to higher average congestion.

This scenario is identical to Fleet street in every way except the road network. In all other scenarios, it is assumed that Melbourne operates on a “business as usual” basis for road investment. However, the reduction in demand for car travel in the Fleet street scenario, combined with the platooning impacts on road capacity, may allow road investment to be reduced. This scenario has no investment in new major road projects beyond those already under construction.

In this scenario, public transport as a proportion of total motorised trips increases slightly from 28% to 30% in the main Fleet street scenario and the average delay increases from 3.3 s/km to 5.8 s/km. Overall, the changes in key metrics such as average delays, network speeds and mode of travel are small. This suggests that if a Fleet street scenario were to eventuate, a lower level of investment in freeways and arterial roads in Melbourne could free up public funds with minimal impact on transport performance.

The above analysis relates to an illustrative scenario for the year 2046 only with 100% take-up of on-demand AVs, and is intended to demonstrate the disparate impacts of alternative scenarios rather than a likely future. The small delay times in the Fleet street scenario are a result of input assumptions relating to infrastructure, land use, AV flow factor and on-demand AV fleet size and fare structure. The scenario does not consider infrastructure requirements for a transition period from CDVs to on-demand AVs. Increasing transport demand during the transition period and/or differences in the flow factor of AVs or other input assumptions may result in the need for new road infrastructure.

Figure 3: Removed roads from assumed Melbourne road network in 2046, for the no new (pre-construction) major road projects scenario

7.2.4 Key results: Other variants of Fleet street

Scenario assumptions

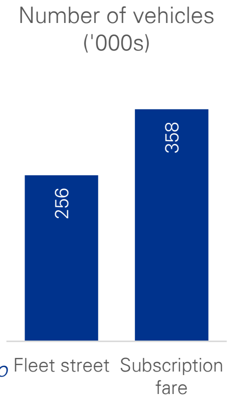
- The following scenarios are variations of Fleet street, which take into account non-technology changes to Melbourne's transport system.
- The Subscription fares scenario assumes that on-demand AV travel operates under a subscription model, where users pay an annual or quarterly fee, and then pay a small fee per trip. This encourages travellers to use on-demand AV travel, because once they are subscribed, the cost to take an on-demand AV trip is very low.
- The Calibrated fleet street scenario assumes that a more realistic fleet size is available, which allows for the modelling of realistic waiting times for on-demand AVs.
- The no new (pre-construction) major road projects scenario assumes that no new major road projects go ahead between now and 2046, limiting the available roads for cars to use in 2046 compared to other scenarios.

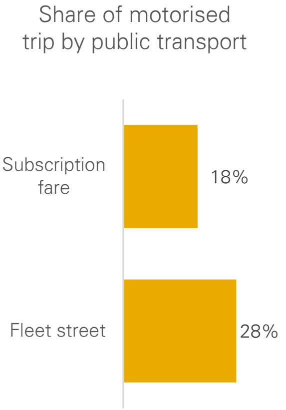
Subscription fares

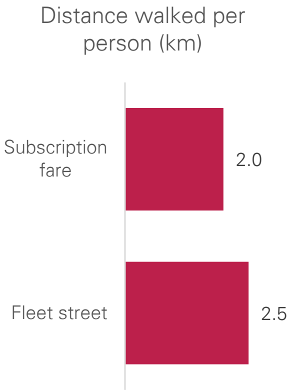
Public transport usage is lower because subscription models encourage on-demand AV use.

Higher on-demand AV use leads to a larger fleet of vehicles.

Less walking occurs when people switch from public transport to more on-demand AVs







Calibrated vehicle fleet

Wait times are longer when the number of on-demand AVs is more realistic

More travellers use public transport when wait times for on-demand AVs are longer.

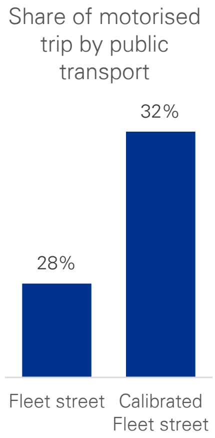
Congestion slightly improves when more people use public transport and less use AVs.

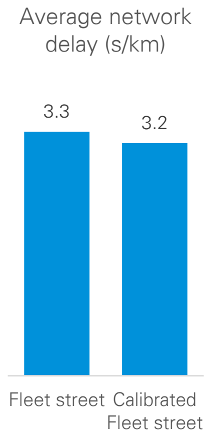
5m 18s

Afternoon peak hour wait time

1m 52s

Daily median wait time

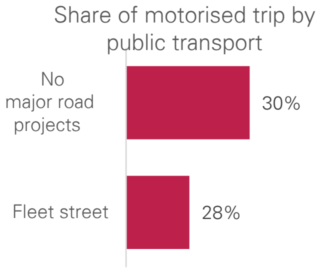


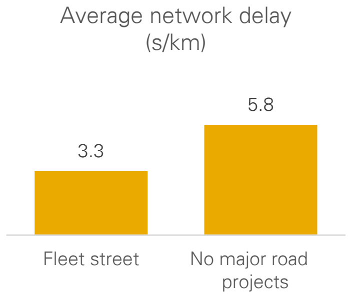


No new (pre-construction) major road projects

The fewer available roads in 2046 has la slight impact on congestion when on-demand AVs are used.

Public transport usage rises slightly as people attempt to avoid slightly higher congestion





7.3 High speed

Congestion	Vehicle fleet	Physical activity	Accessibility
🟢	🟢	🟢	🔴

What is High speed?

The High speed scenario assumes that there is accelerated adoption of AV technologies so that by the year 2031 all private vehicles are replaced with on-demand AVs. That is, the High speed scenario assumes that the Fleet street scenario occurs 15 years earlier[24].

Higher public transport use reduces peak time congestion

Compared to the 2031 base case (or Dead end in 2031), the High speed scenario has a significantly higher share of public transport trips, with 20% of all motorised trips taken on public transport, compared to 14% for the Dead end scenario in 2031. This eases congestion at peak time.

Fewer cars, but empty running keeps total travel distance the same

When empty running is accounted for, the total vehicle kilometres travelled in the High speed scenario is projected to be 0.6% higher than the Dead end scenario for 2031.

The vehicle fleet collapses from 2.9 million to 210,000

The High speed scenario has a major impact on the total number of vehicles required to meet demand. A 93% reduction in the required number of vehicles is projected compared to the Dead end scenario in 2031. This is the same reduction between the Fleet street and Dead end scenarios in 2046.

Physical activity increases to 1.7 km per person with public transport use

The High speed scenario is projected to lead to a 21% increase in walking distance compared to the 2031 Dead end scenario.

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[24] While all of the 2046 AV scenarios were modelled using the MABM, the 2031 High speed scenario was not directly modelled with the MABM. Rather, the MABM 2046 scenario results were used to infer outcomes for a 2031 High speed scenario by applying the same proportional changes projected for the 2046 Fleet street scenario to 2031 as were modelled with the Dead end scenario and the 2031 Base case.

8 What if different technologies co-exist?

This Section explores scenarios that combine some of the scenarios described in previous sections. Table 15 summarises the outcomes of the main scenarios described in this Section relative to Dead end. Table 16 describes the scenario variants for Slow lane.

Table 15: Vehicles on demand - scenario outcomes

🔴	⭕	-	○	●
Much worse	Slightly worse	Similar	Slightly better	Much better

	Comments	Road congestion	Fleet	Physical Activity	Accessibility
Slow lane	The impacts of on-demand AVs are diluted when CDVs are also on the roads.	○	●	○	⭕
Slow lane with private AVs	The impacts of private AVs are diluted when CDVs are also on the roads.	○	-	⭕	○
Mix of scenarios	Congestion is reduced, particularly in the inner city, and other benefits are also realised.	●	○	○	-

Table 16: Slow lane scenario variants

Variant	Description
Low flow	'Platooning'[25] means that AVs flow 25% more efficiently than CDVs, rather than 75% more efficiently in the main Private drive scenario.
Low MUTT	AV users are more willing to accept longer travel times, due to the increased comfort and convenience of AV travel.
No mode shift	Everyone travels the same way as they would in Dead end. This is to demonstrate the network performance impacts before taking into account the impacts of induced demand.
Slow lane with private AVs	All vehicles are privately owned, but half the population has access to an AV and half have access to a CDV

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[25] Platooning is the ability of AVs to drive with short distances between cars via electronic coupling.

8.1 Slow lane

Congestion	Vehicle fleet	Physical activity	Accessibility
○	●	○	○

What is Slow lane?

The Slow lane scenario assumes that half of all private CDVs are replaced by on-demand AVs[26]. On-demand AVs can platoon while travelling, increasing the efficiency of cars on the roads. However, this ability is somewhat reduced by the presence of regular private cars. On-demand AV users are charged a fare to use the vehicle, while private car users have no fare, but instead experience the usual car vehicle operating costs which are much lower than the on-demand AV fares.

Congestion dramatically reduces, especially in the morning peak

The Slow lane scenario has significantly less road congestion than the Dead end scenario. Average speeds are projected to increase by 39% across the day (66% during the morning peak), while average delays are projected to decrease by 75% compared to the Dead end scenario. The network congestion improvements occur across the network, with similar effects in inner and outer Melbourne. The Slow lane scenario is projected to have slightly higher public transport usage than the Dead end scenario (22% of motorised trips compared to 19% in the Dead end scenario), including 46% more bus boardings.

The vehicle fleet falls from 3.5 million in Dead end to 2.0 million

The Slow lane scenario reduces the total number of vehicles required to meet demand as half of the population opt to use shared AVs. A 43% reduction in the required number of vehicles is projected compared to the Dead end scenario. This is achieved by the AVs having a much higher utilisation (35%) than the private cars (3.9%).

Physical activity increases from 2.1 km in Dead end to 2.2 km in Slow lane, as public transport demand rises

The Slow lane scenario is projected to lead to a 7-8% increase in walking distance per person compared to the Dead end scenario. This is driven by an increase in public transport usage.

Accessibility increases by 2.1% overall

The Slow lane scenario is projected to produce decreases in overall accessibility compared to the Dead end scenario of 2.1%, with similar effects on workers and non-workers. This is because, even though the overall cost of using vehicles is lower, perceived costs of on-demand AV trips are higher because the full cost of the AV (including registration, insurance, electricity and other fees) is built into the individual trip fee. This is not the case for private vehicles.

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[26] Vehicles are randomly located throughout Melbourne at the beginning of the day. The vehicles quickly relocate to service demand, so the initial starting point of the vehicles does not significantly impact on outcomes.

➡ Volume capacity ratios for the Slow lane scenario can be found at the following links in Appendix D for the morning peak (page D.4) and afternoon peak (page D.35).
You can also compare Slow lane with Dead end at the following links: accessibility (page C.3), morning peak flow (page E.3), afternoon peak flow (page E.33), morning peak speed (page F.3) and afternoon peak speed (page F.33). When you're done, you can return using the Alt-left command.

8.1.1 Key results: Slow lane scenarios

Scenario assumptions

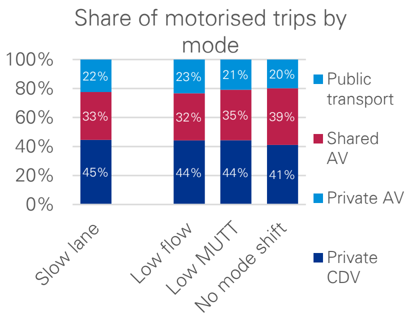
In the Slow lane Scenario, half the population relies solely on a fleet of on-demand AVs and does not own cars. The other half of the population has access to private (ICE) car ownership. Slow lane includes a fleet of on-demand AVs which are used through an on-demand model (i.e. not privately owned) by half of the population. The remainder use traditional (ICE) cars, which are all CDVs (i.e. driven by people).

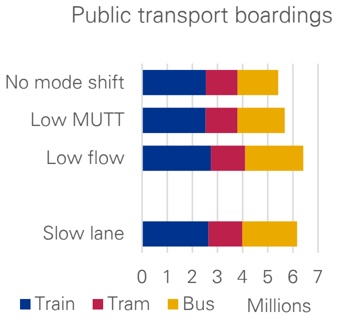
- The Low MUTT run assumes that travellers value time at a lower rate than in the rest of the scenarios.
- The Low flow model run assumes that the platooning factor for AVs is 1.25, rather than 1.75 in other scenarios. This means AVs flow only 25% more efficiently than CDVs (due to platooning), rather than 75%.
- The No mode shift model assumes that travellers choose the same mode of travel as they would in the Dead end scenario.

Travel demand by mode

A lower marginal utility of time in AVs decreases the popularity of public transport in Slow lane.

Public transport usage is highest when the improvement of AVs compared to CDVs is lower.

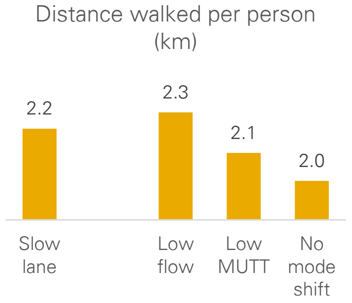


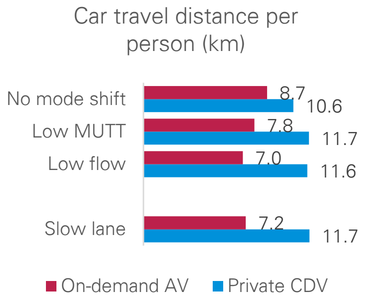


Travel distance

Travellers in the Slow lane scenarios walk between 2.0 and 2.3 km per day on average.

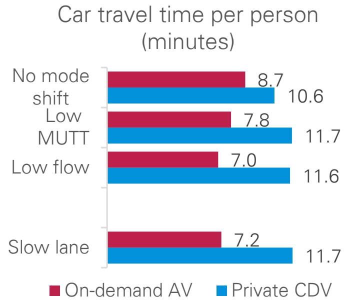
The Low flow model run has more congestion, which disincentivises travel and reduces travel distance per person.

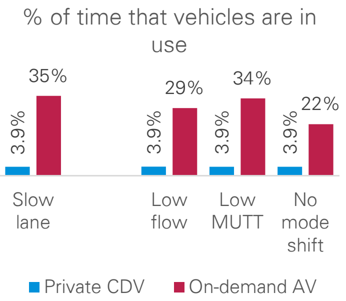




Vehicle utilisation

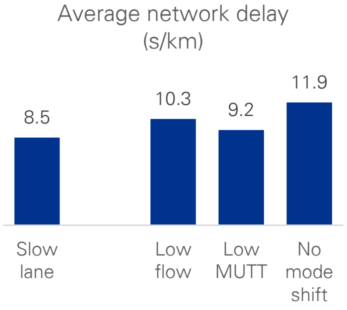
Vehicle utilisation is highest in the No mode shift run, because there is no shift towards public transport.

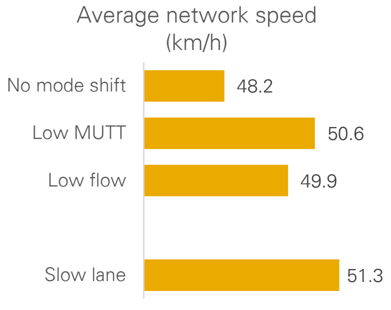




Road network

The average delay for Slow lane model runs remains relatively low. Low flow delays are slightly higher due to the reduced flow capacity of AVs. No mode shift has the most congestion, since travellers do not shift towards public transport.





8.2 A variant of Slow lane with private AVs

8.2.1 Private slow lane

When half the population has a private AV instead of access to on-demand AVs, accessibility and congestion rise, while public transport usage and active transport fall.

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion is higher than Slow lane but lower than Dead end.	Vehicle fleet is similar to Dead end and 73% higher than the main Slow lane scenario.	Physical activity is lower than Slow lane and Dead end, but slightly higher than Private drive.	Accessibility is much higher, because on-demand AVs (which reduce accessibility) are replaced with Private AVs (which are more convenient and increase accessibility).

Much like Slow lane, this scenario splits its population equally between travellers with access to CDVs and travellers with access to AVs. However, unlike Slow lane, the AVs that travellers can use are privately owned rather than operating under a vehicle on demand model.

Public transport mode share in the Private slow lane scenario is about halfway between Dead end (19%) and Private drive (14%), at 17% of motorised trips. Physical activity is also between the two scenarios, at 1.9 km per person (compared with 1.8 km for Private drive and 2.1 km for Dead end).

Average delays across a typical weekday are lower in Private slow lane than Private drive. This is because CDVs are not able to be sent home empty to avoid parking fees, so they do not add to congestion as much as the private AVs do. This highlights the threat of private AVs causing major congestion due to empty running, particularly in inner areas.

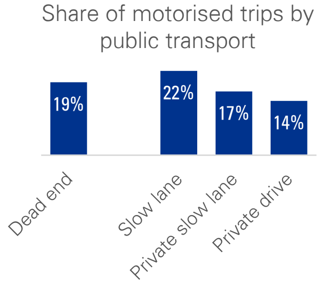
Slow lane AV scenarios

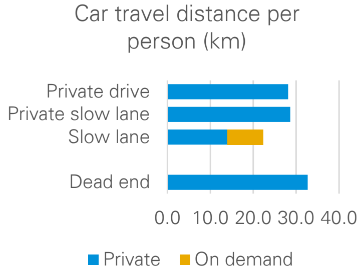
Travellers in the Slow lane AV scenario undertake more trips in AVs and less in public transport compared to Slow lane.

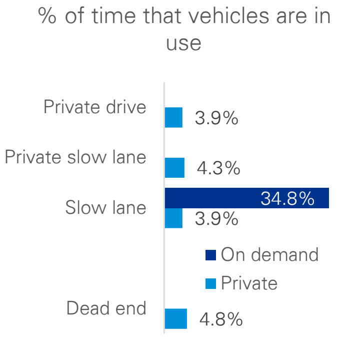
Private slow lane travellers walk 1.9 km, compared to 1.8 km for Private drive and 2.1 km for Slow lane.

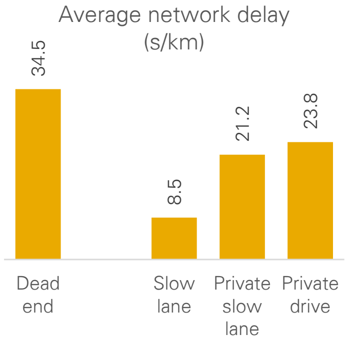
Vehicle utilisation is higher when all vehicles are AVs, because travellers are more likely to use their AVs for a trip than their CDVs.

Private slow lane has higher delays than Slow lane because travel per person is higher. Private drive has higher peak delays due to more empty running


Share of motorised trips by public transport


Car travel distance per person (km)


% of time that vehicles are in use


Average network delay (s/km)

8.3 The Mix of scenarios

Congestion	Vehicle fleet	Physical activity	Accessibility
●	○	○	-

What is the Mix of scenarios?

The Mix of scenarios represents a future where private AVs, vehicles on demand and zero emission CDVs all co-exist. This represents a mix of the Electric avenue (zero emission CDVs), Private drive (private AVs) and Fleet street (on-demand AVs).

The split of vehicle types is determined by geography. In the inner suburbs, 75% of travellers use on-demand AVs and do not own a private car. This proportion is 50% for middle suburbs and 25% for outer suburbs. Of private vehicles, 95% are private AVs and 5% are private zero emission (electric) CDVs.

The Mix of scenarios also assumes an area-based charge for the inner city of $5 in peak times and $2.50 in other times to mitigate congestion caused by empty running. This means that private vehicles must pay to drive in the inner city areas of Melbourne. The area-based charge does not apply to on-demand AVs.

Congestion reduces, and is almost eliminated in the morning peak

The Mix of scenarios has significantly less road congestion than the Dead end scenario. Average speeds are projected to increase by 52% across the day and almost double during the morning peak (89% increase). Average delays in the morning peak are 99.5% reduced compared to Dead end, whereas average delays across the day are 91% reduced compared to Dead end. The network congestion improvements occur across the network, but are seen most strongly in the inner city. The Mix of scenarios is projected to have higher public transport usage than the Dead end scenario (22% of motorised trips compared to 19% in the Dead end scenario).

The vehicle fleet falls from 3.5 million in Dead end to 2.2 million

The Mix of scenarios reduces the total number of vehicles required to meet demand, since many travellers use on-demand AVs. However, the vehicle fleet is higher than in Slow lane and approximately 11 times the size of the Fleet street fleet.

Physical activity increases from 2.1 km in Dead end to 2.2 km in Mix of scenarios, as public transport demand rises

The Mix of scenarios is projected to lead to a 7-8% increase in walking distance per person compared to the Dead end scenario. This is driven by an increase in public transport usage.

Accessibility is similar to the Dead end scenario

The combination of different vehicle technologies dilutes the overall accessibility effects of new vehicle technologies. In Fleet street, the widespread use of on-demand AVs reduces accessibility because of their cost and the wait times, whereas in Private drive the use of private AVs raises accessibility. In the Mix of scenarios, overall accessibility is similar to Dead end on average. However, residents of inner areas tend to have lower accessibility than in Dead end, and residents of outer areas higher accessibility than Dead end.

➡ Volume capacity ratios for the Mix of scenarios can be found at the following links in Appendix D for the morning peak (**page D.27**) and afternoon peak (**page D.58**).
You can also compare the Mix of scenarios with Dead end at the following links: accessibility (**page C.26**), morning peak flow (**page E.26**), afternoon peak flow (**page E.56**), morning peak speed (**page F.26**) and afternoon peak speed (**page F.56**). When you're done, you can return using the Alt-left command.

8.3.1 Key results: Mix of scenarios

Scenario assumptions

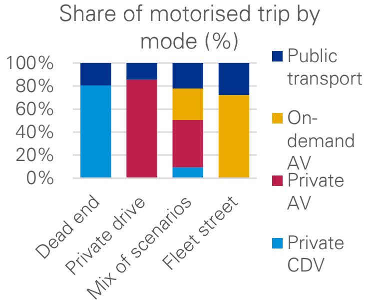
The Mix of scenarios represents a future where private AVs, vehicles on demand and private zero emission (electric) CDVs all co-exist. In the inner suburbs, 75% of travellers do not own a private car and instead rely on on-demand AVs. This proportion is 50% for middle suburbs and 25% for outer suburbs. The remainder of the population have access to private vehicles, 95% of which are private AVs and 5% of which are private zero emission (electric) CDVs. The Mix of scenarios also assumes an area based charge for private vehicles in the inner city of $5 in peak times and $2.50 in other times. This helps to mitigate congestion caused by empty running. On-demand AVs are not charged this fee.

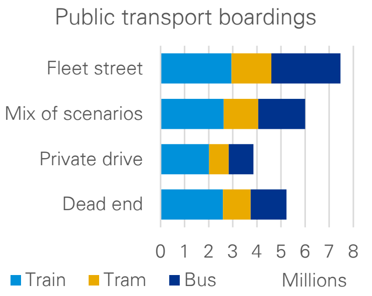
The Mix of scenarios is compared with Fleet street and Private drive (which includes empty running). This is because the vehicle technologies in Mix of scenarios include on-demand AVs (like Fleet street) and private AVs (like Private drive). Dead end is included to illustrate how the Mix of scenarios differs from the base case.

Travel demand by mode

Public transport usage in Mix of scenarios is higher than in Dead end, particularly for buses and trams.

This, combined with the lower on-demand AV mode, indicates that inner city residents in particular are switching to public transport.

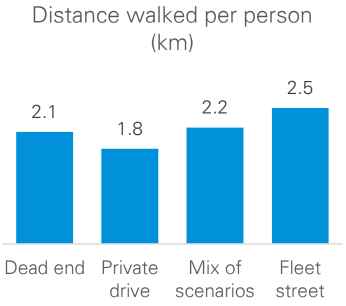

Share of motorised trip by mode (%)

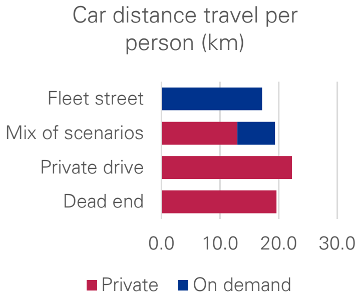

Public transport boardings

Travel distance

Travellers in the Mix of scenarios have slightly higher walking distances than Dead end.

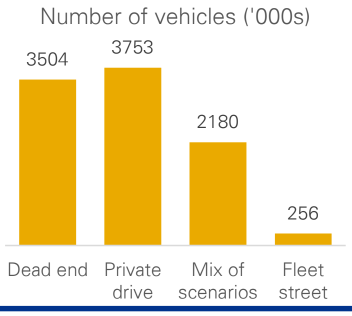
Car distance per person for the Mix of scenarios between Fleet street and Private drive. Private AVs are more utilised than on-demand AVs.

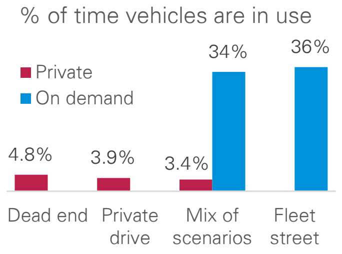

Distance walked per person (km)


Car distance travel per person (km)

Vehicle utilisation

The mix of scenarios fleet size is 30% less than Dead end.

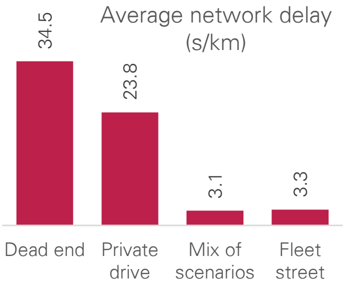

Number of vehicles ('000s)

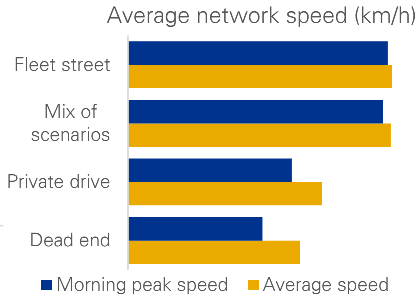

% of time vehicles are in use

Road network

The morning peak delay is almost eliminated in the Mix of scenarios, due to the many on-demand AV travellers in the inner city, and the area based charge.

Despite the private vehicles, the Mix of scenarios network speeds are almost as good as in Fleet street.


Average network delay (s/km)


Average network speed (km/h)

9 What if we have different patterns of urban development?

Some of the scenarios explored in this report have major impacts on travel behaviour and accessibility. As a result, it is expected that they would also impact on where Melburnians choose to live and work. This Section explores the changes in outcomes of the Mixed and Private drive scenarios under two alternative urban development patterns – an expanded low density city and a centralised high density city.

The alternative urban development patterns tested are derived from work done by Infrastructure Australia (IA) in their *Future Cities* paper released in February 2018[27]. The changed urban development patterns are treated as an exogenous input to the MABM, and are not generated by the MABM.

The scenarios represent systematic, but not large changes in aggregate to Melbourne's urban development patterns. This reflects that most of the dwellings and business premises for Melbourne in 2046 are already 'locked in', either because the buildings already exist or are already planned.

9.1 Expanded low density city

This alternative urban development scenario is derived from the "Expanded Low Density" scenario in Infrastructure Australia's Future Cities report. The change in population density for this scenario is shown in Figure 4. The change in employment density is shown in Figure 6. This scenario has 1.5% of Melbourne residents with their location shifted towards the outer areas relative to the baseline urban development scenario and 0.4% of Melbourne jobs are shifted.

9.2 Centralised high density city

This alternative urban development scenario is derived from the "Centralised High Density" scenario in Infrastructure Australia's Future Cities report. The change in population density for this scenario is shown in Figure 5. The change in employment density is shown in Figure 7. This scenario has 6.6% of Melbourne residents with their location shifted towards the inner areas relative to the baseline urban development scenario and 10.0% of Melbourne jobs are shifted.

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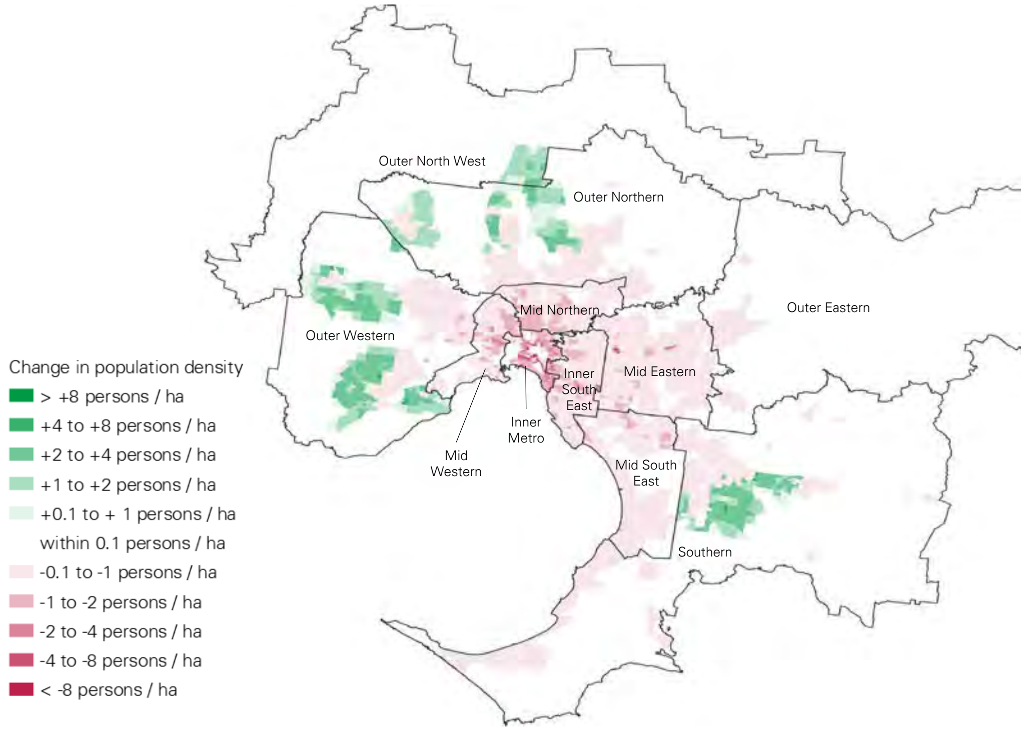
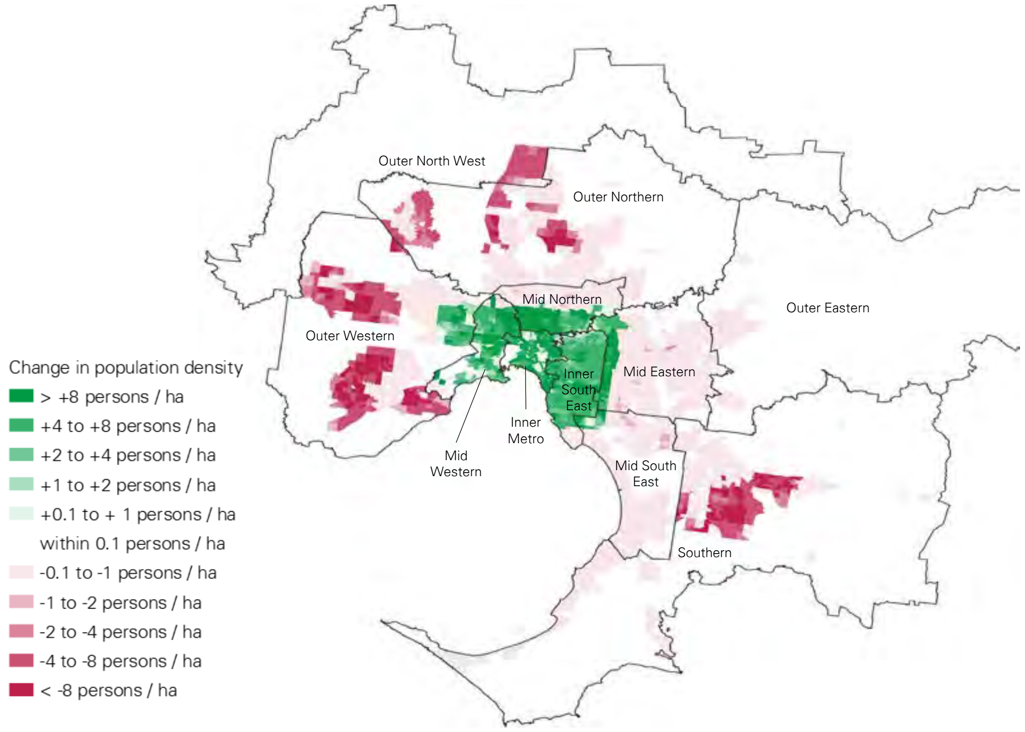
[27] Infrastructure Australia (2018), Future Cities: Planning for our growing population, Available from https://goo.gl/gLTMkB.

Figure 4: Change in population density, expanded low density



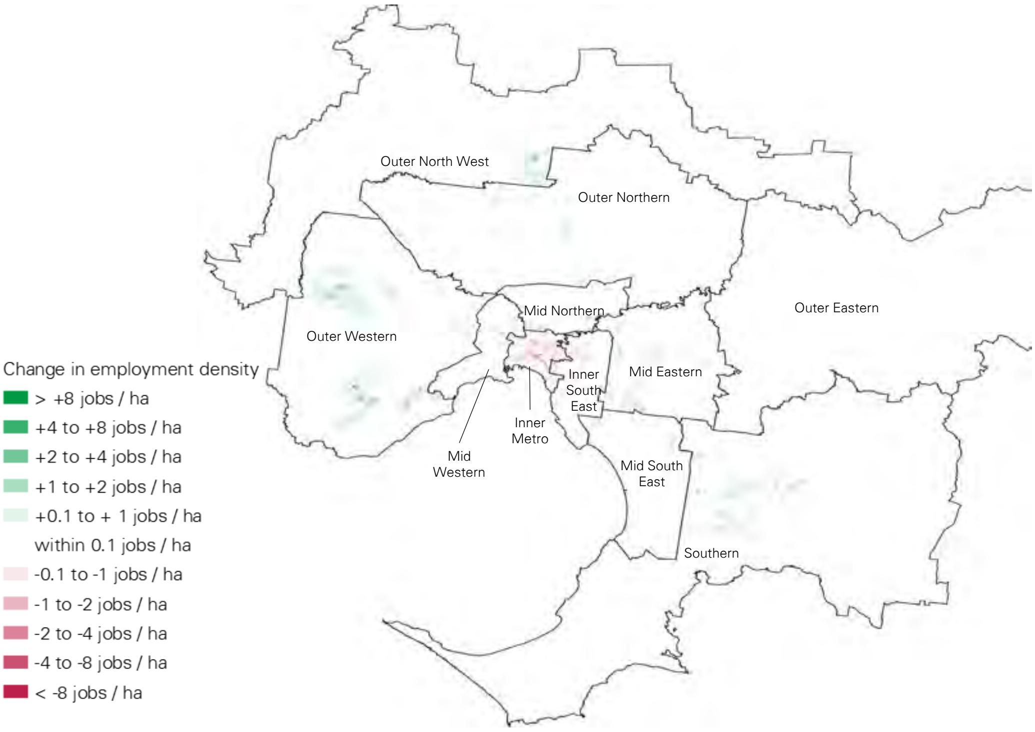
Source: Infrastructure Australia

Figure 5: Change in population density, centralised high density



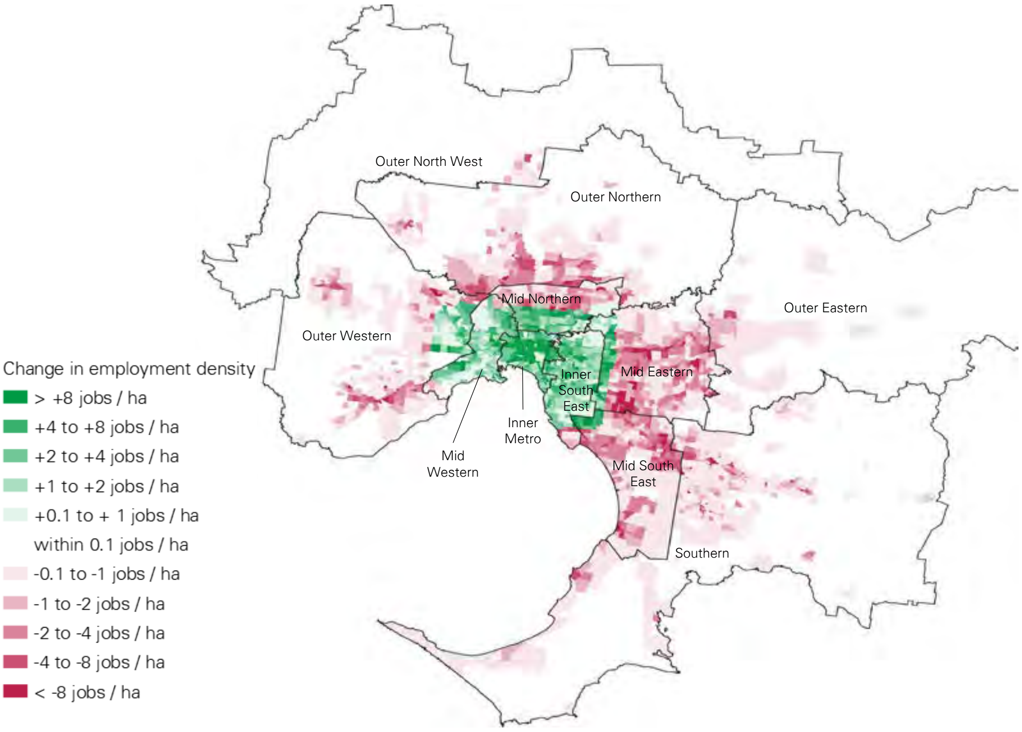
Source: Infrastructure Australia

Figure 6: Change in employment density, expanded low density



Source: Infrastructure Australia

Figure 7: Change in employment density, centralised high density



Source: Infrastructure Australia

9.3 Alternative urban development outcomes

We tested both the Mix of scenarios and the Private drive scenarios with baseline urban development patterns against the two alternative urban development scenarios – expanded low density and centralised high density. Generally, the impacts of the land use scenarios we tested are minor relative to the much larger impacts of automated vehicle technology and on-demand AVs. The extent of changes to land use that these technologies could generate is unknown – the horse and cart, passenger rail and automobile all had fundamental impacts on how our cities are shaped, and new transport technologies could similarly have fundamental impacts. The outcomes of these scenario variants are described in detail in the remainder of this Section.

9.3.1 Mix of scenarios – expanded low density

People shift modestly towards private cars and public transport as people in outer areas look to avoid using on-demand AVs due to high fares and wait times.

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion is slightly higher than the Mix of scenarios, but still much lower than Dead end.	The overall vehicle fleet is slightly larger than the Mix of scenarios, with more private AVs and fewer shared AVs.	Physical activity is similar to the Mix of scenarios and slightly higher than Dead end.	Accessibility is similar to both the Mix of scenarios and Dead end.

The level of public transport use is higher in the expanded low density scenario than the baseline for the Mix of scenarios. This is because the use of on-demand AVs is expensive in the outer areas, with longer trips on average. Wait times for on-demand AVs also tend to be long in outer areas. The Mix of scenarios assumes 25% of people in outer areas use on-demand AVs, so many of these people look to avoid on-demand AV fares and instead use public transport.

For this reason, this scenario sees a shift away from on-demand AVs towards both private cars and public transport. As a result, a larger vehicle fleet is also required due to the higher levels of car dependence and car mode share.

The outcomes of this scenario highlights that on-demand AVs are generally less viable for people who live in outer areas than people who live in denser, inner areas. However, the changes between the Mix of scenarios and the expanded low density scenario are minor.

9.3.2 Mix of scenarios – centralised high density

Private car use stays about the same, but people shift modestly from on-demand AVs to public transport which provides a cheaper alternative to on-demand AVs.

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion is higher than the Mix of scenarios, but still much lower than Dead end.	The overall vehicle fleet is slightly smaller than the Mix of scenarios, with fewer private AVs and fewer shared AVs as people shift to public transport.	Physical activity is slightly higher than the Mix of scenarios and slightly higher than Dead end.	Accessibility is similar to both the Mix of scenarios and Dead end.

Similarly to the expanded low density scenario, public transport use is higher in the centralised high density scenario than the baseline scenario, but for different reasons. In this scenario, people are less reliant on cars than with baseline urban development patterns. Road congestion is also higher in inner areas as a result of higher population density in those areas. These factors facilitate a shift away from cars and towards public transport. There is also a shift away from on-demand AVs towards public transport, as people are able to avoid on-demand AV fares by shifting to public transport, which has higher service levels in inner areas. However, the changes between the Mix of scenarios and the centralised high density scenario are minor.

What's the evidence? Alternative urban development scenarios have only a slight effect on Victoria's transport outcomes in the Mix of scenarios. To see the change in volume capacity ratios, please compare the morning peak volume capacity ratio for the baseline Mix of scenarios, the centralised scenario and the expanded scenario (**pages D.27-D.29**) in Appendix D, and the afternoon peak capacity ratios (**page D.58-D.60**). You can also compare morning peak flow (**page E.26-E.28**), afternoon peak flow (**page E.56-E.58**), morning peak speed (**page F.26-F.28**) and afternoon peak speed (**page F.56-F.58**). When you're done, you can return using the Alt-left command.

9.3.3 Key results: Mix of scenarios under alternative urban development

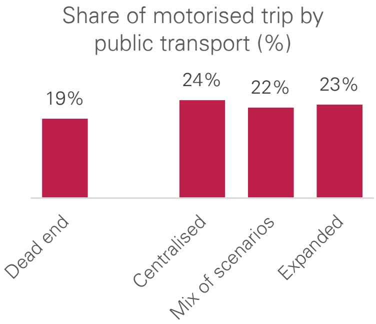
Scenario assumptions

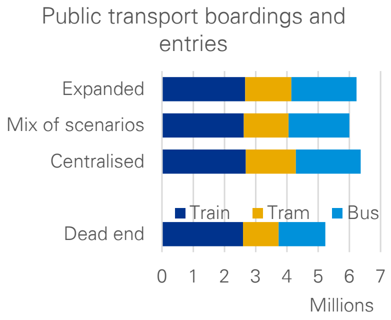
- The following scenarios are variations of the Mix of scenarios, where CDVs and AVs co-exist in Melbourne. All scenarios assume that there is a mix of CDVs, on-demand AVs, private AVs and public transport trips in Melbourne.
- The Mix of scenarios follows Victoria in Future's expectation of urban development patterns in 2046.
- The centralised scenario projects travel demand based on a version of Melbourne where population and jobs is more concentrated in inner areas than the main Mix of scenarios. This centralised high density land use scenario was developed by Infrastructure Australia.
- The expanded scenario projects travel demand based on a version of Melbourne where population and jobs are more spread out than the main Mix of scenarios. This expanded low density land use scenario was developed by Infrastructure Australia.

Travel demand by mode

Public transport usage is lowest in the main Mix of scenarios run.

In the centralised scenario, people shift from private cars to public transport. In the expanded scenario, people shift from shared AVs to private AVs and public transport.

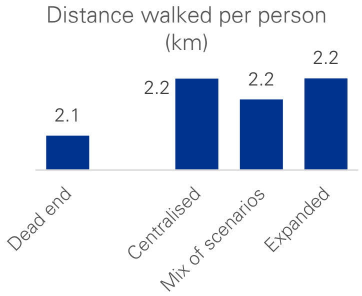

Share of motorised trip by public transport (%)

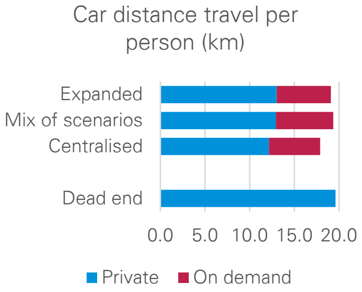

Public transport boardings and entries

Travel distance

Physical activity increases in both the centralised and expanded scenario runs, as public transport increases.

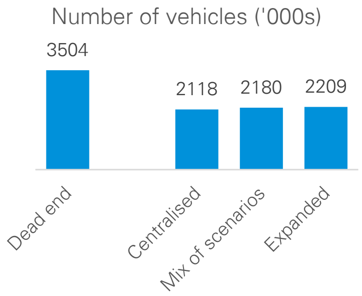
Car travel distance is lowest in the centralised scenario.

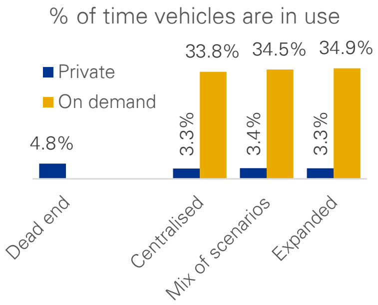

Distance walked per person (km)


Car distance travel per person (km)

Vehicle fleet

The expanded scenario requires a larger fleet size than the main scenario run, which is higher in turn than the centralised scenario.

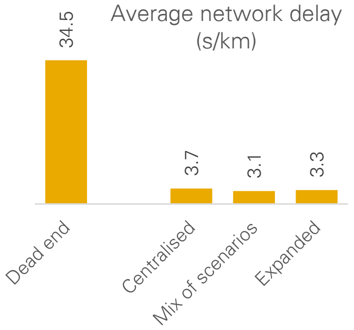

Number of vehicles ('000s)

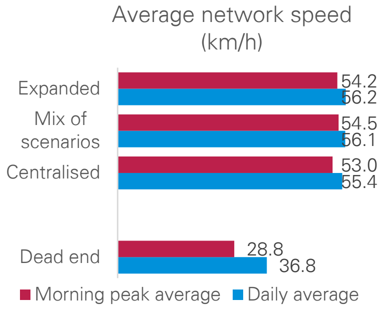

% of time vehicles are in use

Road network

The average delay for the main scenario run is lower than both the centralised and expanded scenario runs, but all runs are much lower than Dead end.

Inner city congestion arises in the centralised scenario due to higher population density, and in the expanded scenario due to higher car dependence.


Average network delay (s/km)


Average network speed (km/h)

9.3.4 Private drive – expanded low density

People shift modestly towards car use and away from public transport, although most people use private cars regardless.

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion is higher than Private drive, but lower than Dead end.	The overall vehicle fleet is slightly larger than Private drive due to higher car dependence.	Physical activity is similar to Private drive and lower than Dead end.	Accessibility is similar to Private drive and higher than Dead end.

The expanded low density scenario for Private drive sees a modest shift away from public transport and towards private car use relative to the baseline. This is because of poorer public transport service levels in outer areas and more dispersed locations of activities for those residents. This higher level of car dependence also leads to modest increases in congestion, fleet size and vehicle kilometres travelled. These changes only occur on a small scale, and are far outweighed by impacts of the introduction of Private AVs.

9.3.5 Private drive – centralised high density

There is a significant shift away from private cars and towards public transport due to higher public transport service levels in the inner city.

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion is slightly higher than Private drive, but lower than Dead end.	The overall vehicle fleet is slightly smaller than Private drive due to lower car dependence.	Physical activity is similar to Private drive and lower than Dead end.	Accessibility is similar to Private drive and higher than Dead end.

The centralised high density scenario for Private drive sees a shift towards public transport and away from private car use relative to the baseline. This is because people live in areas with higher public transport service levels, and their activities are more concentrated. As a result, this scenario sees an increase in public transport mode share (from 14% in the baseline to 16% with centralised high density) and a slight decrease in fleet size. However, despite the increased use of public transport, congestion worsens slightly relative to the baseline urban development patterns. This is due to the higher population density in inner areas – the areas with the highest levels of road congestion. Similar to the expanded low density scenarios, the changes in key measures of success are relatively small compared to Private drive.

What's the evidence? Alternative urban development scenarios have only a slight effect on Victoria's transport outcomes in Private drive. To see the change in volume capacity ratios, please compare the morning peak volume capacity ratio for the centralised scenario (page D.30) and the expanded scenario (page D.31) in Appendix D, and the afternoon peak capacity ratios for the centralised and expanded scenarios (page D.61-D.62). You can also compare morning peak flow (page E.29-E.30), afternoon peak flow (page E.59-E.60), morning peak speed (page F.29-F.30) and afternoon peak speed (page F.59-F.60). When you're done, you can return using the Alt-left command.

9.3.7 Key results: Private drive with alternative urban development

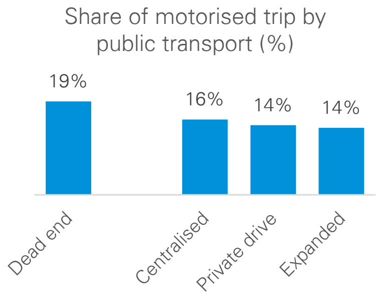
Scenario assumptions

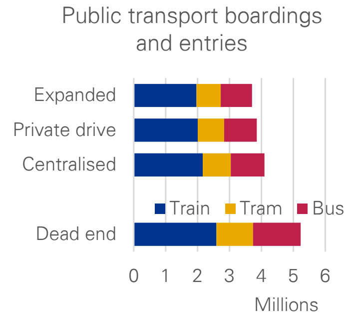
- The following scenarios are variants of the Private drive scenario, where travellers have access to private AVs and public transport, but no on-demand AVs or private CDVs.
- The Private drive scenario follows Victoria in Future's expectation of urban development patterns in 2046.
- The centralised scenario projects travel demand based on a version of Melbourne where population and jobs is more concentrated in inner areas than the Private drive. This centralised high density land use scenario was developed by Infrastructure Australia.
- The expanded scenario projects travel demand based on a version of Melbourne where population and jobs are more spread out than the Private drive. This expanded low density land use scenario was developed by Infrastructure Australia.

Travel demand by mode

In the centralised scenario, people use public transport more, but still less than Dead end.

Use of public transport in the expanded scenario is slightly lower than in Private drive.

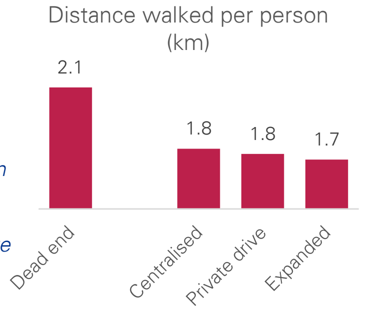


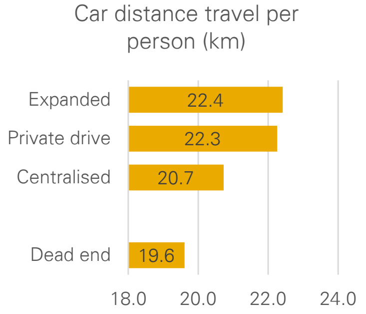


Travel distance

Travellers walk less in the expanded scenario because they are less likely to use public transport.

Car travel distance reduces in the centralised scenario, and is slightly higher in the expanded scenario. All Private drive runs have more car travel than Dead end.

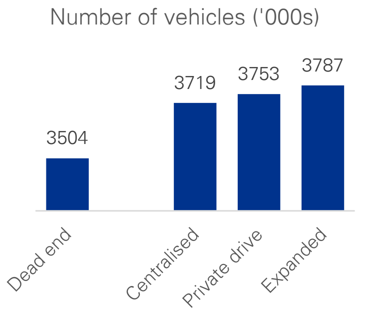


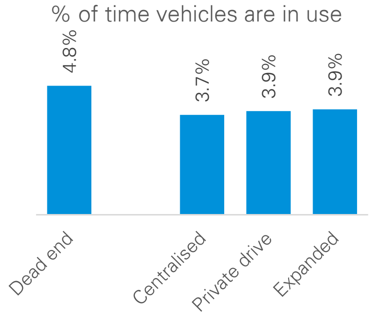


Vehicle fleet

The expanded scenario requires a higher fleet size than Private drive, which is higher than the centralised scenario.

Private drive, centralised and expanded scenarios all have larger fleet sizes than Dead end.

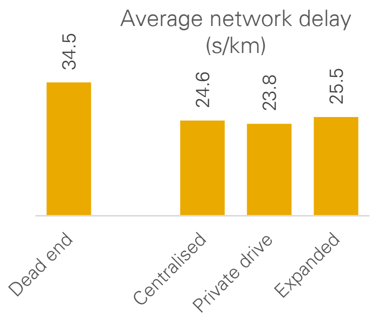


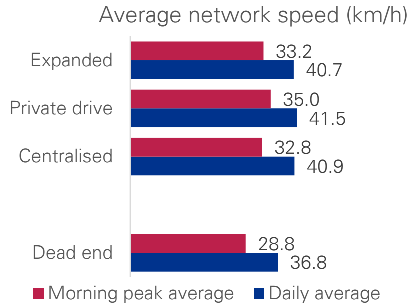


Road network

Network delay is higher in both centralised and expanded than Private drive.

Congestion is higher with centralised due to higher population in congested areas, and with expanded because of higher car dependence.





10 What about public transport?

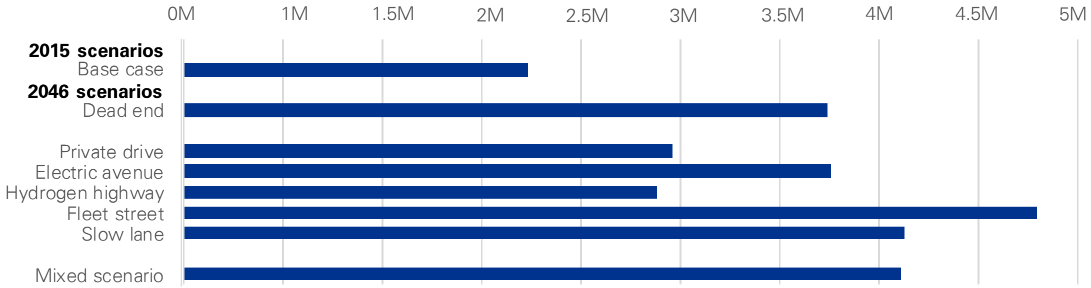
This section provides a stronger focus on outcomes relating to Victoria's public transport system of the main scenarios as described in Section 3 of this report. Comparisons with the main scenarios (in 2046) are made with today (represented by the 2015 Base case) and the Dead end (2046 'business as usual') scenario.

Public transport patronage grows strongly in all the main scenarios

Figure 8 shows the daily number of public transport trips for each scenario – a measure of overall public transport usage. There is significant variation between the scenarios. The scenario with the highest public transport patronage (Fleet street) has nearly doubled that of the lowest patronage (Private drive), and the Dead end scenario is somewhere in between.

One thing that all the future scenarios have in common is that they have much higher levels of patronage than 2015. Even the scenario with the lowest patronage (Private drive) has more than double today's patronage, and the scenario with the highest patronage (Fleet street) has over four times today's patronage.

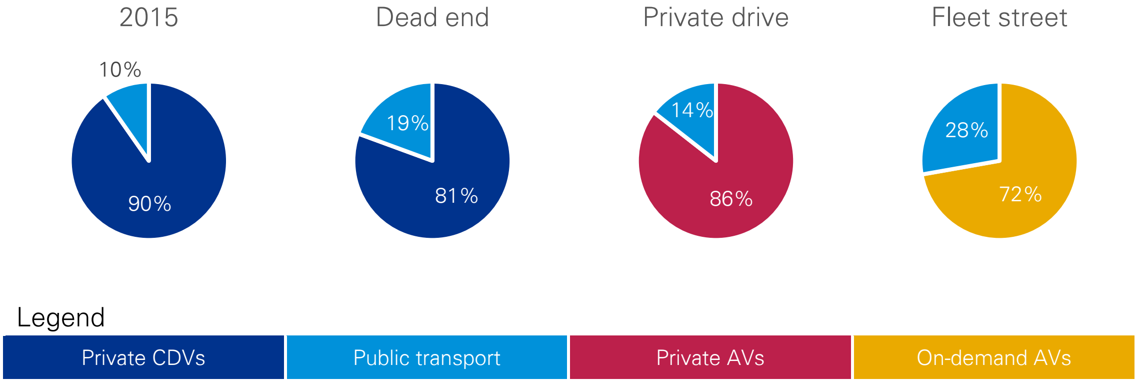
Figure 8: Total daily public transport trips by scenario



Source: MABM

The projected growth has two main drivers: population growth and increase in the share of motorised transport that occurs on public transport. Figure 9 shows the mode share for selected scenarios, including 2015, Dead end and the two scenarios with the lowest and highest public transport patronage: Private drive and Fleet street respectively.

Figure 9: Mode share for motorised transport, selected scenarios

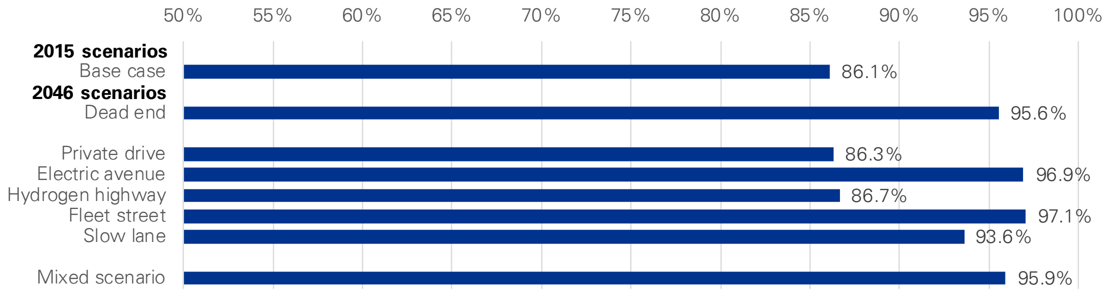


Source: MABM

All the main scenarios have significant crowding on heavy rail

Figure 10 shows the average modelled and projected level of crowding during the morning peak on heavy rail (i.e. commuter rail) services for various scenarios[28]. A crowding level of 100% means that the trains are on average at the maximum level of crowding for which they were designed. All of the main projected scenarios have heavy rail crowding of at least the 2015 level, and some (Fleet street, Electric avenue) are significantly higher than the 2015 level.

Figure 10: Experienced levels of heavy rail crowding, morning peak (7am – 9am)

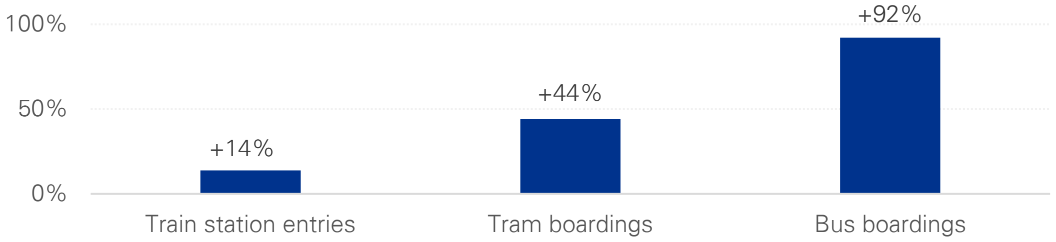


Source: MABM

Buses and trams are particularly important for vehicles on demand

Figure 11 shows the difference in train station entries, tram boardings and bus boardings between the Dead end and Fleet street scenarios. While there is an increase in use of all public transport modes, the largest increases are on buses, and to a lesser extent trams. This is because users look to save money by avoiding fares for AV on-demand and instead pay lower public transport fares. The Fleet street scenario has more patronage of public transport for a broader range of everyday activities (beyond just commuting), and these diverse locations are better served by buses and trams than trains.

Figure 11: Differences in public transport use between Dead end and Fleet street



Source: MABM

Rail volume-capacity plots can be found in Appendix D from **page D.63**. When you're done you can return using the Alt-left command.

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[28] The figure shows an average for all line groups. Some line groups are projected to significantly exceed load standards. For the Dead end scenario, the Burnley and Melbourne Metro (Parkville) line groups are projected to be at load standard, and the Clifton Hill and Caulfield line groups are projected to significantly exceed load standard.

10.1.1 Key results: Public transport across the scenarios in 2046

Scenario assumptions

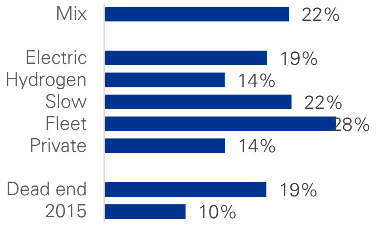
- Dead end and Electric avenue do not include AVs. In Dead end, vehicles are powered by fossil fuels, whereas in Electric avenue, vehicles are powered by electricity.
- Private drive and Hydrogen highway include AVs, which are all privately owned. In Private drive, AVs are electric and in Hydrogen highway, they are powered by hydrogen fuel cells.
- Fleet street includes AVs that perform customer trips on demand (not privately owned). In Slow lane, half the population has the option of using on-demand electric AVs and half the population use people-driven cars powered by fossil fuels. The Mix of scenarios includes private zero-emission CDVs, private AVs and on-demand AVs.
- In all scenarios, AVs are 75% more efficient on roads than CDVs due to platooning, mode shares are calculated by the model, and private AVs can perform empty runs (i.e. trips without passengers).

Mode share and boardings

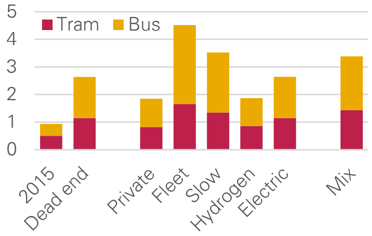
Only scenarios with on-demand AVs have higher public transport share than Dead end.

Bus boardings vary more than tram boardings between scenarios.

Share of motorised trips on public transport



Tram and bus boardings (millions)

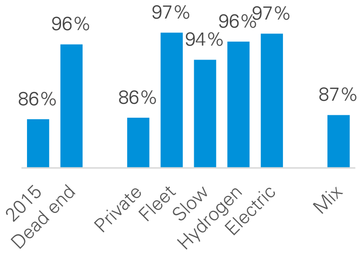


Rail transport

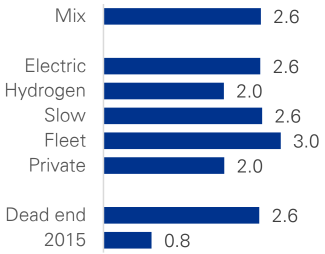
Rail crowding is worse than current rates in every 2046 scenario, except Private drive.

If rail crowding is 100%, it means that trains are as full as they are designed to be (as opposed to as many people can physically fit)

Experience of rail crowding



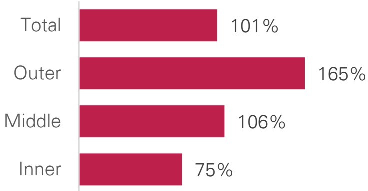
Train station entries (millions)



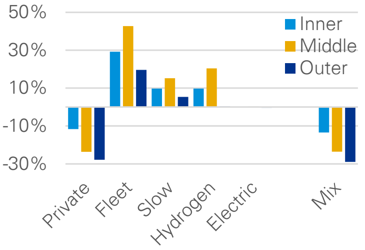
Demand by region

On-demand AV scenarios encourage middle suburb PT boardings, while private AV scenarios discourage public transport, particularly from the outer suburbs.

Change in PT boardings by region - 2015 to 2046 Dead end



Change in PT boardings by region (versus Dead end)

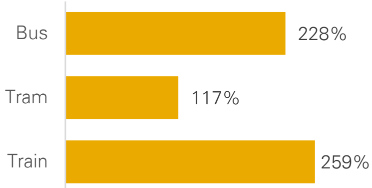


Morning peak demand

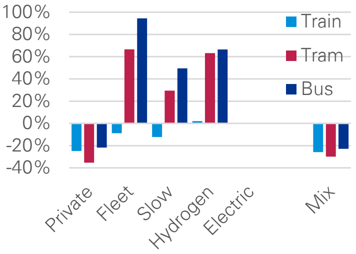
Dead end in 2046 is characterised by significant growth in train demand..

Outer suburb growth reflects significant population growth from a small base in 2015.

Change in total morning PT boardings - 2015 to 2046 Dead end



Change in total morning PT boardings (versus Dead end)



10.2 Public transport scenarios

10.2.1 Replacing buses with DRT services (Fleet street)

Replacing bus services with DRT vehicles may improve accessibility outcomes for people in outer areas in the Fleet Street scenario

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion stays the same compared to Fleet street, no mode shift.	The vehicle fleet is slightly higher, as a greater number of lower capacity DRT vehicles are required to replace larger buses.	Physical activity declines slightly as people as people do not have to walk to bus stops.	Accessibility increases, as the convenience of bus travel increases.

In this scenario, bus users in the Fleet street, no mode shift scenario were moved into DRT vehicles which can hold a maximum of eight people. Users are charged the same price as a bus fare. The DRT vehicles can make up to four pickups/drop-offs per journey of two persons each. The DRT vehicles will pick up additional passengers en-route, as long as the detour does not increase any individual passengers total journey time more than 40% above what their direct journey time would have been in a standard on-demand AV.

The introduction of DRT led to a 5% improvement in accessibility outcomes, compared to the Fleet street, no mode shift scenario. These vehicles are usually faster than a bus and can drop the user directly at their destination, which reduces walking time. While they are less direct than the standard on-demand AVs due to servicing multiple passengers per journey, the relatively low fare makes them a relatively attractive transport option.

What's the evidence? Significant accessibility improvements were seen for residents of outer areas in this scenario, with adults with no car the largest beneficiaries. This is due to the greater convenience and faster travel times of pooled on-demand AVs relative to buses (**page C.18**). When you're done, you can return using the Alt-left command.

10.2.2 Private AV station drop-off and pick-up

Removing capacity constraints in Park n Ride for Private drive scenario has little effect, but this may change for scenarios where congestion is a problem.

Congestion	Vehicle fleet	Physical activity	Accessibility
Congestion slightly decreases, due to the slight increase in public transport usage (15% compared to 14% for Private drive).	The vehicle fleet is similar to Private drive.	Physical activity is similar to Private drive.	Accessibility is similar to Private drive.

Private AVs may allow owners to be dropped off by their AVs, with their AVs then continuing on to park somewhere else, either close to the train station or return home. This effectively removes car parking constraints at train station car parks. This scenario has minimal impact on traveller behaviour or road network performance in the Private drive scenario. The proportion of motorised trips on public transport rises slightly, from 14% (Private drive) to 15%.

Passengers of private AVs in the Private drive scenario experience minimal congestion. In this scenario, the driver is most likely to prefer to continue the private AV trip all the way to their destination.

In a scenario with congested roads or road pricing, this may be a different story, as drivers may be incentivised to drive less, or avoid driving in inner areas. In this scenario, there may be substantial benefits to AV station drop-off and pick-up by avoiding train station car park capacity constraints.

10.2.3 Key results – Public transport scenarios

Scenario assumptions

- The Fleet street DRT scenario assumes that buses are replaced with AVs, which allow travellers to choose pickup and dropoff locations. Bus users from the Fleet street scenario are assigned to DRT vehicles. Travellers share their AVs with other travellers who are going in similar directions. This increases the travel time but reduces the monetary cost of travel, compared with on-demand AV travel. In Fleet street, all other travellers use public transport or on-demand AVs.
- The Private AV Station drop-off and pick-up scenario is a variant of Private drive where Park and ride facilities have unlimited capacity. This allows the model to pick up any latent demand for public transport by AV users who cannot park and ride (or drive through and ride) due to capacity constraints in Park and ride areas.

Replacing buses with DRTs

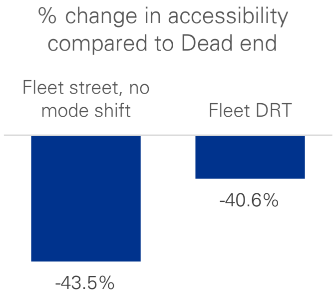
Accessibility increases in the Fleet street DRT scenario, as DRTs are faster and in some cases more direct than buses.

However, accessibility in the Fleet street DRT scenario is still below Dead end.

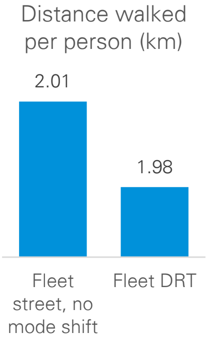
Physical activity is lower when DRTs replace buses, because travellers do not have to walk to bus stops.

The vehicle fleet size rises as extra AVs are needed to replace buses.

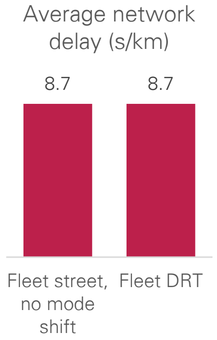
Congestion is similar in Fleet street scenarios with or without DRTs, because roads are relatively clear.


% change in accessibility compared to Dead end

The average occupancy of a DRT was 2.3 passengers in Fleet street DRT


Distance walked per person (km)

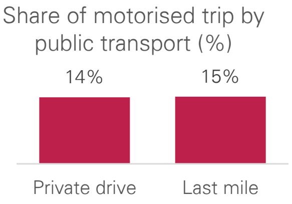
The average wait time for a DRT was 17 minutes and 3 seconds

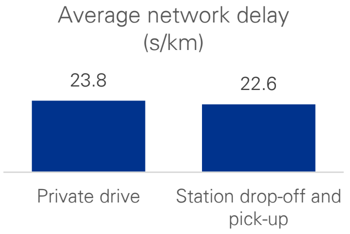

Average network delay (s/km)

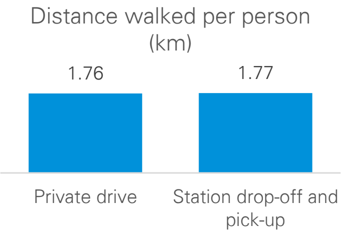
Private AV Station drop-off and pick-up scenario

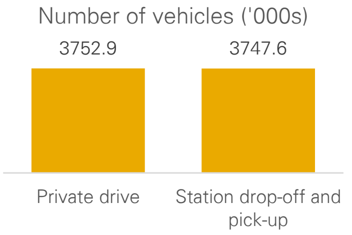
Removing capacity constraints of Park and Ride facilities in the Private drive scenario has a negligible impact on most traveller metrics. This is because private AV users would usually drive all the way to their activity.

However, under a scenario with significant congestion, removing capacity constraints from Park and Ride areas may reveal latent demand for public transport by drivers.


Share of motorised trip by public transport (%)


Average network delay (s/km)


Distance walked per person (km)


Number of vehicles ('000s)

11 What influences the outcomes?

Table 17 summarises key influencers of vehicle technology outcomes and the broad effect of each influence on the key measures of success.

Table 17: Influencers of scenario outcomes

🔴 Much worse
⭕ Slightly worse
- Similar
○ Slightly better
🟢 Much better

Influence	Comments	Road congestion	Vehicle flleet	Physical activity	Accessibility
More comfort and convenience of driving	AVs allow occupants to undertake activities such as reading, sleeping, watching movies or participating in work activities. Therefore, AV users are likely to care less about travel times, and will be happy to spend longer times in an AV compared to a CDV.	🔴	⭕	⭕	○
Mass take-up of vehicles on demand	AVs on demand would allow consumers to completely forego private ownership, and instead rely on on-demand vehicles which are much cheaper and more convenient than today's taxis. This is because no driver needs to be paid and fixed costs are split between many users. Mass take-up would also reduce the wait times and create economies of scale and network effects.	⭕	🟢	⭕	⭕
Less 'sunk' travel costs	AVs on demand may be paid with a fare (including a time and distance component). While this fare would be much lower than today's taxis, it would still be greater than the per-trip running cost of a private car. This is because most costs of vehicle ownership are 'sunk', such as financing and maintenance, and are note perceived by travellers on a trip-by-trip basis.	🟢	○	🟢	🔴
Higher effective road capacity	AVs are not restricted by the limits of human spatial awareness and reaction times. This means that AVs can operate safely with much smaller gaps between vehicles. The ability of AVs to travel in tight groups of vehicles is called platooning.	🟢	-	⭕	🟢
Empty running	AVs can travel without any occupant. This means that AVs do not need to park at the location of their owner's activity. This ability of private AVs to undertake empty running might benefit the owner, but also cause additional congestion, since the vehicle is travelling more on the network. AVs on-demand also do empty running in between dropping off one passenger and picking up the next.	🔴	⭕	⭕	⭕

Source: MABM & KPMG Analysis

11.1.1 How outcomes in scenarios vary when we change our assumptions

Scenario assumptions

Because there are multiple model runs for Private drive, Fleet street and Slow lane, the key outcomes of the scenarios can be viewed as a 'range", rather than a single projection.

- The No empty running model run excludes private AVs from performing trips without passengers.
- The Low MUTT model run assumes that travellers value the comfort and convenience of AVs, and are happy with longer travel times as a result.
- The Low flow model run assumes that the benefit of AVs on road congestion is 1.25, rather than 1.75 in other scenarios. This means AVs are only 25% more efficient on the roads than CDVs, rather than 75%.
- The No Mode Shift model assumes that travellers choose the same mode of travel as they would in the Dead end scenario.

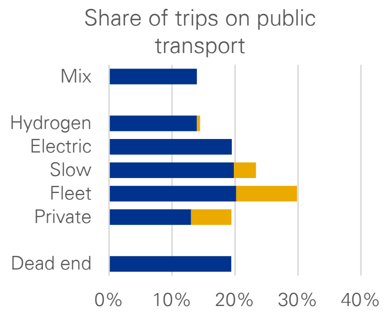
Legend

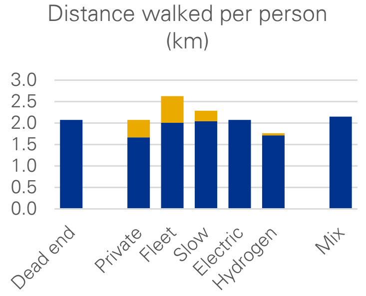
These bars show the minimum results

These bars show the difference between minimum and maximum results

Public transport and walking

All Private drive scenarios have lower public transport use than Dead end, while all Fleet street and Slow lane show higher use.

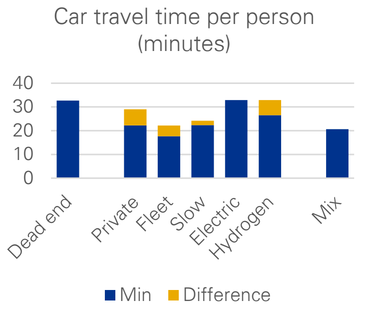

Share of trips on public transport

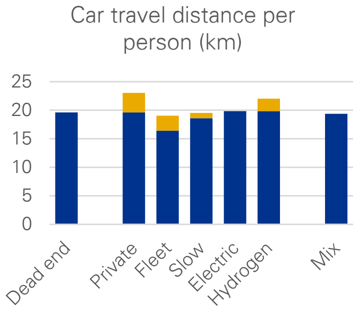

Distance walked per person (km)

Car travel distance

Travel distance is highest in the Private drive scenario with empty running allowed.

Travel distance in Fleet street is lower than Dead end if AV efficiency is diluted (i.e. Low flow run).

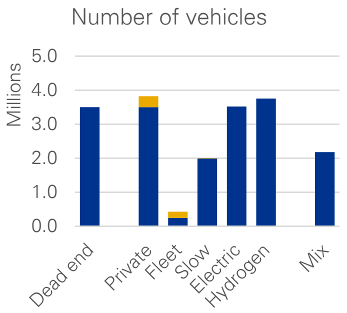

Car travel time per person (minutes)

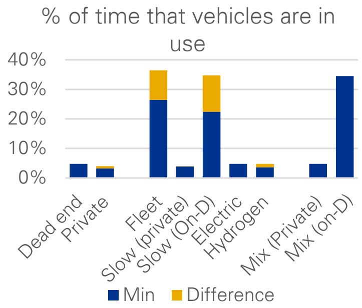

Car travel distance per person (km)

Vehicle fleet

Vehicle fleets are largely unaffected by scenario assumption variations.

Fleet street vehicle utilisation ranges significantly, from 26% (no mode shift) to 36% (Low flow).

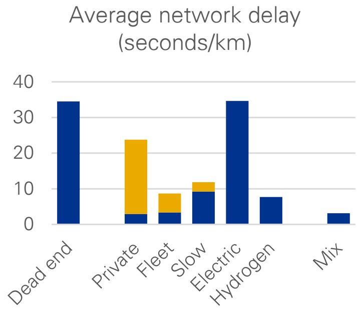

Number of vehicles

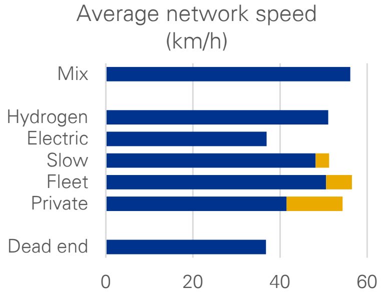

% of time that vehicles are in use

Road network

Network delays are highest for Electric avenue and Private drive – Empty running model runs.

Fleet street network speeds remain high regardless of scenario assumption variations.


Average network delay (seconds/km)


Average network speed (km/h)

11.2 More comfort and convenience of driving

Road congestion	Vehicle fleet	Physical activity	Accessibility
●	○	○	○
Road congestion increases because people see travel time as less of an inconvenience	The vehicle fleet increases because AVs are more attractive	Physical activity falls as people shfit from public transport to AVs	Accessibility increases as the perceived time cost of travel falls

AVs reduce the value of travel time savings

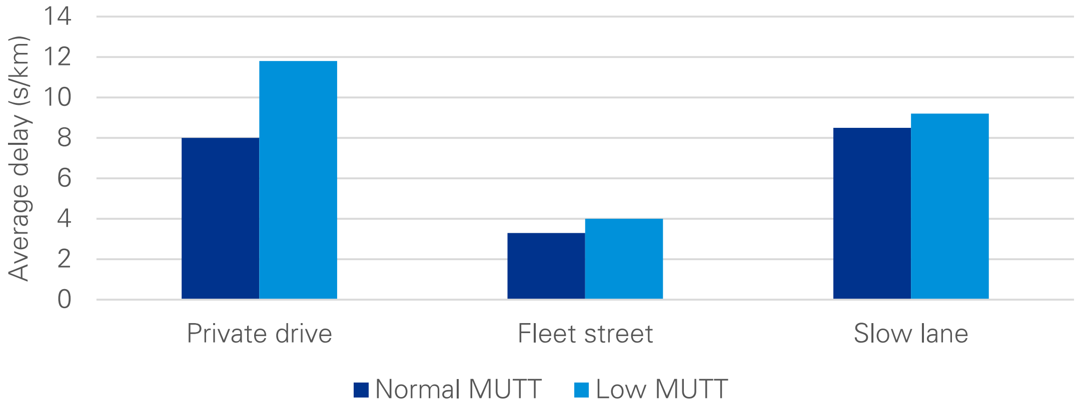
AVs allow occupants to undertake activities in private, such as reading, sleeping, watching movies, or work activities. Therefore, it is likely that AV occupants will not care as much about travel times, and will be happy to spend longer times in the AV compared to a private car.

All else being equal, this increases congestion

This ability to undertake activities while travelling is facilitated by the AVs, which are a feature of all of the scenarios apart from the Dead end and Electric avenue scenarios. All else being equal, not caring as much about travel times leads to more traffic congestion, less public transport use and less walking.

We tested this effect explicitly, and found that Low MUTT increased congestion in each of the private drive, Fleet street and Slow lane scenarios. In the Private drive scenario, Low MUTT led to a nearly 50% increase in average delays. This is demonstrated in Figure 12.

Figure 12: Average network delay (s/km), Low MUTT vs Default MUTT



Source: MABM

Various runs were undertaken varying the marginal utility of travel time to test its impact on outcomes. You can find some detailed results at the following links for the Private drive scenario morning peak flow (**page E.7**), afternoon peak flow (**page E.37**), morning peak speed (**page F.7**), afternoon peak speed (**page F.37**). Similar results exist for the Fleet street and Slow lane scenarios in the same Appendices. When you're done you can return using the Alt-left command.

11.2.1 Isolating the effects of comfort and convenience: Low MUTT runs

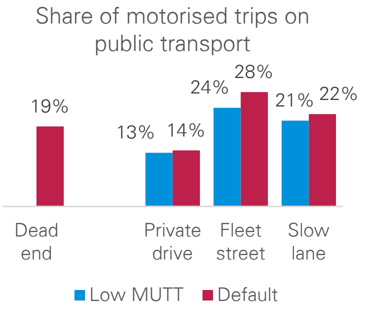
Scenario assumptions

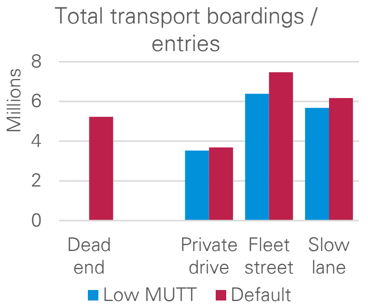
In the Low MUTT scenarios, all travellers have a lower perceived value of time when travelling in AVs, and are not as dissatisfied with long travel times as they are in a CDV. The value of time savings is halved for AV travel in low MUTT model runs.

- Private drive includes AVs, which are all privately owned. Both Private drive runs include no empty running.
- Fleet street includes AVs, which carry out customer trips on-demand and are not privately owned.
- In Slow lane, half the population has the option of using on-demand AVs and half the population owns a traditional private (ICE) car.
- AVs are assumed to flow 75% more efficiently on the roads than CDVs in all scenarios.

Public transport

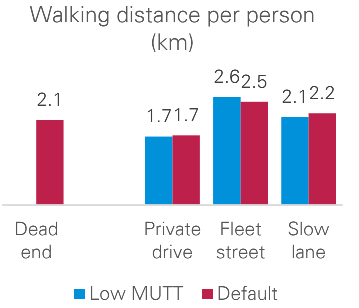
Less public transport is used in low MUTT model runs because the comfort and convenience of AVs compared to public transport offsets some of the time costs of using congested roads.

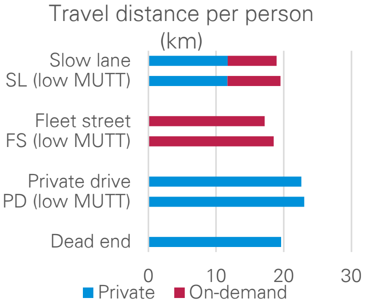

Share of motorised trips on public transport


Total transport boardings / entries

Travel distance

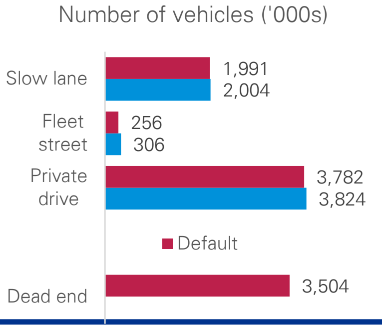
Travel distance is higher in low MUTT model runs, because demand for travel is less affected by road congestion.

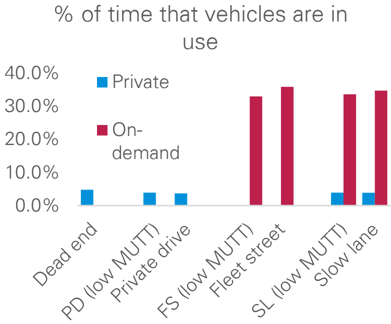

Walking distance per person (km)


Travel distance per person (km)

Vehicle fleet

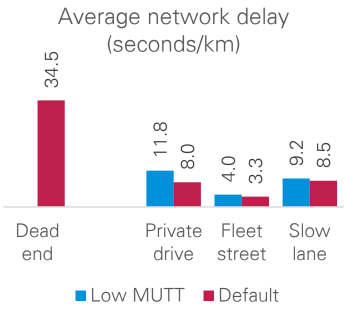
The vehicle fleet is not affected much by changes in the marginal utility of travel time.

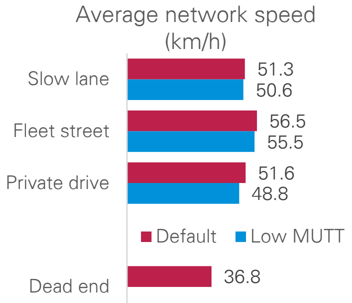

Number of vehicles ('000s)


% of time that vehicles are in use

Road network

Delays are higher when MUTT is lower, because people are more willing to wait in traffic, and so more travellers are clogging up the roads.


Average network delay (seconds/km)


Average network speed (km/h)

11.3 Mass take-up of vehicles on demand

Congestion	Vehicle fleet	Physical activity	Accessibility
○	●	○	○
Congestion worsens due to empty running between fares, adding around 13% to vehicle kilometres travelled.	The more that on-demand AVs are used, the fewer cars Melbourne needs in order to meet its travel needs.	People may use on-demand AVs to substitute public transport and active modes.	People have to wait for the vehicles to pick them up, adding to their overall journey time.

Vehicles on demand could replace private car ownership

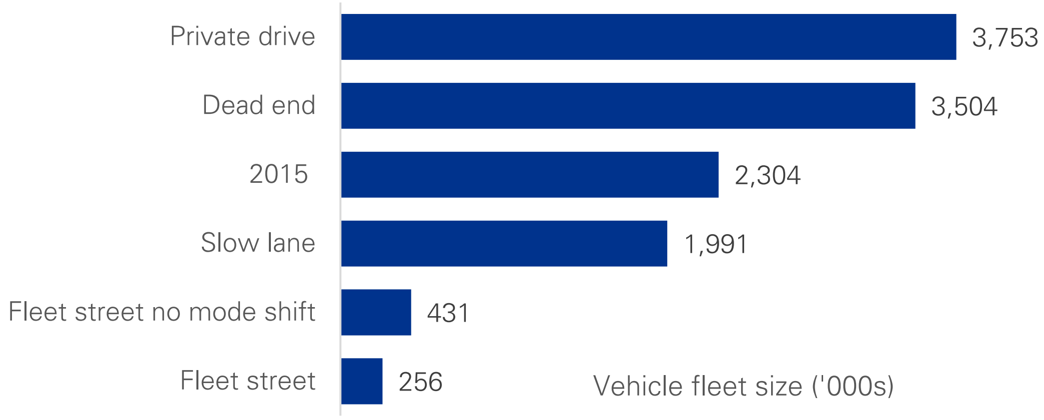
AVs on demand would allow consumers to completely forego private ownership, and instead rely on a taxi style service which is much cheaper and more convenient than today's taxis. This is because no driver needs to be paid. The literature suggests that this could reduce fares by about one-third, and this could be enough to bring the cost of using AVs on-demand for daily travel below the cost of private car ownership[29].

If mass take-up were to occur, the larger fleet would create efficiencies that would minimise wait times as well as creating economies of scale and network effects.

This could dramatically reduce the size of the vehicle fleet required to service Melbourne's road transport needs

Modelling shows that the overall fleet size could reduce by 88% to 93%, as shown in Figure 13. Modelling suggests that wait times would be acceptable, with an average wait time of less than six minutes during the morning peak in the Fleet street scenario (and even lower at other times of the day).

Figure 13: Vehicle fleet size, selected scenarios



Source: MABM

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[29] Refer to Section 4.3 of the separate report KPMG (2018), *Vehicles advice – financial analysis*.

11.3.1 Isolating the effects of mass take up of vehicles on demand

Scenario background

The key difference between the Private drive (no mode shift) and Fleet street (no mode shift) is the vehicle ownership model. In Private drive (no mode shift), travellers choose the same mode of travel as in Dead end, but use private AVs rather than private CDVs. In Fleet street (no mode shift), travellers choose the same mode of travel as in Dead end but use on-demand AVs instead of private CDVs.

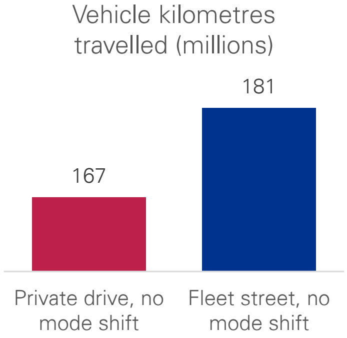
On-demand AVs incur fares and waiting times, and cars undertake empty runs (i.e. trips with no passengers) between customers. Empty runs add to congestion. Private AVs, on the other hand, are the same as CDVs except passengers are not required to manually drive the cars. In the Private drive (no mode shift) scenario, there are no empty runs.

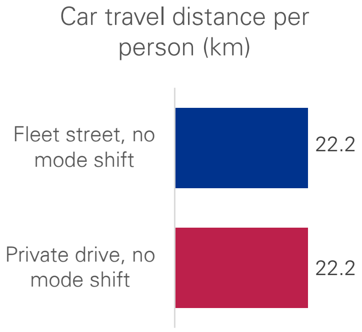
Comparing between Private drive (no mode shift) and Fleet street (no mode shift) isolates the effects of on-demand AVs compared to private AVs, before taking into account the behavioural effects of perceiving the full cost of fares (see Section 6.4 on sunk costs for more details on this).

Travel distance

Using on-demand AVs for the same trips as private AVs increases the total distance that cars drive on roads.

This is because on-demand AVs travel between customer trips, whereas private AVs do not (assuming empty running is not allowed).


Vehicle kilometres travelled (millions)


Car travel distance per person (km)

Vehicle fleet

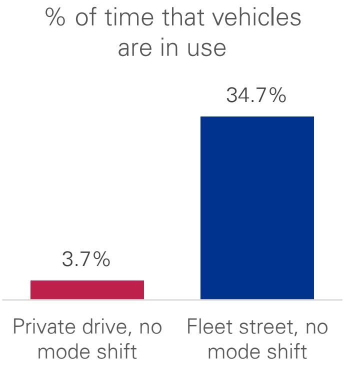
The vehicle fleet in the Fleet street (no mode shift) scenario is much lower than in Private drive (no mode shift), because the same number of private vehicle trips can occur with much fewer vehicles, if vehicles are shared in an on-demand model.

These vehicles are used much more of the time (34.7% compared to 3.7%).

Dead end and Private drive (no mode shift) 3.5 million

Fleet street (no mode shift) 431 thousand

Total number of private vehicles used on a typical weekday


% of time that vehicles are in use

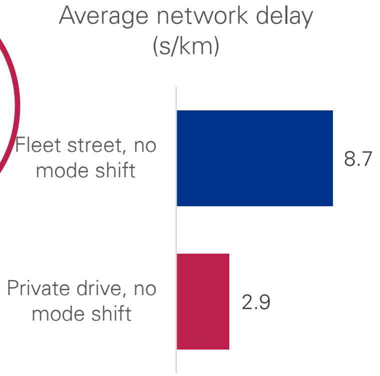
Travel experience

Congestion is worse when on-demand AVs are used for the same trips as private AVs, because on-demand AVs incur empty runs as part of their operating model.

However, on-demand AVs are also cheaper overall (because fixed costs are shared among many users) and avoid parking fees.

13% of travel distance of on-demand AVs occur while the vehicle is empty

Peak hour wait time is 5 mins 39 seconds in Fleet street (no mode shift)


Average network delay (s/km)

11.4 Less 'sunk' vehicle costs

Congestion	Vehicle fleet	Physical activity	Accessibility
🟢	○	🟢	🔴
Congestion falls as people are more likely to substitute driving for public transport and active modes.	Higher perceived trip-by-trip costs may encourage more people to buy their own private cars.	Physical activity increases as people are more likely to use public transport or walk directly between destinations.	Perceived trip-by-trip costs rise (despite lower annual costs) and accessibility reduces by 18%.

Less sunk cost and more perceived trip-by-trip cost reduces travel demand

The cost of purchasing a private vehicle is considered a sunk cost, as this cost is generally not taken into account when deciding whether or how to travel. For any individual trip using a private vehicle, the perceived cost of travel only includes the running costs (i.e. fuel or energy), the travel time and other costs such as tolls and parking.

The costs of using an on-demand AV differs to that of private AVs. For private AVs, the owner pays overhead costs (e.g. capital costs, insurance, registration, maintenance), and bases trip decisions on variable costs (e.g. fuel). However, the price of on-demand AV trips has to build in all the overhead costs, because the overhead costs are shared among all on-demand AV users. This means that instead of these costs being seen as "sunk", they are incorporated into each trip decision for an individual user.

On-demand AV costs could also be perceived as sunk costs if the cost is recovered via a subscription fee rather than a per trip fee, or if the government subsidises the service. However, for the purpose of this study, the use of on-demand AVs involves paying a fare to cover the cost of running the service, including the cost of purchasing the vehicles.

This may reduce your annual costs of travel, but also negatively impacts your sense of freedom of mobility

Even though using on-demand AVs increases the perceived cost of each trip, it in fact reduces the cost of driving for the community as a whole. This is because the overhead costs, such as financing, maintenance, registration and insurance, are shared among many users.

Despite this, because of an increase in the perception of the cost of each trip via a taxi fare, this decreases the accessibility (i.e. feeling of freedom of mobility) of people in the MABM results. This is exacerbated by the need to wait for a vehicle, rather than have it at or near your home ready to go.

It also decreases congestion and increases physical activity, as people are more likely to use public transport and active modes to avoid on-demand vehicle fares.

11.4.1 Isolating the effects of sunk vehicle costs: Fleet street scenarios

Scenario background

All Fleet street scenarios include on-demand AVs, and no private cars. In Fleet street (no mode shift), travellers choose the same method of travel as in Dead end, but use on-demand AVs in place of cars. But in the Fleet street scenario, traveller decisions are influenced by on-demand AV fares.

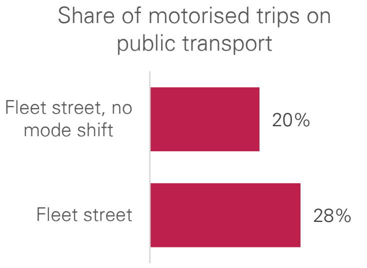
People view private car travel as cheaper than on-demand AV fares, because when people own cars, they pay a number of upfront costs (cost of the car, registration, insurance, servicing) which are “sunk”, meaning they are not part of day-to-day travel decisions. But on-demand AV fares “build in” all these costs, which means travellers are confronted with the full cost of running cars at each travel decision.

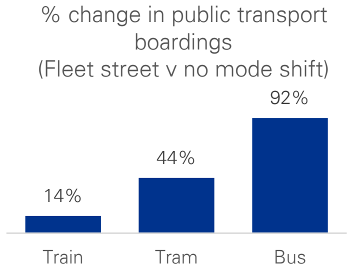
This means that people who own cars may make more trips than people who use on-demand AVs, even though the overall cost of using on-demand AVs is actually lower than private cars (because upfront costs are shared between many users through fares). This may be a behavioural barrier to the cheaper option of using more on-demand AVs.

The No mode shift model assumes that travellers choose the same mode of travel as they would in the Dead end scenario. In all scenarios, AVs are 75% more efficient on roads than CDVs due to platooning, and the value of time savings for travellers is the same as in Dead end

Public transport

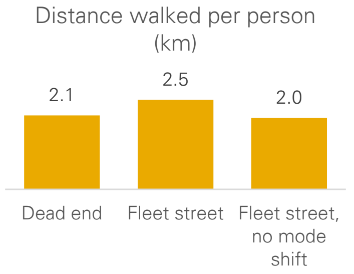
People are more likely to use public transport when only on-demand AVs are available, because they are confronted with the full cost of using AVs day-to-day (in fares) rather than only the marginal costs of private AVs (e.g. fuel)

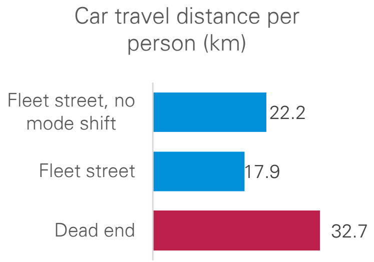




Travel distance

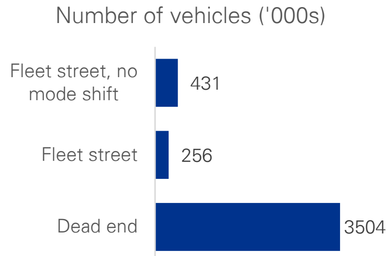
On-demand fares discourage people from using private transport. When travellers incorporate fares into their decisions, walking distance is longer and car travel is shorter.

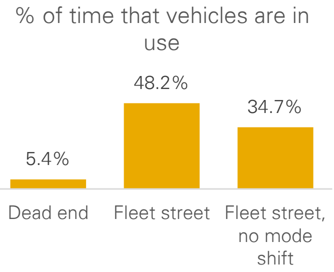




Vehicle fleet

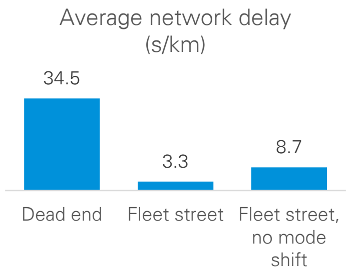
The vehicle fleet almost halves when sunk costs are taken into consideration, because less people choose private travel.

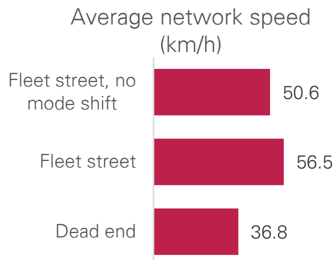




Road network

Delays are much lower in both Fleet street scenarios compared to Dead end due to the low fleet size, but delays are smaller and speeds are higher when sunk costs are considered by travellers.





11.5 Higher effective road capacity

Congestion	Vehicle fleet	Physical activity	Accessibility
●	-	○	●
Congestion reduces with platooning.	The vehicle fleet is relatively unaffected.	Walking distance falls due to lower public transport use.	Accessibility increases as congestion falls.

Platooning of AVs increases effective road capacity

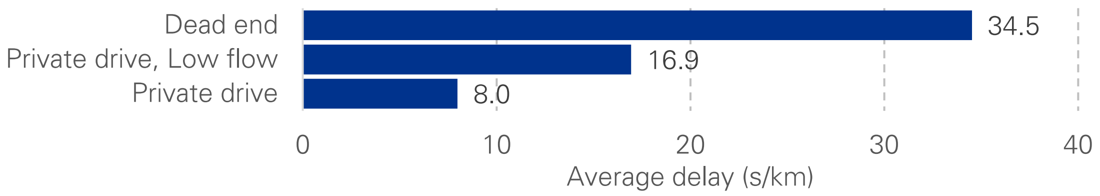
AVs are not restricted by the limits of human spatial awareness and reaction times. This means that AVs can operate safely with much smaller gaps between vehicles. The ability of AVs to travel in tight groups of vehicles is referred to as platooning. Platooning is a key feature of AVs and is facilitated by vehicle to infrastructure (V2I) and/or vehicle to vehicle (V2V) communication technology. Platooning occurs in all scenarios except for Dead end and Electric avenue.

The degree to which platooning can facilitate increases in vehicle throughput, and therefore road capacity, is an area of current investigation and debate. Literature reviews undertaken by the Technical University of Berlin (TUB) concluded that the appropriate increase in flow capacity is between 1.5 and 2.0[30]. For the purpose of this study, a mid-point of 1.75 was assumed to be the factor applied to uplift existing road capacities due to vehicle platooning. However, noting that the precise impact of platooning is subject to considerable uncertainty, alternative low flow factors of 1.25 were modelled as sensitivity tests. Regardless of the extent of platooning impacts on road capacity, the story is the same – AVs will allow us to get more performance from our existing road infrastructure, particularly our freeways.

This gives us the opportunity to reduce congestion and improve accessibility

The Private drive scenarios demonstrate the significant accessibility and congestion benefits that are available if we can enable platooning on our roads. This is demonstrated in Figure 14.

Figure 14: Average delay (s/km), Dead end vs Private drive, Low flow vs Private drive



Source: MABM

The only behavioural difference between the Dead end and Hydrogen highway scenarios is the ability for vehicles to platoon. You can find more information about how Hydrogen highway compares to Dead end at the following links: morning peak flow (**page E.5**), afternoon peak flow (**page E.35**), morning peak speed (**page F.5**), afternoon peak speed (**page F.35**). When you're done you can return using the Alt-left command.

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[30] See discussion and references in KPMG (2018), *2046 Reference Scenario and AZEVIA Model Development Report*.

11.5.1 Isolating the effects of AV flow factor changes: Low flow scenarios

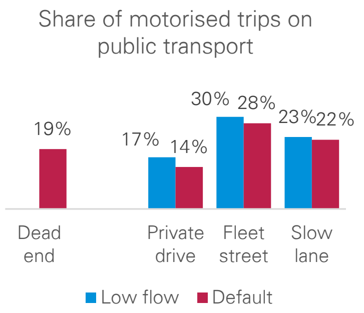
Scenario assumptions

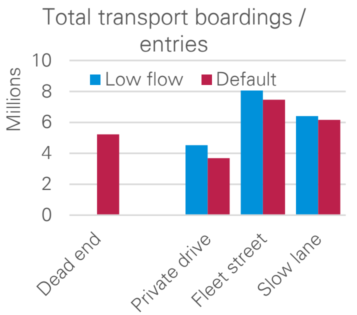
- Private drive includes privately owned AVs. There are no CDVs or on-demand AVs in this scenario.
- Fleet street includes AVs, which carry out customer trips on-demand and are not privately owned.
- In Slow lane, half the population does not own a car and instead relies on on-demand AVs, and half the population owns a traditional private (ICE) car.
- In the scenarios shown, it is assumed that AVs flow 25% more efficiently than CDVs. The main runs of each scenario assume AVs flow 75% more efficiently than CDVs.
- In all model runs, mode shift is determined by the model, private AVs are not allowed to do empty trips and marginal utility of time is the same as the Dead end scenario.

Public transport

Low flow scenarios all have higher public transport demand than their High flow counterparts.

When the effect of AVs on road capacity is diminished, congestion is higher and less people choose car travel.

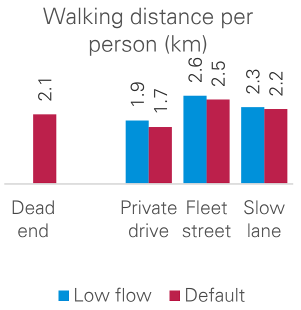

Share of motorised trips on public transport

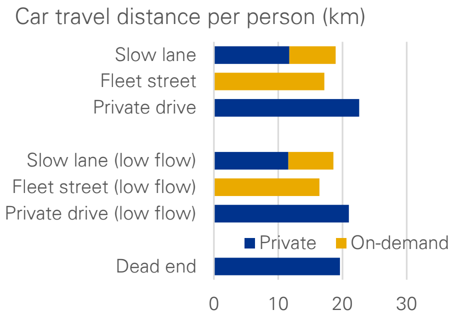

Total transport boardings / entries

Travel distance

Walking distance is higher in Low flow model runs, reflecting higher public transport usage.

Travel distance in cars per person is lower in Low flow runs due to a shift towards public transport.

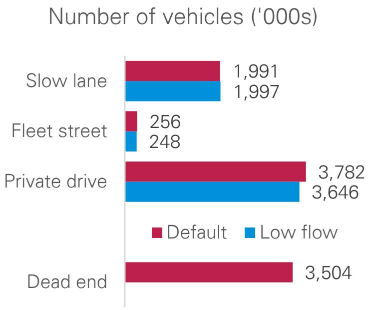

Walking distance per person (km)

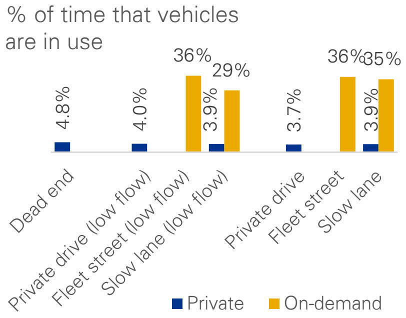

Car travel distance per person (km)

Vehicle fleet

The vehicle fleet is similar under each scenario, regardless of the flow factor of AVs.

Vehicles are in use slightly longer under the Low flow runs due to more congestion.

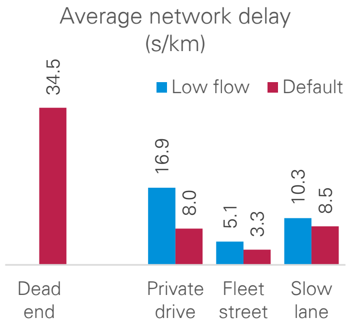

Number of vehicles ('000s)

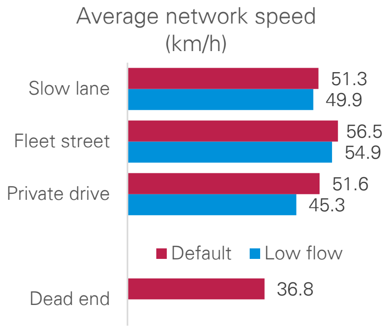

% of time that vehicles are in use

Road network

When the flow factor of AVs are lower, the road network is slower and has longer delays.

Private drive scenarios include the most car trips, and delays are more than doubled in the Low flow run.


Average network delay (s/km)


Average network speed (km/h)

11.6 Empty running

Congestion	Vehicle fleet	Physical activity	Accessibility
●	-	-	○
Congestion increases with empty running, particularly in inner areas.	The vehicle fleet is relatively unaffected.	Physical activity is relatively unaffected.	Slight negative effect on accessibility due to additional congestion

Unoccupied automated vehicles generate additional traffic

Automated vehicles can travel without any occupant. This means that AVs do not need to park at the location of their owners. For example, after arriving at a destination, private AVs can be sent home and then return later to pick up the owner and therefore avoid the need to pay parking charges.

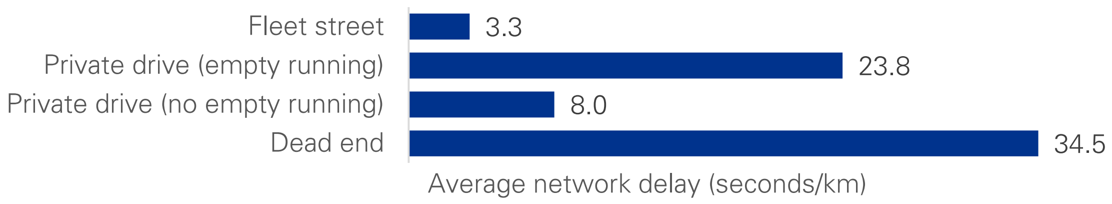
This ability of private AVs to undertake empty running can be a benefit to the owner, but also cause additional congestion, since the vehicle is travelling more on the network. On-demand AVs also exhibit a degree of empty running when travelling between different users, similar to empty running of existing taxis.

This is bad news for congestion, particularly in the CBD and inner suburbs

The Private drive, empty running scenario had significantly more delay in the inner cordon than the Private drive scenario. This is primarily due to the ability for people to avoid paying high parking fees in inner areas – they simply send their car home. This makes them more likely to drive into inner areas, adding to congestion. In addition, the empty kilometres driven by their vehicles add directly to congestion. The total delay experienced in the immediate surrounds of the CBD rose from 24,000 hours in the Private drive scenario to 70,000 hours in the Private drive, empty running scenario, a major deterioration in performance. This is shown in Figure 15. The significant negative impacts of empty private AVs on inner city congestion can also be seen in Figure 1 in section 5.2.2 (page 21).

The Fleet street scenario had 13% of distance travelled by vehicles on-demand being empty (i.e. on the way to pick up a passenger). This value rose to 19% in the immediate surrounds of the CBD. This highlights that empty running causing congestion in inner areas is a problem for vehicles on demand as well as private AVs (though not to the same extent).

Figure 15: Total delay (s/km), Private drive vs Private drive, Empty running



Source: MABM

11.6.1 Isolating the effects of empty running of private AVs

Scenario assumptions

The Empty running model run explores a future where private AVs are allowed to perform trips without people inside the vehicles. This could include dropping the car owner at a location then driving back to the owner's home to avoid parking charges. This model run explores how allowing Empty running on private AVs affects travel behavior and the demands on Melbourne's road network.

- The Dead end scenario includes only private CDVs and public transport, whereas the Private drive and Hydrogen highway model runs include public transport and privately owned AVs, but no on-demand AVs and no CDVs.
- In all model runs, AVs flow 75% more efficiently on roads than CDVs and the marginal utility of time is the same as the Dead end scenario.

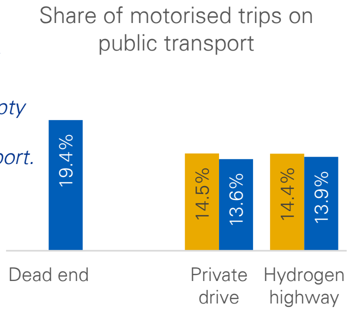
Legend

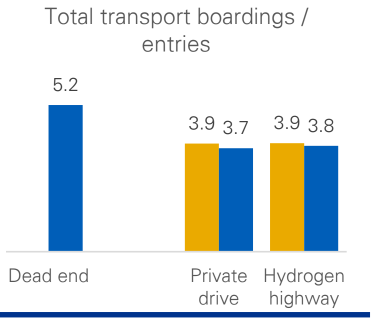
No empty runs
Empty running

Public transport

Public transport usage is slightly higher when private AVs can do empty runs. This is because empty runs cause congestion, causing people to switch to public transport.

Empty running scenarios still have lower public transport usage than Dead end when there are no on-demand AVs.

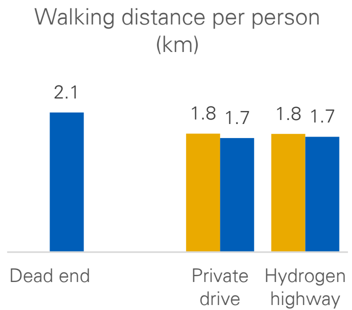

Share of motorised trips on public transport

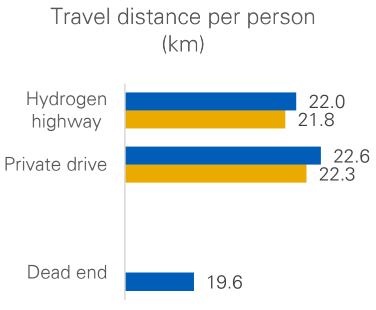

Total transport boardings / entries

Travel distance

Allowing Empty running increases walking distance through higher public transport usage.

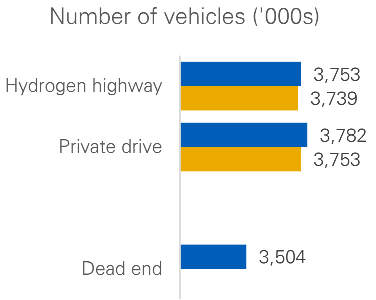
Travel distance per person increases with Empty running, because of extra trips taken with no occupants.

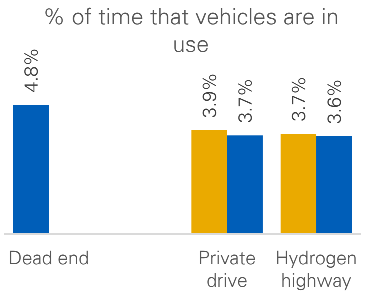

Walking distance per person (km)


Travel distance per person (km)

Vehicle fleet

Empty running increases vehicle utilisation because of the extra empty trips.

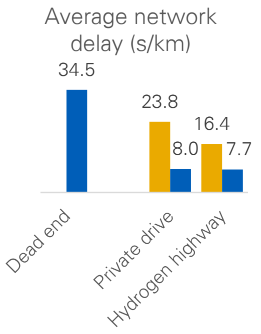

Number of vehicles ('000s)

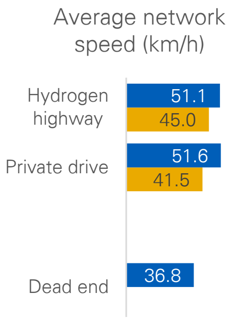

% of time that vehicles are in use

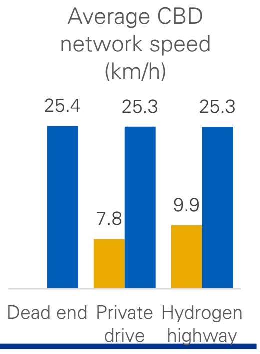
Road network

The introduction of private AVs significantly reduces congestion and delays.

But adding Empty running offsets much of this benefit, by adding more car trips on the roads.


Average network delay (s/km)


Average network speed (km/h)


Average CBD network speed (km/h)

12 How should we respond?

New transport technologies will have major influences on the way our cities and towns look, feel and function. The future of transport technologies is changing rapidly and is subject to considerable uncertainty. Techniques, such as scenario analysis (as used in this report) and real options analysis for dealing with uncertainty in long term planning for infrastructure, will be needed to navigate this uncertainty. New transport technologies present opportunities to realise major economic, social, environmental and liveability benefits, but they also come with threats of potential negative impacts if not appropriately managed. Some of these opportunities and threats are summarised below.

12.1 Opportunities and threats

The impacts of new transport technologies on our cities and towns will be profound and long lasting. If appropriately managed, these technologies could afford major economic, social, environmental and liveability benefits to Victorians. This section outlines some major opportunities and threats arising from new vehicle technologies, as well as the potential impacts of these opportunities and threats.

12.1.1 Opportunities

› Reduce the size of the fleet

The Fleet street scenario demonstrates that the same road transport task (with no mode shift to public transport) could be serviced by 7% as many vehicles as the Dead end scenario, with an average passenger wait time of less than six minutes in the morning peak and an average wait time of less than three minutes overall. A move to shared ownership would dramatically reduce the overall fleet size in Victoria.

+ Consumers save money by sharing fixed costs (e.g. finance, maintenance, insurance, registration, tyres) with numerous others who use the same vehicle.
+ Less raw materials are needed to build cars, leading to environmental benefits.
+ Fleet vehicles are highly utilised and are rarely parked. Vehicles are also able to be parked outside of dense areas, freeing up valuable land from being used for parking.
+ Fleet vehicles do not need to park in high-value areas (e.g. near activity centres or other locations where people visit) which frees up roadside parking space for other uses such as extra driving space, urban green space, active transport infrastructure (e.g. bike paths), community facilities, linear parks or housing.

Get more from our existing road infrastructure

The Private drive and Hydrogen highway modelling demonstrates that there are major road capacity improvements available from platooning, especially on freeways. The higher the proportion of AVs on the road, the greater the benefits. The Fleet street scenario also demonstrates that road performance improvements result from higher rates of public transport patronage.

+ Travel time savings for commuters.

+ Delay of major capital road investments, saving taxpayer money.

+ Less raw materials are needed to build roads, leading to environmental benefits.

+ Improved connectivity and productivity of Victoria’s businesses.

+ Improved freight productivity.

What’s the evidence? The modelling shows that platooning has the ability to lead to major improvements in the performance of Melbourne’s road network, despite induced demand that offsets part of the benefit. For more discussion and modelling results on this topic, please refer to **Section 11.5**. Also see the changes in vehicle flows in the Private drive (**page E.1**) and Hydrogen highway (**page E.5**) scenarios relative to the Dead end scenario in Appendix E, as well as volume capacity ratio plots in **Appendix D** and change in speed plots in **Appendix F**. Better performance from existing roads means we do not need to invest as heavily in new road capacity if we have a high proportion of AVs on our roads in future. This is demonstrated in the “No new (pre-construction) major road projects” scenario in **Section 7.2.3**. When you’re done, you can return using the Alt-left command.

Improve amenity and liveability

New technologies will help us get more value from our existing road infrastructure if appropriately managed. If this can be realised, it may be possible to re-evaluate the roles of some of our urban roads, reducing the traffic on them. This would help to design cities that are safer, more universally accessible, are better places to spend time in, and encourage active forms of transport such as walking and cycling.

+ Improved amenity and liveability in local neighbourhoods.

Make transport pricing fairer

The current system of transport pricing is not fair or equitable. The system relies on private vehicle registration (which is the same for everyone regardless of how much they drive), fuel excise and the parking levies. These sources of funding may become obsolete with electric vehicles, vehicles on demand and private AVs that can avoid parking costs. These revenue sources will therefore need to be replaced. This presents an opportunity to make transport pricing better and fairer. An integrated transport pricing approach would help to pay for public infrastructure in a more equitable way and also manage demand to get the most out of our infrastructure.

+ Fund infrastructure in a way that beneficiaries of infrastructure pay for it.

+ Intelligently and fairly manage demand in our busiest areas and our busiest times.

Reduce transport disadvantage

Currently, only people of driving age with both car ownership and a valid driver's license are able to access the benefits of private car travel. With AVs, it may be possible for a larger segment of society to access the freedom of mobility benefits that can only currently be accessed by driving. For example, school age children may be able to 'drive' to school in an AV, and elderly or disabled people who are not able to drive may have improved access to opportunities.

+ Provide universal access to the benefits of private car travel

12.1.2 Threats

Congestion due to empty running of private AVs

The Private drive scenario demonstrates a major reduction in average speed and increase in average delay when people are able to send their private AVs home to avoid parking costs. This is caused by two factors.

Factor 1: The cost of sending your car home to park is much lower than the cost of parking in the CBD and inner areas. Empty running reduces the downside of driving to work – and therefore many more people drive instead of using public transport. This adds to congestion in the inbound direction during the morning peak and in the outbound direction in the afternoon peak.

Factor 2: The empty vehicles being sent home add directly to vehicle kilometres travelled and congestion, as people are delayed behind the empty cars being sent home. These empty cars add directly to traffic and congestion, particularly in the afternoon peak.

- More traffic and congestion in our busiest (inner) areas.

- More traffic and congestion in peak directions and times.

Congestion due to comfort and convenience of AVs

Road users benefit from not having to actively drive when they use AVs. However, this benefit has a potential negative side effect. If people are happy to accept longer travel times and more congestion as they sleep, read, work or consume entertainment in the privacy of their AV, they slow down the roads for those who are in a hurry. This is demonstrated in the 'Low MUTT' variants of the Private drive, Fleet street and Slow lane modelling scenarios.

- More traffic and congestion in peak directions and times.
- More traffic and congestion in our busiest (inner) areas.

Congestion due to empty running of on-demand AVs

The Fleet street scenario demonstrates that around 13% of kilometres driven by on-demand AVs occur with no passengers (i.e. on the way to collecting passengers). This proportion reaches 16% during the morning peak when demand is strongly skewed to inbound CBD and inner city trips. This adds to traffic and congestion, particularly in the CBD and inner areas of Melbourne.

- More traffic and congestion in our busiest (inner) areas.
- More traffic and congestion in peak directions and times.

What's the evidence? The Fleet street scenario had the best outcomes for congestion of all the modelled scenarios. A summary of the effects of main scenarios appears in **Section 5**, and detailed discussion of Fleet street scenario is in **Section 7.1**. The primary driver of this result is the fare of on-demand AVs – a cost which is perceived in full, unlike with private AVs where much of the cost is 'sunk', and not perceived on a trip-by-trip basis. This is described in detail in **Section 11.4**.

Controlling for the effects of sunk costs, empty running of on-demand AVs (in between dropping off one passenger and collecting the next one) increases vehicle kilometres travelled and adds to congestion, particularly in the busiest areas for drop-offs, such as the CBD and major transport hubs like train stations. This is a threat that will need to be managed. This is discussed in detail in **Section 11.6**.

When you're done, you can return using the Alt-left command.

Delays getting in and out of on-demand AVs

The Fleet street scenario demonstrates that the areas with the highest demand for on-demand AVs are in the inner areas. The high demand for on-demand AVs in these areas will lead to delays as on-demand AVs constantly stop to allow passengers to enter and leave the vehicles.

- More delays on the roads in our busiest (inner) areas.

Congestion due to urban sprawl

The Private drive scenario shows major increases in accessibility in Melbourne's outer areas, with little change in the inner and middle areas. This will make outer areas more attractive for developers and residents, and will lead to increasing urban sprawl, particularly along freeway corridors. These people will also prefer private ownership and will have higher rates of car use. With urban sprawl, we risk eroding the capacity benefits for our freeways by flooding them with additional demand from the outlying areas.

- More traffic and congestion in peak directions and times.

What's the evidence? The scenarios described in this report do not account for changes in urban development patterns, but rather assume that the distribution of population and jobs within Melbourne is the same for all the modelled scenarios. It is widely acknowledged that land use is affected by transport, as new high speed and high capacity infrastructure encourages urban sprawl. Many of the modelled scenarios include major changes in accessibility, implying that land use impacts of these scenarios are likely to be significant, including urban sprawl for scenarios with private AVs (see Private drive on **page C.1**). This would likely lead to additional congestion, particularly in outer areas. Conversely, scenarios with on-demand AVs are likely to lead to densification, as accessibility worsens in outer areas relative to business as usual (see Fleet street on **page C.2**).

We tested some alternative urban development scenarios to examine their impacts on the measures of success described in this report. The outcomes are described in detail in **Section 9**. When you're done, you can return using the Alt-left command.

Poor accessibility and equity outcomes

The Fleet street scenario shows major decreases in accessibility in Melbourne's outer areas. This is because on-demand AV fares have time and distance components, and are more costly for long trips from outer areas, compared with inner city travel. These outer areas also have fewer public transport alternatives. These areas tend to have lower household incomes. These factors could combine to create major inequality for residents of outer areas if they need to rely solely on on-demand AVs and public transport. All of the other scenarios also had more inequality of accessibility relative to the Dead end scenario, because the new technologies benefit some segments of the population more than others.

- Increasing transport disadvantage in outer areas.
- Increasing economic inequality from lack of access to economic and social opportunities.
- Reducing social mobility due to lack of access to economic and social opportunities.

Reduced productivity of our CBD and inner core

In the Private drive scenario, congestion increases more in inner areas. This is because driving becomes more attractive as a whole, due to platooning, increased comfort and convenience and lower operating costs. People save time on their entire journey, but the last part of the journey becomes slower as traffic funnels into the inner areas from all over the city. This is further aggravated by private AV empty running, which adds more traffic and congestion in the inner areas. This could have major negative impacts on the inner core of Melbourne, which is the engine of the Victorian economy.

- Lower productivity and poorer economic outcomes due to reduced connectivity of businesses in the inner core.
- Less attractive place for migrants and investors, as poorer economic outcomes would mean less employment and business opportunities.
- Less attractive place for tourists and visitors.

12.2 Potential responses

We have provided a number of potential responses that are designed to realise the opportunities and mitigate the threats of new vehicle technologies. The responses are intended to support and reinforce one another. Further detailed analysis will be required to develop a holistic and integrated policy response.

12.2.1 Non-build

Create an integrated transport pricing strategy

The new transport technologies discussed in this report will force us to re-think how we price transport in Victoria. The Government should consider preparing an integrated transport pricing strategy that addresses the following objectives:

Objective 1: Incentivise people to use on-demand AVs for everyday travel *rather than private ownership of AVs*. This will enable the benefits that come from reducing the fleet.

Objective 2: Incentivise people to use a mix of on-demand AVs, public transport, walking and cycling for everyday travel. In addition to the health benefits from more and active public transport use, this will also help to maximise the performance of the road network. This means that when people are in a hurry, they will be able to get to their destination quickly.

Objective 3: Manage demand in the busiest times and locations. Melbourne's parking levies serve an important role in managing demand in our busy inner areas. With AVs that can avoid parking costs, these levies lose their effectiveness. An area-based or cordon charge may be introduced to replace the demand management function of the parking levy.

The Government should also consider other mechanisms such as peak pricing, distance-based pricing and other pricing regimes to manage demand. Ensuring that any pricing regime is fair and equitable, and does not lead to poor accessibility and equity outcomes, will be important.

Objective 4: Fund infrastructure in a fair and equitable way. Ensure that the people and businesses who benefit the most from the road infrastructure are the ones who pay the most for it.

Objective 5: Dis-incentivise empty running. Owners of private AVs will easily be able to avoid any parking charges, and simply send their cars home (or to park on the street in nearby suburbs), adding to congestion. Empty running of private AVs could be directly priced to discourage this behaviour if technically feasible.

› Reduce the fleet
› Make transport pricing fairer
‹ Avoid congestion due to empty running of private AVs
‹ Avoid congestion due to empty running of on-demand AVs
‹ Avoid delays getting in and out of on-demand AVs
‹ Avoid congestion due to comfort and convenience
‹ Avoid poor accessibility and equity outcomes
‹ Retain productivity of our CBD and inner core

Address coverage and fares for on-demand AVs

The Government should consider preparing a strategy to encourage the use of on-demand AVs in outer areas with the following objectives:

Objective 1: Improve coverage in outer areas. Wait times for on-demand AVs are expected to be higher in outer areas than inner areas. Policy or regulatory mechanisms to ensure that outer areas have minimum agreed levels of service for on-demand AVs may be needed.

Objective 2: Address pricing in outer areas. Private businesses may choose to charge higher fares to passengers in outer areas to compensate for the additional empty running required to service those passengers. Regardless, these passengers will be hit the hardest by on-demand vehicle fares due to higher average trip time and distance. Policy or regulatory mechanisms might be necessary to ensure people in outer areas are not unduly disadvantaged, while ensuring that on-demand AV operators remain viable with sustainable pricing models.

Objective 3: Consider the split of fixed and variable payment plans. Private businesses may choose to offer 'unlimited plans', where the user has an unlimited amount of travel for a monthly, quarterly or annual payment, with no additional cost per trip. At the other extreme, there may be no upfront payment and only a variable cost per trip (similar to today's vehicles on demand). Policy or regulatory mechanisms to ensure an appropriate balance between protecting the freedom of mobility of people in outer areas with the need to manage excessive travel caused by unlimited plans may be needed.

Objective 4: Incentivise use of on-demand AVs to access high capacity public transport services. Incentives may be necessary to encourage the use of vehicles on demand as a feeder service for high capacity public transport (e.g. rail). This may help to discourage private ownership, reduce congestion and protect the accessibility of residents of outer areas.

› Reduce the fleet

› Reduce transport disadvantage

‹ Avoid congestion due to urban sprawl

‹ Avoid poor accessibility and equity outcomes

Plan for population growth in inner and middle suburbs

Residents of outer areas may prefer private ownership over vehicles on demand, due to the accessibility benefits and the lack of high quality alternatives to driving. A detailed land use strategy that is consistent with the possible future scenarios defined by IV, ensuring affordable housing in areas with good access to opportunities by public transport, walking and cycling will be necessary. This may help to discourage private ownership and reduce congestion.

> Reduce the fleet

< Avoid congestion due to urban sprawl

Re-evaluate the road hierarchy

AVs are able to make much more efficient use of road infrastructure. If the recommendations in this report are enacted to manage congestion from induced demand, it may be possible to modify and repurpose parts of the Victorian road network. This presents an opportunity to provide more liveable spaces for residents, including parks and other public spaces.

> Improve amenity and liveability

12.2.2 Build

Build communications infrastructure to enable platooning

Vehicle to infrastructure (V2I) communications infrastructure may be required to enable the benefits of platooning. This may include roadside units or equipment and safe communication channels to communicate with individual AVs' on-board units or equipment.

> Get more from our existing road infrastructure

Invest in high quality alternatives to driving

Government should consider initiatives to make public transport, walking and cycling more attractive for everyday activities. This is particularly important in the inner areas, where road congestion is the most severe. This will help to encourage people to take up on-demand vehicles, rather than private AVs. It is important that this is implemented in conjunction with an integrated transport pricing strategy (as described in the following section).

> Reduce the fleet

Invest in high capacity trunk public transport

Melbourne’s inner core is the engine of the Victorian economy, and the trains provide the fuel, large volumes of highly skilled and productive knowledge workers.

Despite road capacity improvements from platooning, any additional road capacity into the CBD and inner areas will be relatively small. This is because of the constrained roads and many intersections in these areas. To continue to fuel Melbourne’s economy, we will need to have more high capacity trains bringing high volumes of knowledge workers into the inner core.

- ❮ Retain productivity of our CBD and inner core

Provide parking and drop-off/pick-up locations for AVs

New infrastructure will be required to park AVs and provide drop-off/pick-up space for AVs, which may be provided or facilitated by Government. There are two main objectives:

Objective 1: Discourage people from sending private AVs home. Owners of private AVs will easily be able to avoid any parking charges, and simply send their cars home (or to park on the street in nearby suburbs), adding to congestion. Appropriately located and low-priced (or free) parking depots may be needed at appropriate locations to prevent people from doing this. This should be undertaken in conjunction with an integrated transport pricing strategy (as described in the following section). Alternatively, empty running of private AVs could be directly priced to discourage empty running if technically feasible.

Objective 2: Integrate drop-off/pick-up areas with transport hubs. It will be important to integrate on-demand AV pickups and drop-offs with major transport hubs like train stations. It will be important to provide appropriately laid out and regulated drop-off/pick-up areas for this to occur to prevent delays and poor amenity outcomes. This will also help to encourage people to use on-demand AVs to access train stations – allowing people in outer areas to maintain accessibility to key opportunities such as jobs, education and healthcare. Similar facilities may be required in busy areas like the CBD and other major activity centres. Strategies and specific analysis will be required to understand how best to provide access for on-demand AVs in and near high demand areas such as peak periods on weekdays in the CBD and on game day at the MCG.

- ❯ Reduce the fleet
- ❮ Avoid congestion due to empty running of private AVs
- ❮ Avoid delays getting in and out of on-demand AVs
- ❮ Avoid poor accessibility and equity outcomes
- ❮ Retain productivity of our CBD and inner core

Appendix A: Detailed scenario assumptions and results

Appendix A: Detailed scenario descriptions, assumptions and results

This appendix lists the asssumptions relating to each of the modelled scenarios and is designed for quick reference.

A detailed definition of the scenario variables (MUTT, VOC, Empty running etc.) is contained in Section 3 of the main report.

- MUTT factor is the marginal utility of time. The lower the MUTT factor, the less travelers value the time of travel in their decision making. The value of time may become less important with the introduction of AVs, because AV are more convenient to travel in (i.e. travelers can sleep, eat, work or consume entertainment during the trip).
- No mode shift means the scenario is run assuming that travelers make the same choices as in the Dead end scenario. This model run is used to isolate the effects of the new vehicle technologies, before increased popularity of AVs or other travel modes are taken into account. They are still able to change their time of travel and their route or choice of public transport service.
- The flow factor represents the increased efficiency of AVs. In most scenarios the AV flow factor is 1.75, meaning AVs flow 75% more efficiently than conventionally driven vehicles (CDVs). In Low flow model runs, this is reduced to 25%.
- Empty running refers to the ability of private AVs to make trips without owners (e.g. to return home in order to avoid parking)

Run name	Run description	Year	Automated vehicles	Vehicles on demand	Zero emission vehicles	Mode shift	Empty running	MUTT factor	VOC c/km	Flow factor
2015 comparison	The baseline 2015 run described in the MABM Calibration and Validation Report[1].	2015	✗	✗	✗	✓	✗	1.0	17.6	1.0
2031 comparison	The 2031 MABM "business as usual" projection described in the MABM Calibration and Validation Report[4].	2031				✓	✗	1.0	17.6	1.0
Dead end	This is the no change, 'business as usual' scenario as described in the 2046 Reference Scenario and AZEVIA Model Development Report[2]. None of the new transport technologies are taken up by 2046. The fleet is entirely composed of traditional CDVs which are privately owned. This forms a reference scenario in that it is similar to existing fleet composition and ownership models.	**2046**				✓	✗	**1.0**	**17.6**	**1.0**
Private drive	**All vehicles are automated, but are privately owned. The AVs are zero emission – they are powered by electricity, not fossil fuels.**	**2046**	✓	✗	✓	✓	✓	**1.0**	**5.0**	**1.75**
- No empty running	Private vehicles are not allowed to make trips without occupants (e.g. to drop travellers at a destination then return home).	*2046*				✓	✗	*1.0*	*5.0*	*1.75*
- Low MUTT	The perceived value of time is lowered. This means travellers are not as concerned about the time of travel, as they are in other scenarios.	*2046*				✓	✗	*0.5*	*5.0*	*1.75*
- Low flow	The AV flow factor is lowered. This means AVs are still more efficient than CDVs in terms of road capacity, but by a smaller margin.	*2046*				✓	✗	*1.0*	*5.0*	*1.25*
- No mode shift	Mode share stays the same as in Dead end. This means travellers are not able to change their transport mode choice when new technologies arrive.	*2046*				✗	✗	*1.0*	*5.0*	*1.75*
- Area based charge	A base charge of $2.50 is applied for private vehicles that drive in the inner city area, with a higher $5.00 charge applicable at peak times.	*2046*				✓	✓	*1.0*	*5.0*	*1.75*
- Distance based charge	A per-kilometer charge of 12.6c is applied to private vehicle trips. The same charge is applied regardless of location or time of day.	*2046*				✓	✓	*1.0*	*5.0*	*1.75*
- Freight to night	Half of daytime freight traffic is moved to night time.	*2046*				✓	✓	*1.0*	*5.0*	*1.75*
- Expanded markets	Automated vehicles allow a portion of people who couldn't drive in the dead end scenario because they lacked a driver's license to access private vehicles.	*2046*				✓	✗	*1.0*	*5.0*	*1.75*
- Station drop-off and pick-up	Removes capacity constraints in Park n Ride so that an unlimited number of people can use the Park n Ride space anytime.	*2046*				✓	✓	*1.0*	*5.0*	*1.75*
- Centralised land use	More of the population lives in the inner city (as per Infrastructure Australia's Centralised High Density scenario[3]).	*2046*				✓	✓	*1.0*	*5.0*	*1.75*
- Expanded land use	More of the population lives in the outer suburbs (as per Infrastructure Australia's Expanded Low Density scenario[4]).	*2046*				✓	✓	*1.0*	*5.0*	*1.75*

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[1] KPMG and Arup (2017), Model Calibration and Validation Report, Available from https://goo.gl/dZdfwJ.

[2] KPMG (2018), 2046 Reference Scenario and AZEVIA Model Development Report.

[3] Infrastructure Australia (2018), Future Cities: Planning for our growing population, Available from https://goo.gl/gLTMkB.

Run name	Run description	Year	Automated vehicles	Vehicles on demand	Zero emission vehicles	Mode shift	Empty running	MUTT factor	VOC c/km	Flow factor
Fleet street	**All vehicles are automated, and operate as on-demand vehicles. This means that all car travel is undertaken via a fleet of shared, on-demand automated taxis. All vehicles are automated and are powered by electricity, not fossil fuels.**	**2046**	🚗	📱	🔋	✓	✓	**1.0**	**5.0**	**1.75**
- Subscription fare	*Users of vehicles on demand are assumed to have an annual subscription, which reduces the perceived cost per trip*	*2046*	*Shared AVs incur a fare, which includes a: $2 flag fall; 0.07 $/min time based fare; and 0.22 $/km distance based fare, which includes the distance based VOC. DRT fee of $2.78. The subscription fare variant has a flag fall of $0.50 and and distance based fare of 0.05 $/km.*			✓	✓	*1.0*	*5.0*	*1.75*
- Low MUTT	The perceived value of time is lowered. This means travellers are not as concerned about the time of travel, as they are in other scenarios.	*2046*				✓	✓	*0.5*	*5.0*	*1.75*
- Low flow	The AV flow factor is lowered. This means AVs are still more efficient than CDVs in terms of road capacity, but by a smaller margin.	*2046*				✓	✓	*1.0*	*5.0*	*1.25*
- No mode shift	Mode share stays the same as in Dead end. This means travellers are not able to change their transport mode choice when new technologies arrive.	*2046*				✗	✓	*1.0*	*5.0*	*1.75*
- No new (pre-construction) major road projects	Melbourne's assumed 2046 road network does not include any major road projects which do not have committed funding in 2018.	*2046*				✓	✓	*1.0*	*5.0*	*1.75*
- Calibrated fleet size	The number of on-demand AVs available is assmed to be lower, so that realistic wait times can be modelled.	*2046*				✓	✓	*1.0*	*5.0*	*1.75*
- Buses replaced by DRT	Mode share stays the same as in Dead end. Bus trips are replaced by multi-passenger shared AVs (demand responsive transport or DRT).	*2046*				✗	✓	*1.0*	*5.0*	*1.75*
High speed	**Fleet street but in 2031 (this is not run, but inferred from the 2046 Fleet street outputs).**	**2031**	🚗	📱	🔋	✓	✓	**1.0**	**5.0**	**1.75**
Slow lane	**Half of the population uses a vehicle on demand model, and the other half of the population use privately owned CDVs.**	**2046**	🚗 ✗	📱 ✗	🔋 ✗	✓	✓	*1.0*	**5.0**	1.75
- Low MUTT	The perceived value of time is lowered. This means travellers are not as concerned about the time of travel, as they are in other scenarios.	*2046*				✓	✓	*0.5*	*5.0*	*1.75*
- Low flow	The AV flow factor is lowered. This means AVs are still more efficient than CDVs in terms of road capacity, but by a smaller margin.	*2046*				✓	✓	*1.0*	*5.0*	*1.25*
- No mode shift	Mode share stays the same as in Dead end. This means travellers are not able to change their transport mode choice when new technologies arrive.	*2046*				✗	✓	*1.0*	*5.0*	*1.75*
- Private slow lane	Half of the population uses a private AV and half the population uses a private CDV.	*2046*				✓	✓	*1.0*	*5.0*	*1.75*
Electric avenue	**The fleet is entirely composed of electric vehicles (but vehicles are not automated) and are privately owned.**	**2046**	✗	✗	🔋	✓	✗	**1.0**	**5.0**	**1.0**
Hydrogen highway	**All vehicles are privately owned and automated (as in Private drive), but the cars a powered by hydrogen fuel cells.**	**2046**	🚗	✗	H	✓	✓	**1.0**	**17.6**	**1.75**
- No empty running	Private vehicles are allowed to make trips without occupants (to drop travellers at a destination then return home, for example).	*2046*				✓	✗	1.0	17.6	1.75
Mix of scenarios	**On-demand AVs, private AVs and private zero-emission CDVs co-exist, and are distributed across the population based on geography.**	**2046**	🚗 ✗	📱 ✗	🔋	✓	✓	*1.0*	**5.0**	1.75
- Centralised land use	All assumptions are the same expect more of the population lives in the inner city (as per Infrastructure Australia's Centralised High Density scenario[4]).	*2046*				✓	✓	*1.0*	*5.0*	*1.75*
- Expanded land use	All assumptions are the same expect more of the population lives in the outer suburbs (as per Infrastructure Australia's Expanded Low Density scenario[4]).	*2046*				✓	✓	*1.0*	*5.0*	*1.75*

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[4] Infrastructure Australia (2018), Future Cities: Planning for our growing population, Available from https://goo.gl/gLTMkB.

Key results: No automation (Base cases and electric avenue) and public transport scenarios

Scenario category	No automation scenarios				Fleet street DRT comparison		Private drive PT comparison	
Scenario	*2015*	*2031*	*Dead end 2046*	*Electric avenue*	*No empty running (main)*	*Empty running*	*Main scenario*	*Station drop-off and pick-up*
Demographics								
Population	4,493,204	5,988,856	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256
Employment	2,311,127	3,095,696	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579
Trips								
Private CDV	9,843,252	12,054,924	13,473,704	13,467,596	-	-	-	-
Private AV	-	-	-	-	14,700,684	14,581,672	14,768,900	14,531,356
On-demand AV	-	-	-	-	-	-	-	-
Public transport*	1,060,412	1,892,704	3,245,536	3,257,432	2,382,704	2,457,376	2,328,612	2,485,332
Walk trips	1,410,048	2,125,524	3,370,008	3,363,288	3,021,708	3,066,776	3,008,312	3,089,136
Share of motorised trips								
Private CDV	90%	86%	81%	81%	0%	0%	0%	0%
Private AV	0%	0%	0%	0%	86%	86%	86%	85%
On-demand AV	0%	0%	0%	0%	0%	0%	0%	0%
Public transport*	10%	14%	19%	19%	14%	14%	14%	15%
Walking distance (km)								
Total	4,958,293	8,549,033	15,329,310	15,341,944	12,669,829	12,986,226	12,526,842	13,066,855
Per person	1.1	1.4	2.1	2.1	1.7	1.8	1.7	1.8
Road network statistics								
VKT Total	115,498,813	146,253,682	166,948,417	168,810,742	184,405,555	190,332,471	188,972,769	196,627,828
VHT Total	3,173,724	4,256,427	4,539,175	4,575,026	3,611,267	4,229,810	3,665,626	4,673,685
Avg speed km/h	36	34	37	37	51	45	52	42
Avg delay (s/km)	35	41	35	35	8	16	8	23
Public transport statistics								
Station entries	800,512	1,472,184	2,592,088	2,609,168	1,919,412	2,002,788	1,873,088	2,025,612
Tram boardings	503,140	818,148	1,144,232	1,143,596	908,176	856,212	886,056	833,040
Bus boardings	430,424	1,009,484	1,492,652	1,497,568	946,436	1,011,976	927,804	1,038,580
Fleet Size								
Private CDVs	2,304,368	2,883,312	3,503,788	3,522,552				
Private AVs	-	-	-	-	3,753,252	3,738,576	3,782,000	3,747,628
On-demand Avs	-	-	-	-	-	-	-	-
Average VKT per vehicle								
Private CDVs	46.8	46.7	41.4	41.6	41.4	41.4	-	-
Private AVs	-	-	-	-	-	-	-	-
On-demand AVs and DRTs	-	-	-	-	-	126.1	369.8	406.3

*PT includes bus replacement DRT where applicable

Key results: Private automated vehicle scenarios

Scenario category	Base case	Private drive									Hydrogen highway	
Scenario	*Dead end 2046*	*Main scenario*	*Low flow*	*Low MUTT*	*No empty running*	*No mode shfit*	*Area based charge*	*Distance based charge*	*Freight to night*	*Expanded markets*	*Empty running (main)*	*No empty running*
Demographics												
Population	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256
Employment	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579
Trips												
Private CDV	13,473,704	-	-	-	-	-	-	-	-	-	-	-
Private AV	-	14,562,836	14,083,884	14,881,928	14,768,900	13,474,244	14,533,396	14,581,672	14,580,744	14,791,056	14,581,672	14,700,684
On-demand AV	-	-	-	-	-	-	-	-	-	-	-	-
Public transport*	3,245,536	2,461,488	2,832,328	2,228,836	2,328,612	3,246,796	2,490,360	2,457,376	2,445,608	2,306,056	2,457,376	2,382,704
Walk trips	3,370,008	3,075,836	3,180,096	2,996,056	3,008,312	3,370,380	3,082,068	3,066,776	3,079,472	3,008,712	3,066,776	3,021,708
Share of motorised trips												
Private CDV	81%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Private AV	0%	86%	83%	87%	86%	81%	85%	86%	86%	87%	86%	86%
On-demand AV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Public transport*	19%	14%	17%	13%	14%	19%	15%	14%	14%	13%	14%	14%
Walking distance (km)												
Total	15,329,310	13,009,098	13,970,257	12,326,328	12,526,842	15,336,037	13,002,445	12,986,226	12,979,957	12,498,546	12,986,226	12,669,829
Per person	2.1	1.8	1.9	1.7	1.7	2.1	1.8	1.8	1.8	1.7	1.8	1.7
Road network statistics												
VKT Total	166,948,417	197,558,007	177,333,709	192,014,373	188,972,769	166,966,895	196,299,044	190,332,471	197,833,594	193,477,618	190,332,471	184,405,555
VHT Total	4,539,175	4,759,282	3,912,789	3,935,412	3,665,626	3,071,839	4,431,795	4,229,810	4,749,801	3,779,620	4,229,810	3,611,267
Avg speed km/h	37	42	45	49	52	54	44	45	42	51	45	51
Avg delay (s/km)	35	24	17	12	8	3	19	16	23	8	16	8
Public transport statistics												
Station entries	2,592,088	2,010,048	2,283,812	1,802,824	1,873,088	2,593,088	2,017,476	2,002,788	1,997,652	1,872,204	2,002,788	1,919,412
Tram boardings	1,144,232	822,168	1,040,696	836,632	886,056	1,144,684	867,660	856,212	811,036	863,560	856,212	908,176
Bus boardings	1,492,652	1,021,676	1,201,492	885,940	927,804	1,494,416	1,016,688	1,011,976	1,016,968	910,756	1,011,976	946,436
Fleet Size												
Private CDVs	3,503,788											
Private AVs	-	3,752,904	3,645,916	3,823,780	3,782,000	3,503,844	3,729,792	3,738,576	3,755,308	4,039,644	3,738,576	3,753,252
On-demand Avs	-	-	-	-	-	-	-	-	-	-	-	-
Average VKT per vehicle												
Private CDVs	41.4	-	-	-	-	-	-	-	-	-	-	-
Private AVs	-	46.8	42.6	44.5	44.2	41.4	46.7	45.1	46.8	42.5	43.4	45.1
On-demand AVs and DRTs	-	-	-	-	-	-	-	-	-	-	-	-

*PT includes bus replacement DRT where applicable

Key rseults: On-demand AV scenarios

Scenario category	2031 scenarios		Dead end	Fleet street (2046)						
Scenario	*Base case 2031*	*High speed*	*Dead end 2046*	*Main scenario*	*Low flow*	*Low MUTT*	*No mode shift*	*Subscription fare*	*Calibrated fleet size*	*No new (pre-construction) major road projects*
Demographics										
Population	5,988,856	5,988,856	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256
Employment	3,095,696	3,095,696	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579
Trips										
Private CDV	12,054,924	-	13,473,704	-	-	-	-	-	-	-
Private AV	-	-	-	-	-	-	-	-	-	-
On-demand AV	-	9,987,344	-	11,162,784	10,807,700	11,868,240	12,825,752	13,040,384	10,352,524	10,718,368
Public transport*	1,892,704	2,503,173	3,245,536	4,292,344	4,596,772	3,737,364	3,245,332	2,911,812	4,929,788	4,684,508
Walk trips	2,125,524	2,940,636	3,370,008	4,662,364	4,708,660	4,513,920	3,451,144	4,165,296	4,525,196	4,702,948
Share of motorised trips										
Private CDV	86%	0%	81%	0%	0%	0%	0%	0%	0%	0%
Private AV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
On-demand AV	0%	80%	0%	72%	70%	76%	80%	82%	68%	70%
Public transport*	14%	20%	19%	28%	30%	24%	20%	18%	32%	30%
Walking distance (km)										
Total	8,549,033	10,367,856	15,329,310	18,590,650	19,433,511	19,433,511	14,834,502	14,809,773	20,379,323	19,729,375
Per person	1.4	1.7	2.1	2.5	2.6	2.6	2.0	2.0	2.8	2.7
Road network statistics										
VKT Total	146,253,682	146,848,688	166,948,417	167,627,616	160,570,978	179,641,957	181,446,657	197,866,045	161,212,108	154,714,429
VHT Total	4,256,427	2,782,663	4,539,175	2,967,511	2,924,908	3,238,619	3,587,894	3,667,229	2,819,883	2,907,418
Avg speed km/h	34	53	37	56	55	55	51	54	57	53
Avg delay (s/km)	41	-	35	3	5	4	9	5	3	6
Public transport statistics										
Station entries	1,472,184	1,675,523	2,592,088	2,950,108	3,114,960	2,673,596	2,477,764	2,227,084	3,199,824	3,169,424
Tram boardings	818,148	1,180,388	1,144,232	1,650,848	1,723,676	1,466,912	1,379,004	1,189,796	1,791,188	1,752,032
Bus boardings	1,009,484	1,939,646	1,492,652	2,868,016	3,224,256	2,248,804	1,737,576	1,382,384	3,686,332	3,364,900
Fleet Size										
Private CDVs	2,883,312	-	3,503,788							
Private AVs	-	-	-	-	-	-	-	-	-	-
On-demand Avs	-	211,069	-	256,490	248,480	305,663	431,290	358,378	246,317	251,979
Average VKT per vehicle										
Private CDVs	46.7	-	41.4	-	-	-	-	-	-	-
Private AVs	-	-	-	-	-	-	-	-	-	-
On-demand AVs and DRTs	-	612.0	-	568.5	558.2	516.3	369.8	491.2	565.9	528.7

*PT includes bus replacement DRT where applicable

Key results: co-existing technologies and land use scenarios

Scenario category	Base case	Slow lane					Mix of scenarios			Private drive land use comparison		
Scenario	*Dead end 2046*	*Main scenario*	*Low flow*	*Low MUTT*	*No mode shift*	*Private AVs*	*Mix of scenarios*	*Centralised land use*	*Expanded land use*	*Private drive*	*Centralised land use*	*Expanded land use*
Demographics												
Population	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256	7,394,256
Employment	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579	3,929,579
Trips												
Private CDV	13,473,704	7,225,320	7,151,380	7,207,300	6,731,988	7,025,884	1,526,636	1,512,160	1,521,672	-	-	-
Private AV	-	-	-	-	-	7,006,644	6,704,816	6,497,916	6,742,508	14,562,836	14,295,104	14,694,668
On-demand AV	-	5,342,516	5,244,024	5,672,576	6,418,136	-	4,470,300	4,171,804	4,227,604	-	-	-
Public transport*	3,245,536	3,632,872	3,771,148	3,389,600	3,246,012	2,864,048	3,607,800	3,839,084	3,707,668	2,461,488	2,653,204	2,378,372
Walk trips	3,370,008	3,902,584	3,934,512	3,833,544	3,411,372	3,209,248	3,796,272	4,084,860	3,906,372	3,075,836	3,157,516	3,032,784
Share of motorised trips												
Private CDV	81%	45%	44%	44%	41%	42%	9%	9%	9%	0%	0%	0%
Private AV	0%	0%	0%	0%	0%	41%	41%	41%	42%	86%	84%	86%
On-demand AV	0%	33%	32%	35%	39%	0%	27%	26%	26%	0%	0%	0%
Public transport*	19%	22%	23%	21%	20%	17%	22%	24%	23%	14%	16%	14%
Walking distance (km)												
Total	15,329,310	16,473,812	16,909,078	15,832,420	15,087,253	14,151,159	15,900,918	16,228,442	16,232,311	13,009,098	13,191,168	12,813,632
Per person	2.1	2.2	2.3	2.1	2.0	1.9	2.2	2.2	2.2	1.8	1.8	1.7
Road network statistics												
VKT Total	166,948,417	170,748,645	168,605,723	174,997,145	173,614,625	179,921,562	176,508,180	166,593,276	174,573,938	197,558,007	186,060,713	199,172,830
VHT Total	4,539,175	3,331,124	3,380,234	3,458,257	3,604,326	4,246,022	3,144,405	3,007,836	3,103,807	4,759,282	4,548,106	4,891,285
Avg speed km/h	37	51	50	51	48	42	56	55	56	42	41	41
Avg delay (s/km)	35	8	10	9	12	21	3	4	3	24	25	26
Public transport statistics												
Station entries	2,592,088	2,641,324	2,735,688	2,529,040	2,536,664	2,335,344	2,618,480	2,681,340	2,661,840	2,010,048	2,162,628	1,963,516
Tram boardings	1,144,232	1,345,604	1,366,064	1,267,284	1,261,892	976,320	1,433,384	1,604,964	1,478,744	822,168	876,788	761,632
Bus boardings	1,492,652	2,181,380	2,310,616	1,879,152	1,615,588	1,223,940	1,947,852	2,077,592	2,090,088	1,021,676	1,054,700	980,196
Fleet Size												
Private CDVs	3,503,788	1,868,412	1,852,588	1,864,164	1,751,704	1,723,767	103,779	101,093	105,594			
Private AVs	-	-	-	-	-	1,723,767	1,971,805	1,920,771	2,006,290	3,752,904	3,718,860	3,786,876
On-demand Avs	-	122,741	144,451	139,780	251,635	-	104,681	95,878	97,150	-	-	-
Average VKT per vehicle												
Private CDVs	41.4	46.4	46.2	46.4	44.7	44.3	46.8	45.2	45.6	-	-	-
Private AVs	-	-	-	-	-	47.4	47.8	46.8	47.4	46.8	44.1	46.8
On-demand AVs and DRTs	-	506.0	422.7	476.6	291.7	-	531.9	525.6	543.7	-	-	-

*PT includes bus replacement DRT where applicable

Appendix B: Accessibility methodology

Appendix B: Accessibility methodology

What is accessibility?

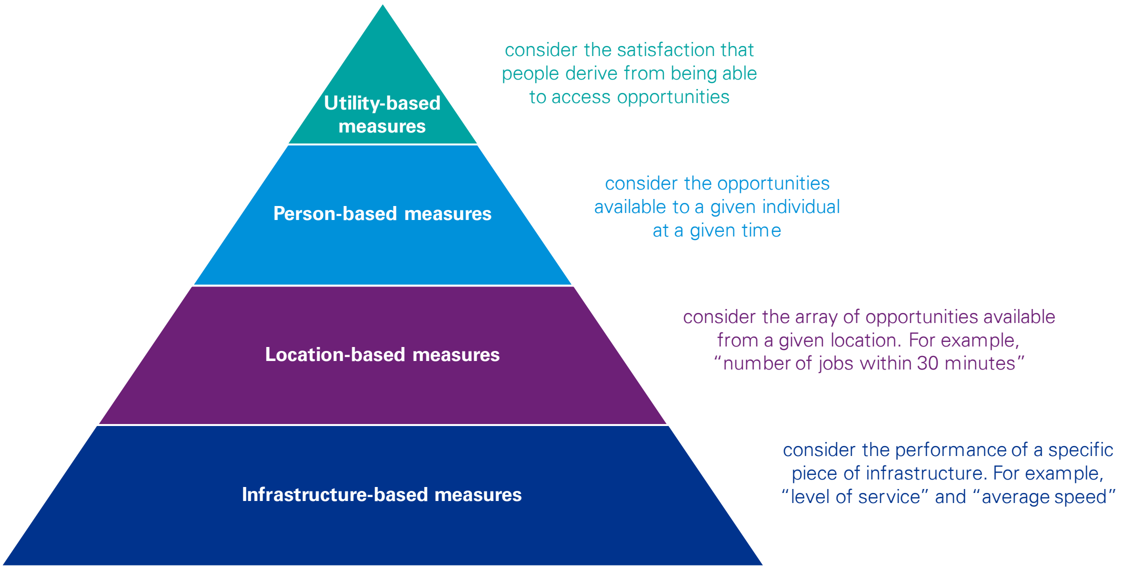
Accessibility is defined as the extent to which a person, at a given place and time, has the ability to access opportunities that they want or need to access. Accessibility represents the ease and convenience with which people can access their chosen activities. This varies from person to person, with activities spanning work, study, leisure and other commitments.

We measure accessibility based on estimates of a person's 'satisfaction' of their day – including how much time they are able to spend at their preferred activities rather than stuck in traffic or on crowded public transport services, and how much money they spend on transport services.

How we measure accessibility

There is no single method for assessing accessibility. Numerous accessibility metrics have been defined and measured for various purposes. Geurs & van Wee (2004) characterise four types of accessibility measures. These are described in Figure B.1.

Figure B.1 Accessibility metrics ranked by suitability to activity based model frameworks



consider the satisfaction that people derive from being able to access opportunities

consider the opportunities available to a given individual at a given time

consider the array of opportunities available from a given location. For example, "number of jobs within 30 minutes"

consider the performance of a specific piece of infrastructure. For example, "level of service" and "average speed"

Most accessibility measures are trip and location based

The choice of accessibility measure is largely driven by the type and availability of data and modelling outputs. Traditional 'four-step' models, which produce aggregated trip counts and travel time data for travel between geographical 'zones' are well suited to location based measures. These location based metrics are commonly used in Australia for accessibility measures. These techniques evaluate accessibility by calculating the number of opportunities (e.g. jobs) that can be reached from a given location, either using a cut-off cost or using a decay curve that weights opportunities based on the cost of reaching them.

Measures that use aggregate trip and location data to assess accessibility have limitations when applied in an activity based simulation framework such as is used in the MABM. While they are useful for analysing spatial interactions between populations and land use, they are generally insensitive to individual variations in preferences and mobility. Usually a particular location is considered as a single unit without consideration of the differing schedules, preferences and attributes of the individuals that live and work at that location.

Another limitation relates to the interaction of a location based measure with the queue based traffic simulation used in the MABM. Rather than statically assigning trips like a four-step model, the MABM includes queuing behaviour. This means congested roads can have sections of free flow and sections of queues, similar to how traffic behaves in reality. Isolated queuing in a particular location may be insignificant for a driver, for whom the queue represents a very minor aspect of their daily travel plan. Conversely, persistent queuing can have a significant negative impact on the apparent accessibility of that location despite being relatively inconsequential for the individuals living or working there.

The measure we use is person and activity based

Our approach compares the 'utility' generated by each person's travel plan under each scenario to determine on an individual level the impact on the ease with which that person can access the activities they want.

In the MABM every individual is scored according to their own success in executing their daily travel and activity plan. Put simply, this 'utility' score increases when a person performs an activity in their plan and decreases when they spend time and money travelling between activities. Because each person has a unique set of location, schedule and preferences, changes in the transport options will affect everyone differently. By comparing an individual's score between two scenarios, we can determine whether a particular transport scenario makes it easier or harder for that person to access their chosen activities. This provides a useful formulation of accessibility with significant advantages:

- Changes in transport conditions are evaluated with respect to each individual's whole day travel plan, not just for a particular time or location.
- Individuals can be aggregated by their attributes to determine the impact of a scenario on a particular group. For example, grouping by socio-economic status, the relative change in score serves as an equity measure.
- While individuals can be aggregated to a certain geography based on home and activity locations, there is no requirement to group people according to a particular spatial boundary system. There is also no assumption that people in the same location have the same accessibility.

Our measure focuses on the impact of transport on individuals

The person and activity based approach adopted in this report leverages the MABM's strength in simulating the interactions of heterogeneous individuals.

Guers and van Wee (2004) identify four components that are theoretically important to be included in an accessibility measure.

1) The ***land-use*** component refers to the spatial distribution and quality of opportunities.
2) The ***transportation*** component refers to the disutility experienced in travelling from a given location to a relevant opportunity. Measures of disutility may include travel time, costs and perceived inconveniences like transfers.
3) The ***temporal*** component refers to the availability of opportunities at different times of day, and the time available for people to participate in those opportunities.
4) The ***individual*** component refers to the needs and preferences of different individuals. For example, how far a person is willing to travel, their car availability or their level of education and skill in assessing which employment opportunities are available to them.

Table B.1 compares the alternative accessibility measures against the above criteria. Our selected activity and person based approach addresses each component by incorporating the actual spatio-temporal travel and activity plans of every person. It also leverages the particular strength of the MABM in modelling divergent individual needs and preferences. This means we can determine which groups are the winners and losers in a particular scenario, not just by geography but by any personal attribute contained the in MABM population.

Table B.1 Comparison of accessibility metric performance against desired components

Component	Trip/Location based	Activity/Person based
Land-use	✓	✓
Transportation	✓	✓
Temporal	✓	✓
Individual	✗	✓

How utility is calculated in the MABM

A technical description of the utility framework used in MATSim is featured in Chapter 3 of the MATSim Book, which can be found can be found at **https://matsim.org/the-book**.

The MABM implements the MATSim framework (Nagel, et al., 2016) to simulate the interactions of millions of individuals in Melbourne as they carry out their own activity plan. In this framework, individuals make travel choices that tend to maximise their own *utility*, which is a numerical representation of their satisfaction with their daily plan.

In general, spending time performing activities as part of their schedule generates *utility* for people, whereas spending time and money travelling between activities generates *disutility*.

Travel plans within MATSim are compared using a scoring mechanism that balances the positive utility associated with undertaking activities, with the disutility associated with travel. For an individual plan, the score (utility) is computed as the sum of all the utility generated from performing activities plus the sum of the (dis)utility generated from travelling, as in Equation B.1.

$$S_{plan} = \sum_{q=0}^{N-1} S_{act,q} + \sum_{q=0}^{N-1} S_{trav,mode(q)}$$

Equation B.1 Scoring (utility) function used in MATSim

The functions governing the scoring of activities and travel modes are pre-established within the MATSim software, however the coefficients for the parameters have been modified to reflect travel behaviour that is representative of the current and projected population of Greater Melbourne. Different activities and mode types have their own functions and parameters which govern their impact on utility.

In addition to global scoring parameters, an individual's score is dependent on their unique characteristics, such as the value they place on money relative to travel time savings. In the MABM this marginal utility of money is a function of household income and affects how people behave in response to tolls, fares and parking charges. For further details on the specification and calibration of utility parameters, please refer to the MABM Calibration and Validation Report (KPMG & Arup, 2017).

References

Guers, K. T. & van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography,* 12(2), pp. 127-140.

KPMG & Arup (2017), *Model Calibration and Validation Report*, Available from https://goo.gl/dZdfwJ.

Nagel, K., Kickhoffer, B., Horni, A. & Charypar, D., 2016. *A Closer Look at Scoring. In: Horni, A, Nagel, K. & Axhausen KW (eds) 'The Multi-Agent Transport Simulation MATSim, pp.23-34),* London: Ubiquity Press.

Appendix C: Accessibility outcomes

Accessibility: Private drive versus Dead end

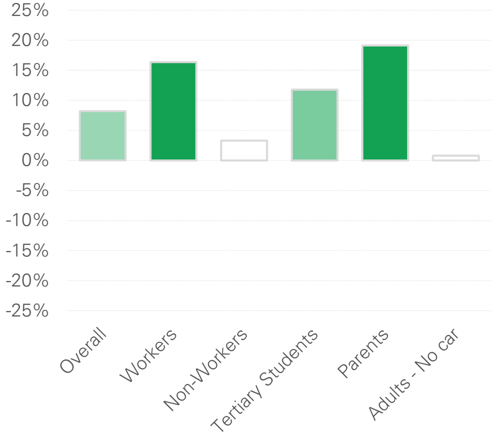
The Private Drive scenario leads to significant accessibility benefits relative to the Dead End scenario for residents of outer areas along and at the end of major freeways.

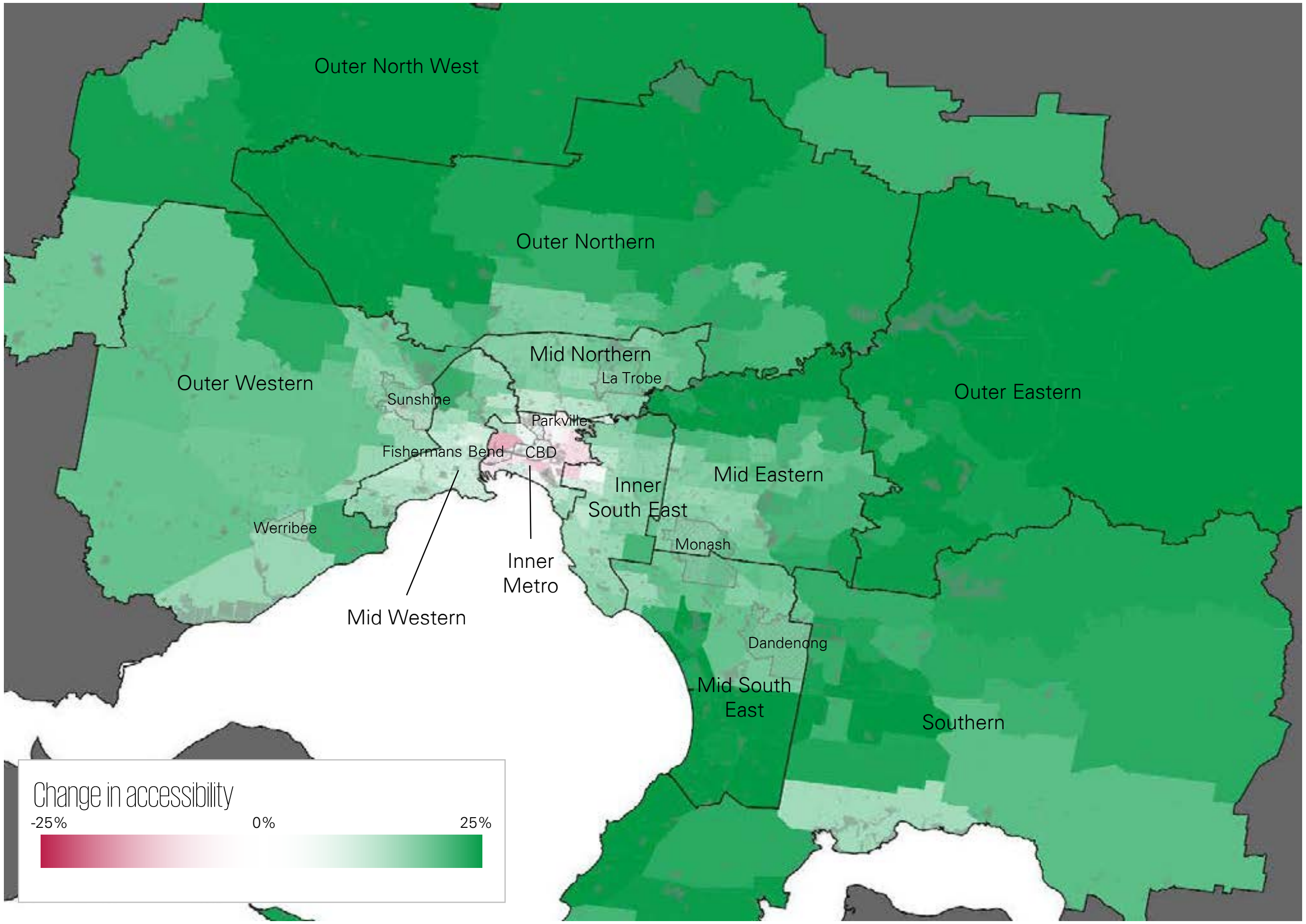
The accessibility improvements are driven primarily by reduced congestion that results from platooning of vehicles. These effects are particularly noticeable on freeways and during peak times in the morning and afternoon.

Those living in the Inner Metro area experience a marginal reduction in accessibility. This is due both to the increase in traffic flow from the outer suburbs and empty vehicles heading home to avoid paying for parking.

Workers and parents of school age children benefit the most as they travel primarily during the peak times.

Change in accessibility





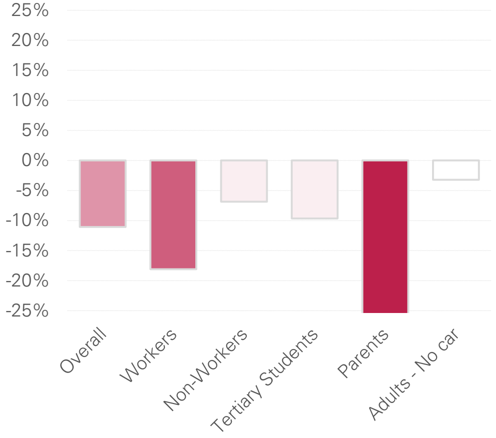
Accessibility: Fleet street vs Dead end

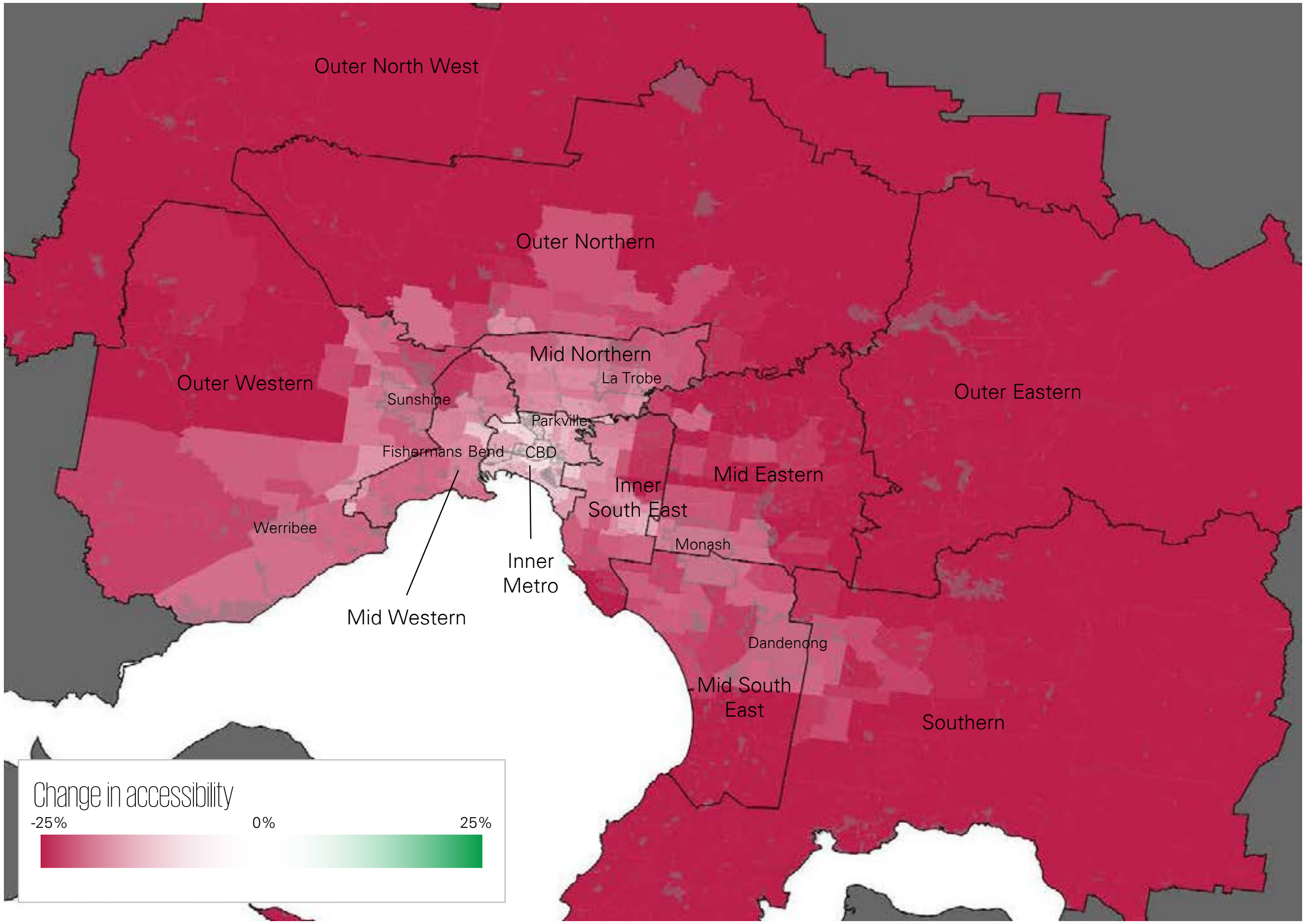
The Fleet Street scenario leads to significant accessibility reductions relative to the Dead End scenario for those living further away from the CBD and marginal reduction for those closer to the city.

These accessibility reductions are driven by the cost of fares, which are time and distance-based. Those making long trips from the outer suburbs are particularly affected. The fare is designed to cover all vehicle related costs, including depreciation, maintenance, insurance etc. If these costs were 'sunk' in a monthly or quarterly payment, accessibility outcomes would be better.

Workers and parents of school age children are impacted the most as they travel the furthest on average.

Change in accessibility



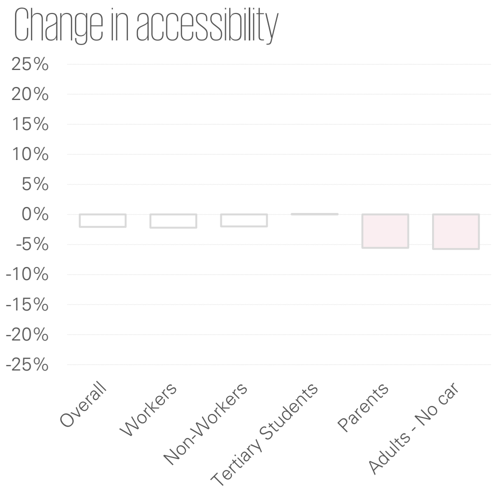


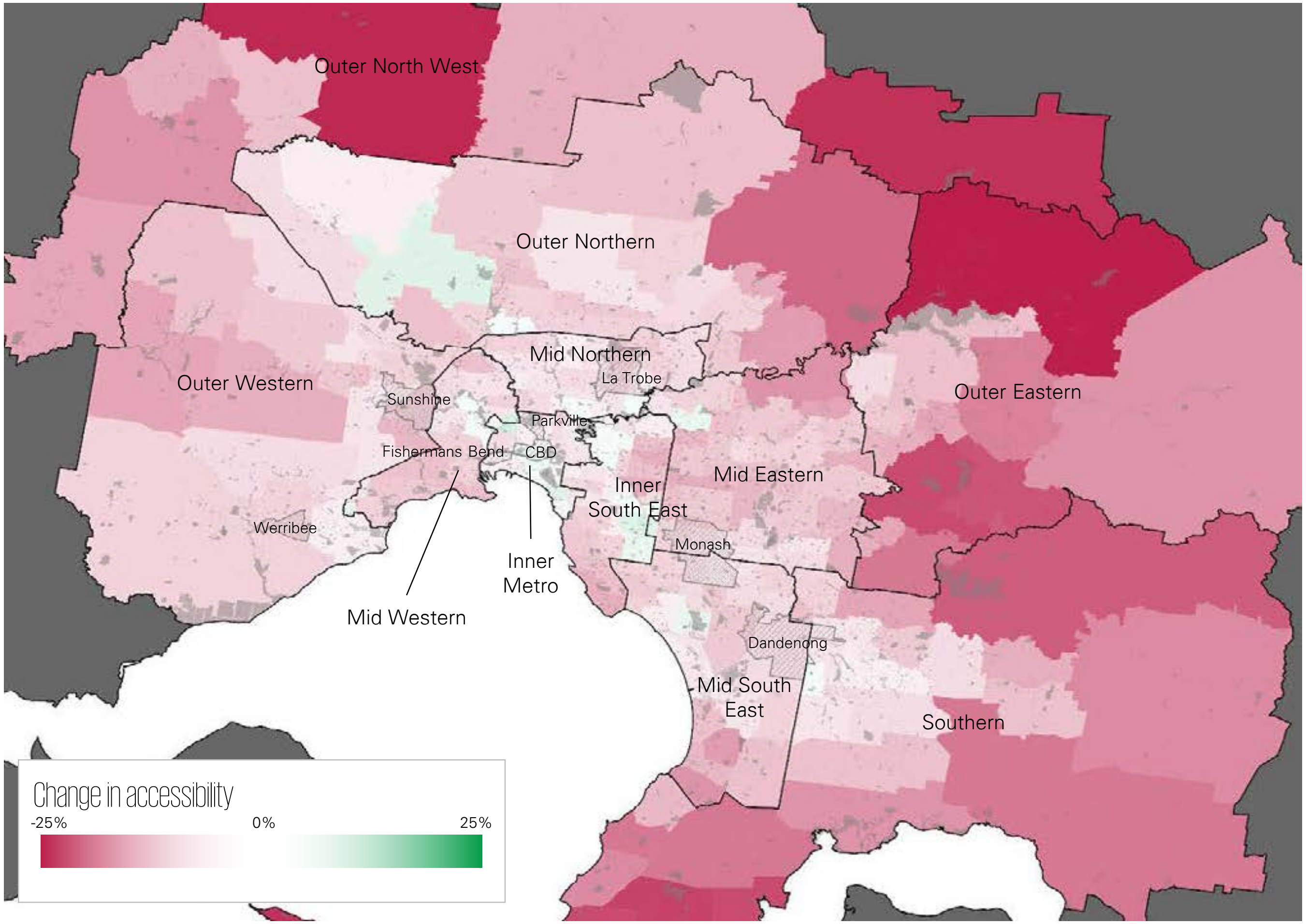
Accessibility: Slow lane vs Dead end

The Slow Lane scenario leads to marginal accessibility reductions relative to the Dead End scenario, with larger impacts for residents of outer areas.

This is for similar reasons as the Fleet Street scenario (see previous page). However, this only affects half of the population – those who use vehicles on demand instead of private ownership.

The remainder of the population (with private car ownership) sees significant accessibility improvements, as the non-car owning population shift to public transport, freeing up the roads. The accessibility benefits and reductions roughly cancel each other out.



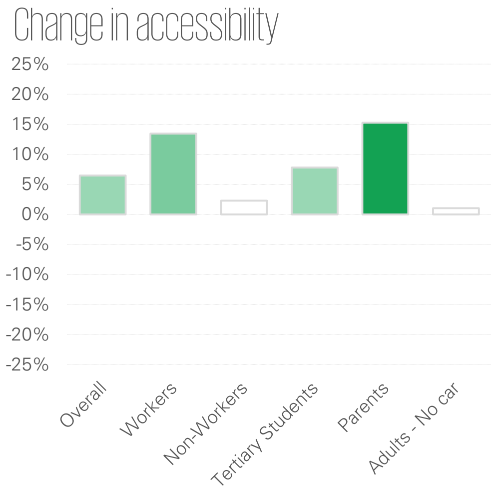


Accessibility: Electric avenue vs Dead end

The Electric Avenue scenario leads to slight accessibility improvements relative to the Dead End scenario, with larger impacts for residents of outer areas.

This is because the lower cost of electricity (5 c/km) compared to the Dead End scenario (17.6 c/km) saves money for travelers. While congestion also increases due to induced demand on roads, consumers value the money savings slightly more than they dislike the increases in congestion.

Workers and parents of school age children benefit the most as they travel longer distances on average.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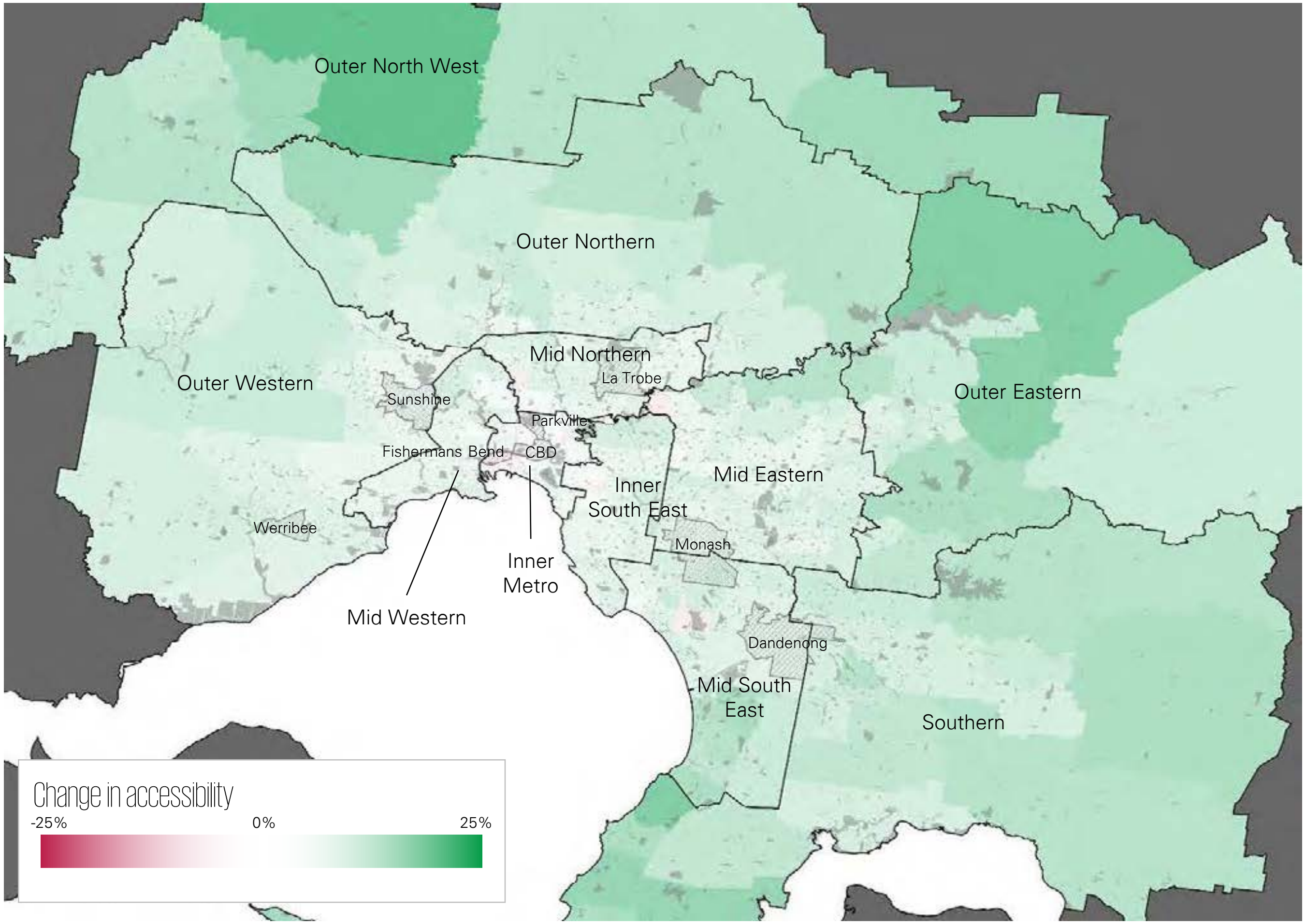
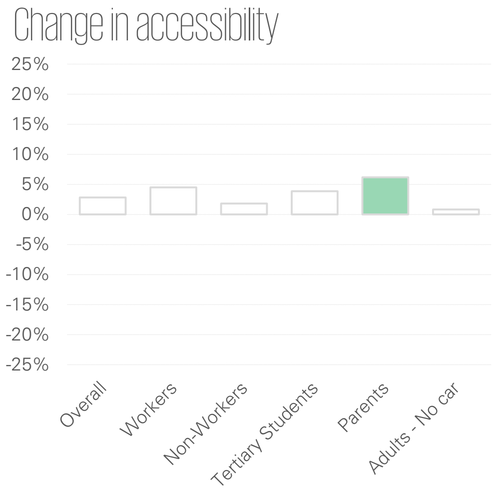


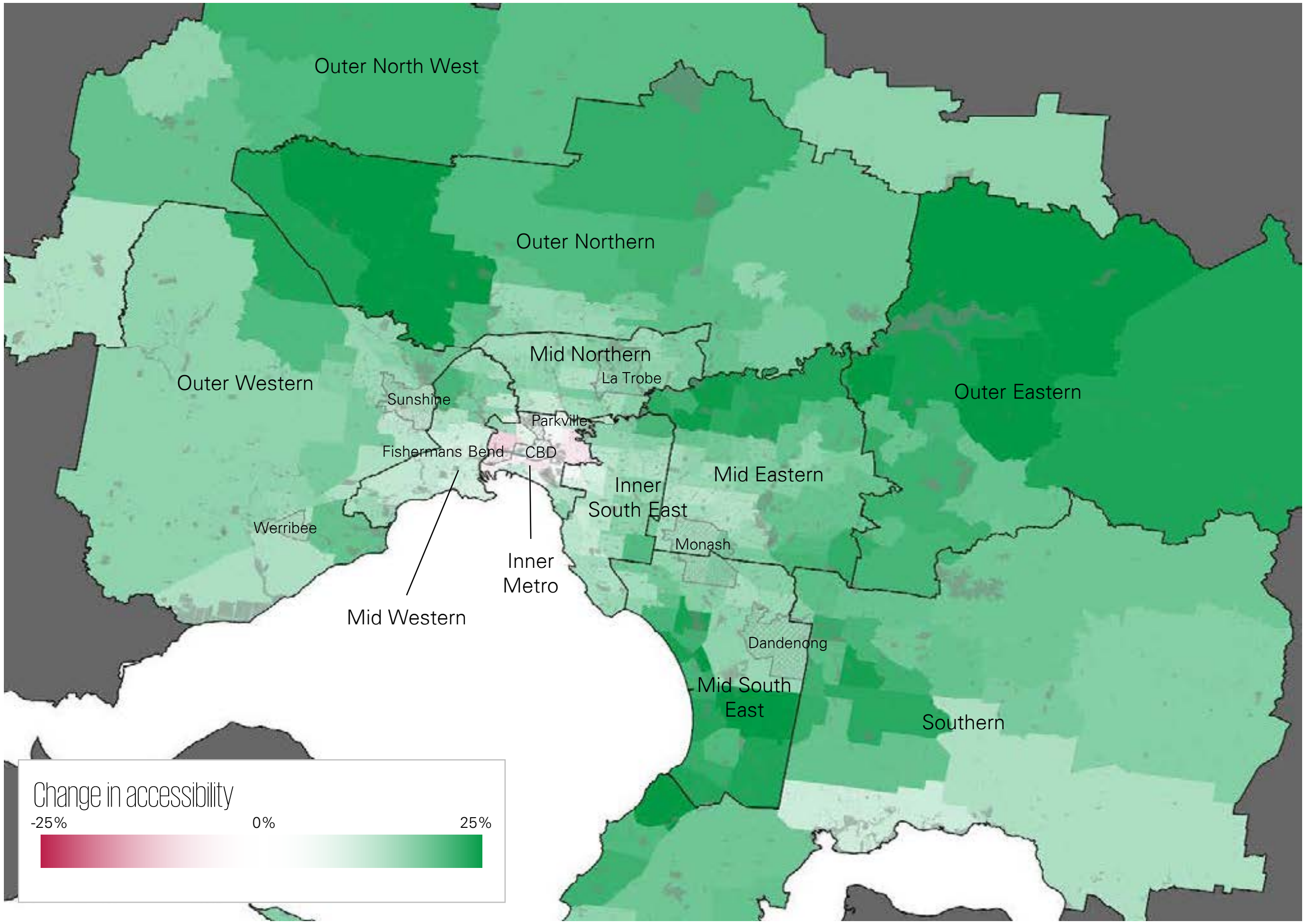
Accessibility: Hydrogen highway vs Dead end

The Hydrogen Highway scenario leads to significant accessibility improvements relative to the Dead End scenario, with larger impacts for residents of outer areas.

These accessibility improvements are driven primarily by increasing vehicle flows and reducing congestion due to platooning of vehicles, particularly on freeways and particularly during peak times in the morning and afternoon.

Workers and parents of school age children benefit the most as they travel primarily during the peak times.



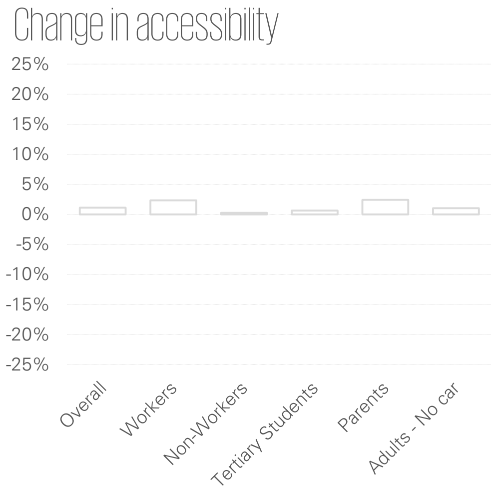


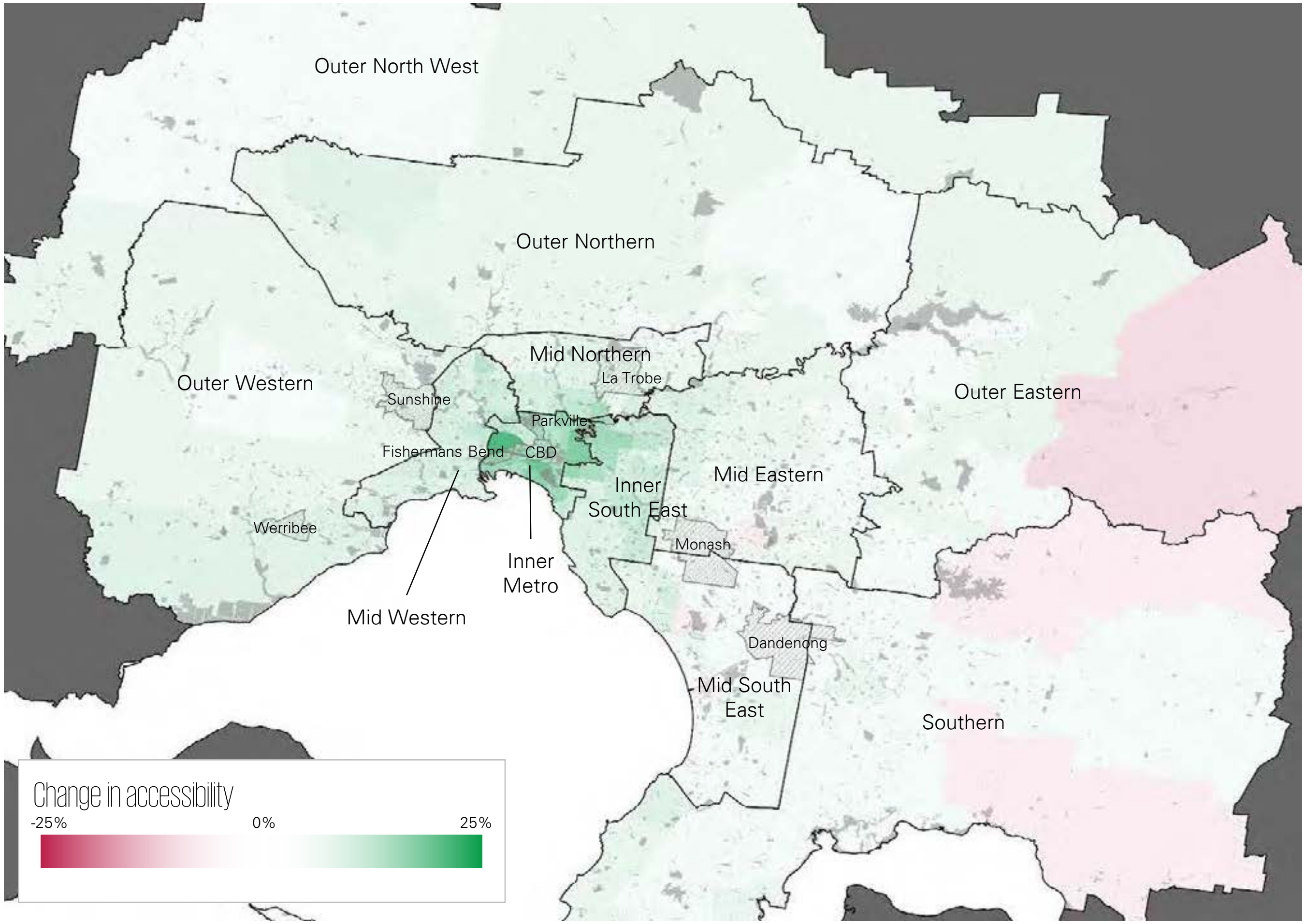
Accessibility: Private drive, No empty running vs Private drive

The No Empty Running variation of the Private Drive scenario leads to accessibility improvements for those living in the inner suburbs, and negligible changes elsewhere.

When empty running is allowed, AV owners send their cars back home to avoid inner city parking charges. These empty vehicles create congestion in inner areas which reduces accessibility for residents.

Removing empty running reduces this extra traffic and also discourages some people from choosing to drive due to the cost of parking. This improves accessibility for residents of the inner city where parking is a significant deterrent from driving.

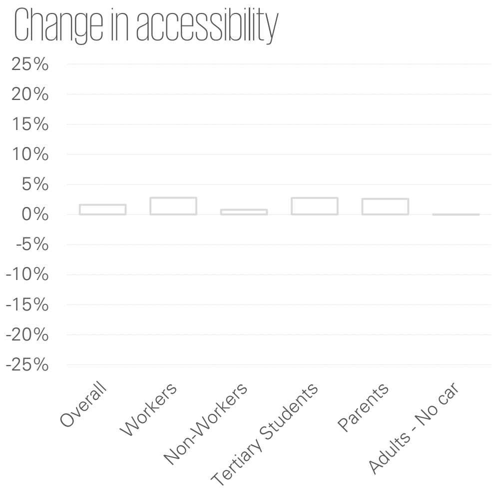


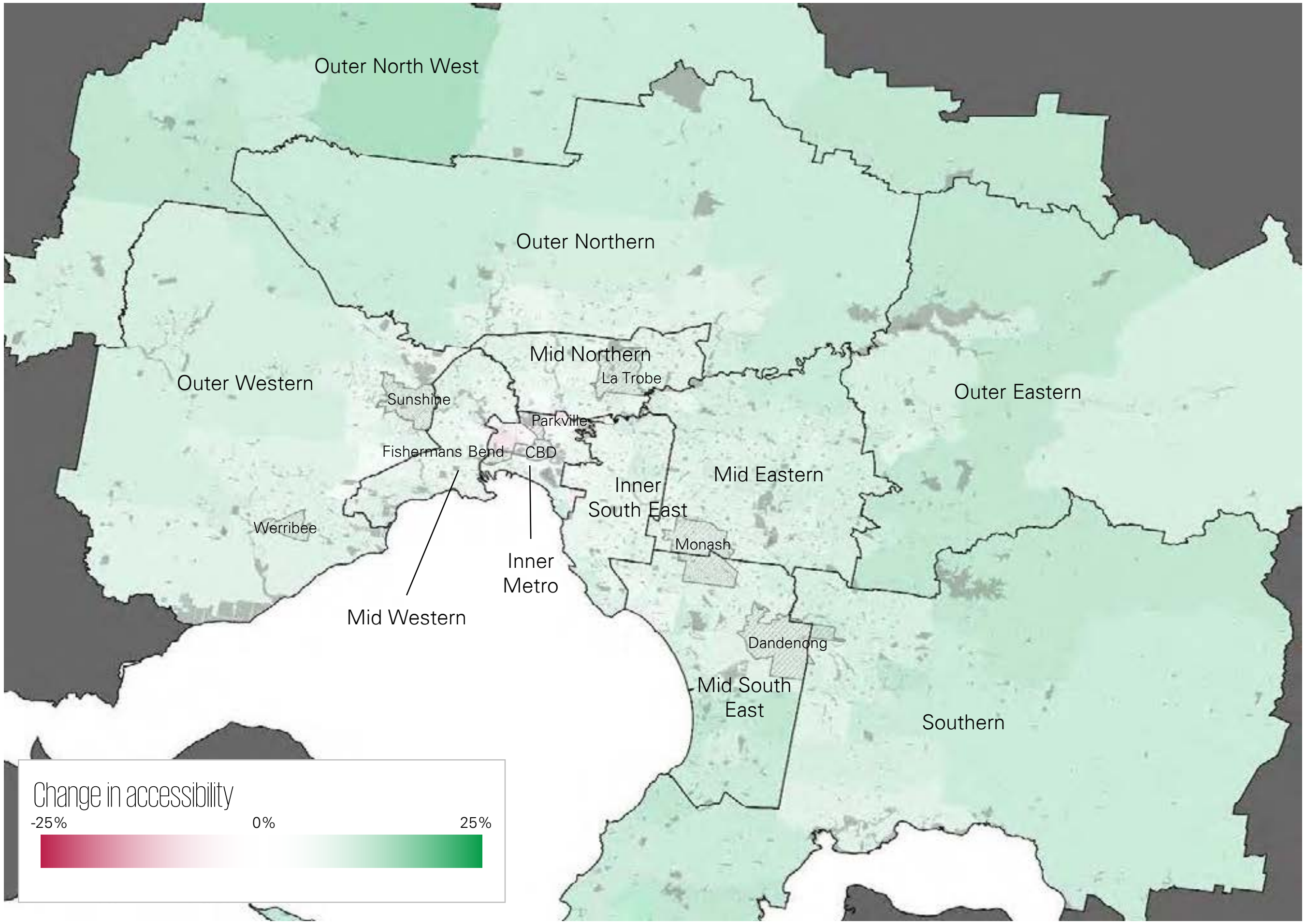


Accessibility: Private drive, Low MUTT vs Private drive, No empty running

The Low MUTT variation of the Private drive scenario leads to slight accessibility improvements relative to the Private drive scenario without empty running.

This is because people are not as dissatisfied with additional travel time due to the comfort and convenience of AVs, so they perceive greater accessibility. While congestion increases due to induced demand on roads, consumers value the comfort and convenience of their AVs slightly more than they dislike the increases in congestion.

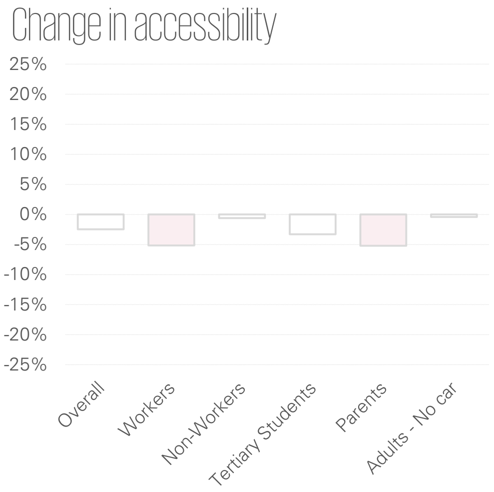


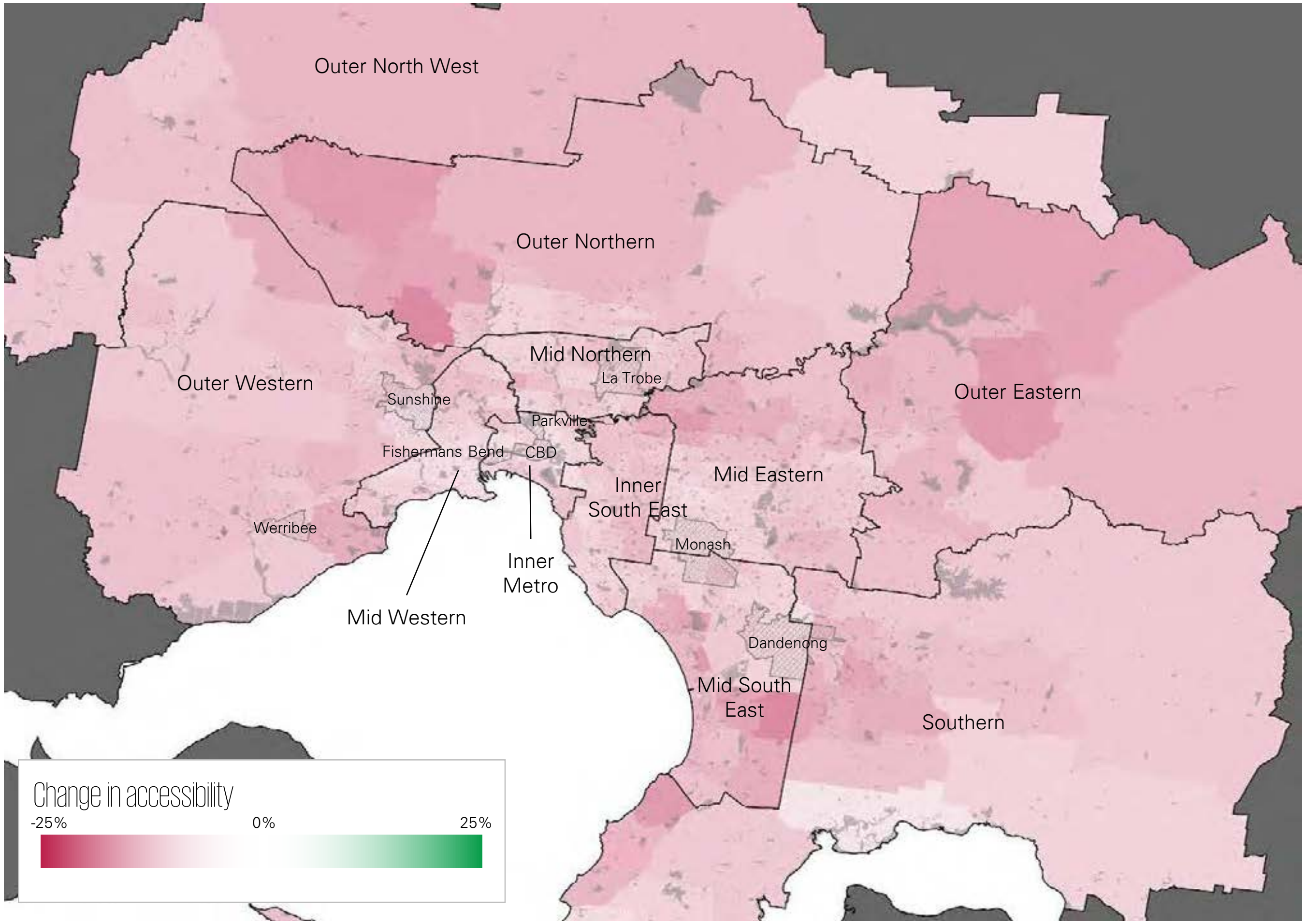


Accessibility: Private drive, Low flow vs Private drive, No empty running

The Low flow variation of the Private drive scenario leads to slight accessibility reductions relative to the Private drive scenario without empty running.

This is because the benefit of platooning is assumed to be lower in this scenario than in the Private drive scenario, leading to poorer accessibility. This highlights the benefits of platooning, particularly for residents who live along or at the end of major freeway corridors.

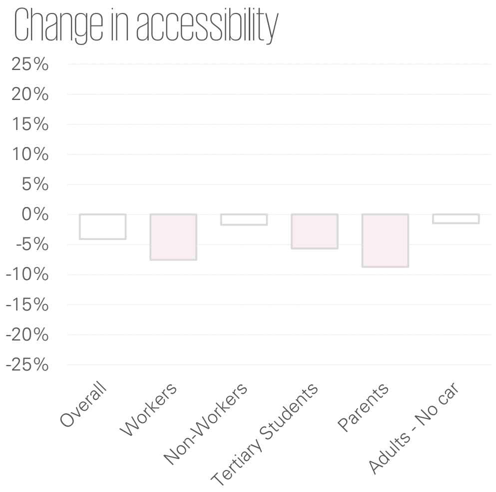

Change in accessibility

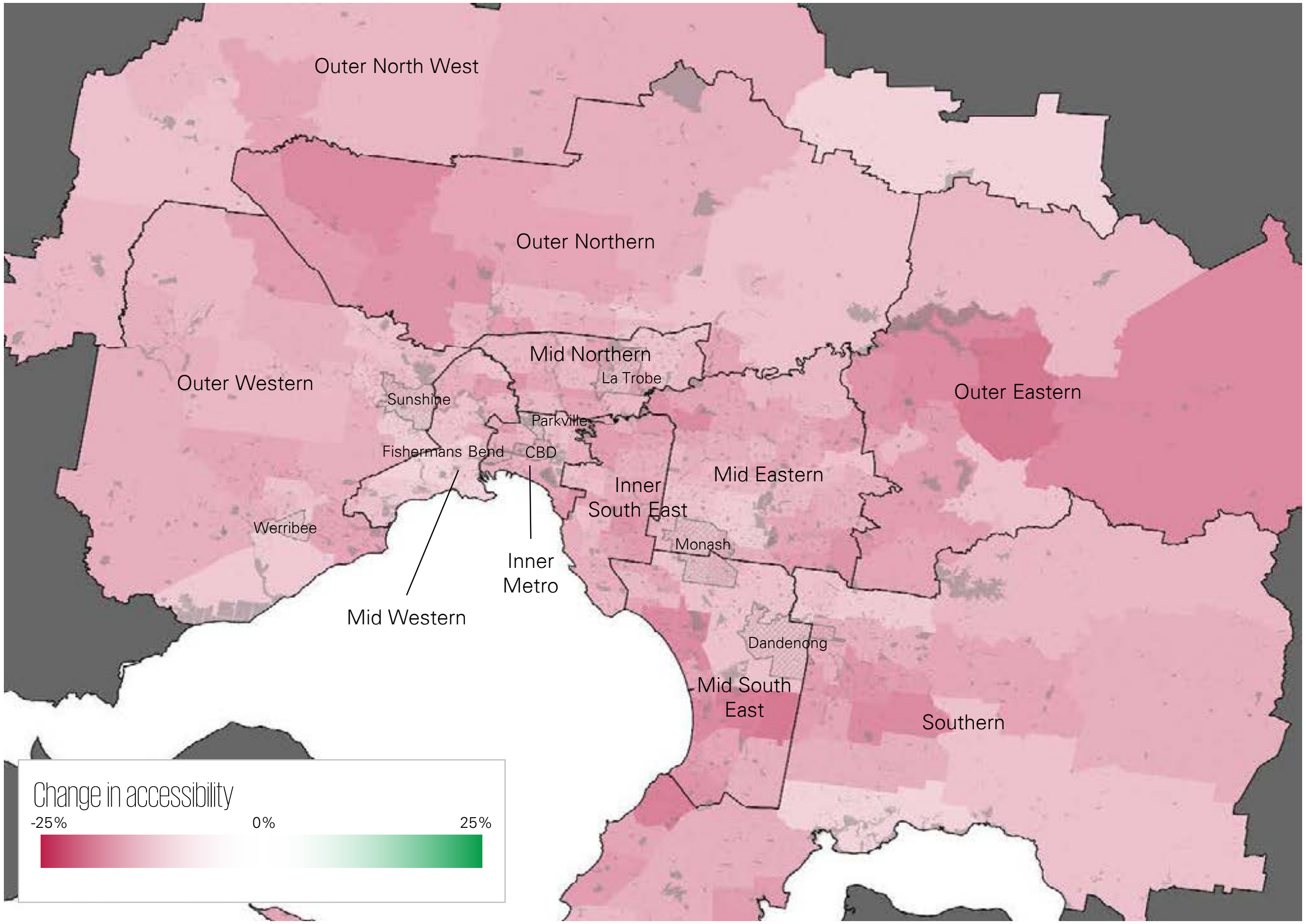


Accessibility: Private drive, No mode shift vs Private drive, No empty running

The No mode shift variation of the Private drive scenario leads to slight accessibility reductions relative to the Private drive scenario without empty running.

This is because people would like to shift away from public and active transport modes towards car to take advantage of the benefits of platooning. However they are constrained from doing so in this scenario, leading to dissatisfaction and therefore poorer accessibility.



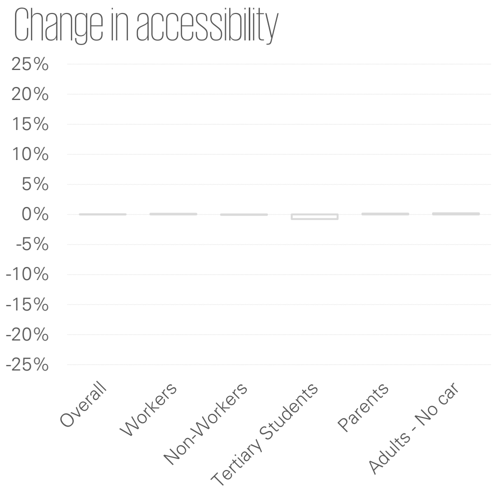


Accessibility: Private drive, Area based charge vs Private drive

The Area based charge variation of the Private drive scenario has negligible impact on the accessibility relative to the private drive scenario.

While charging people to drive in inner areas would tend to reduce accessibility, the charge has the effect of reducing empty running in these locations, which alleviates congestion and has a positive impact on accessibility.

Overall there are no more than minor changes to accessibility for any group.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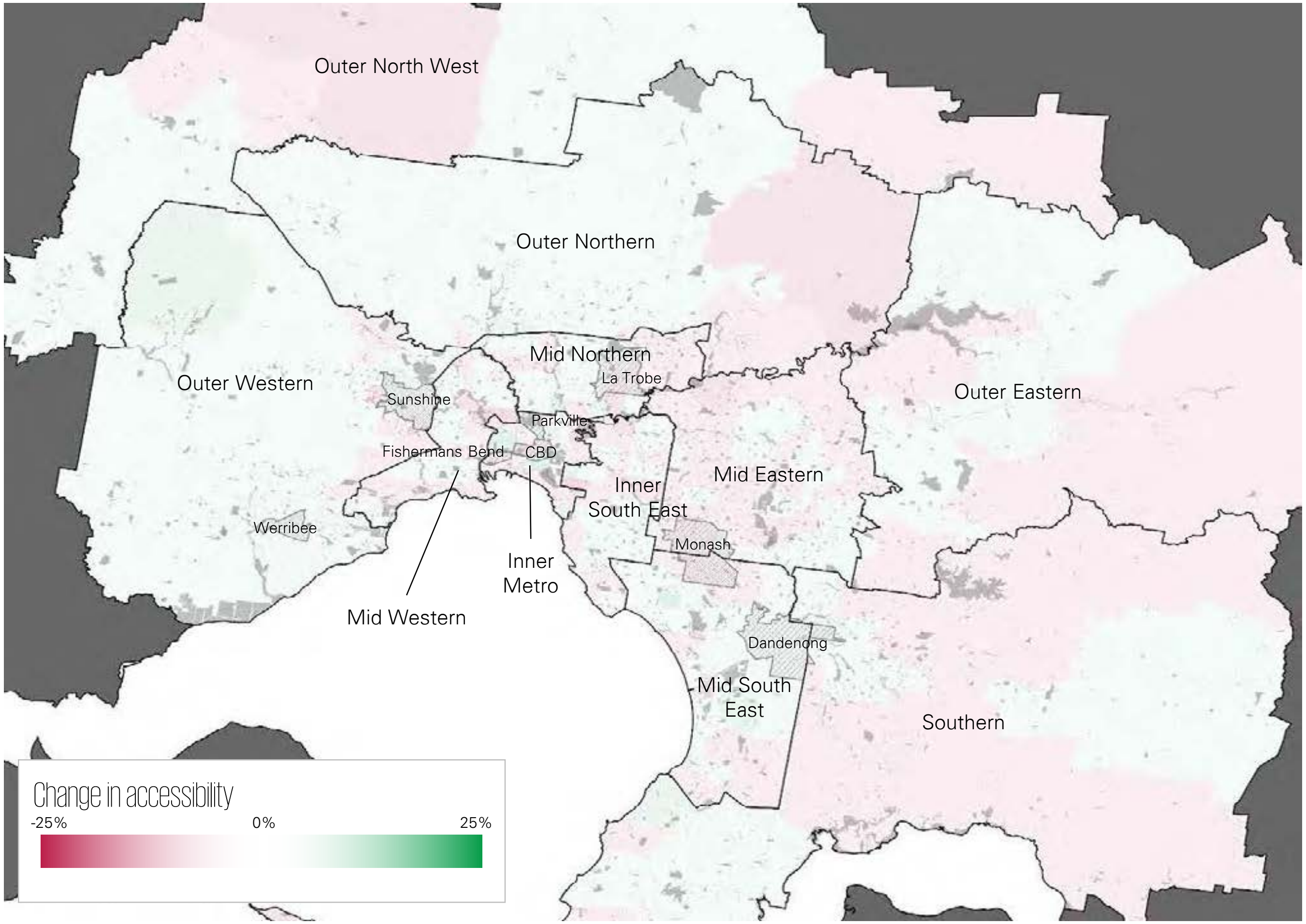


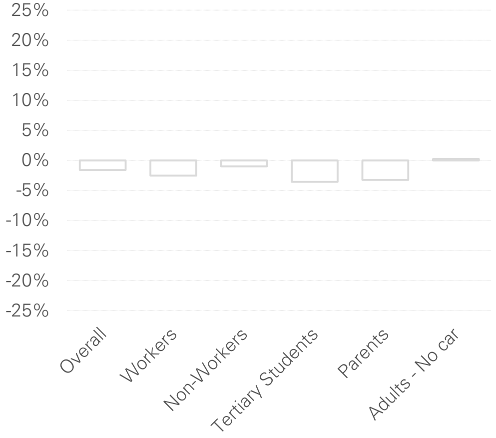
Accessibility: Private drive, Distance based charge vs Private drive

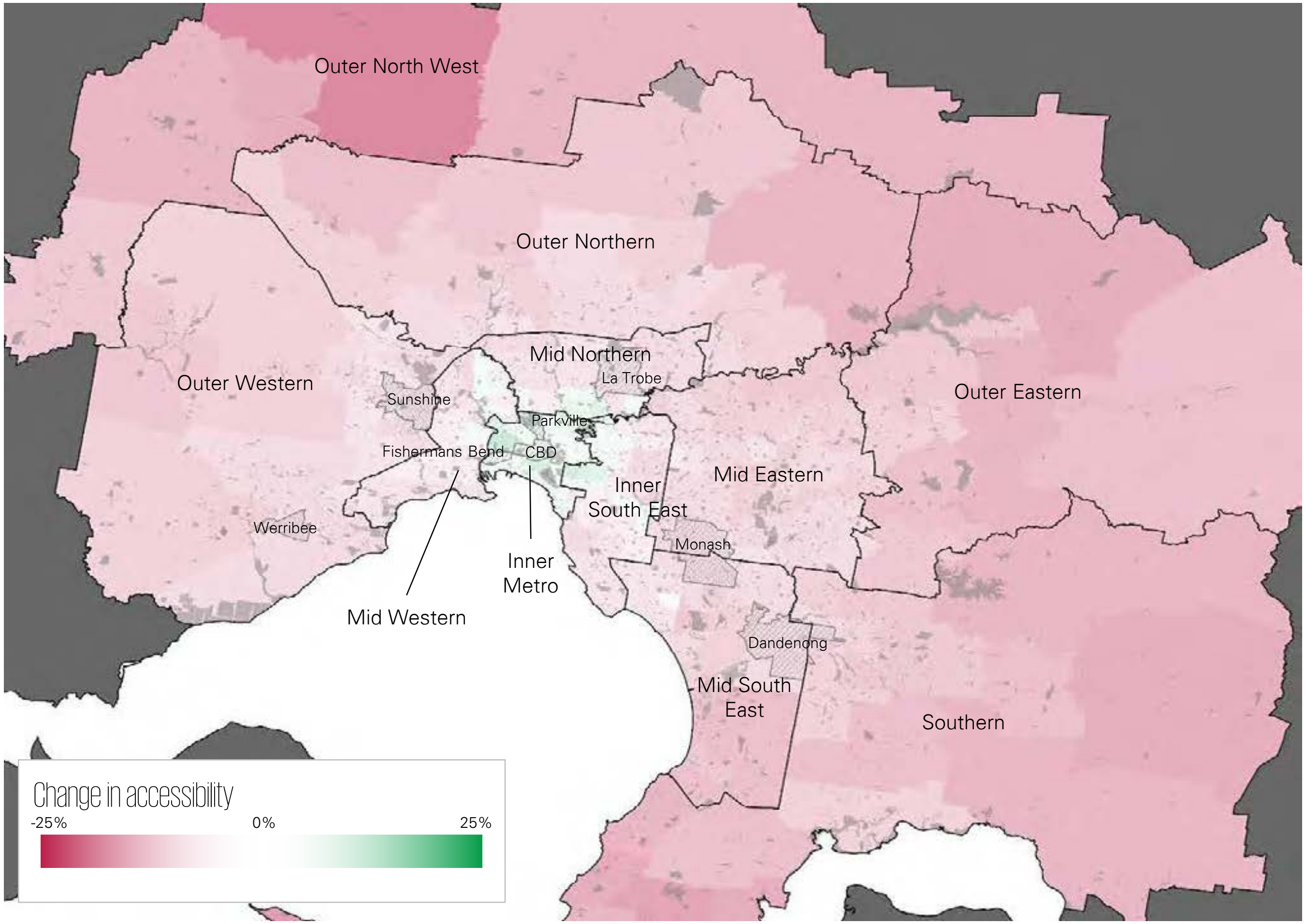
The Distance based charge variation of the Private drive scenario has an overall slight negative impact on accessibility relative to the private drive scenario. However the effect varies significantly by location, with increases in accessibility for areas closer to the CBD, and decreases in accessibility for areas further away from the CBD.

Those who live far from the inner city are the most negatively affected as they are generally more car dependent and drive longer distances.

Conversely those who live in the inner city benefit from fewer cars on the road and lower congestion. These people are more able to avoid the charge as they drive less frequently and for shorter distances.

Change in accessibility

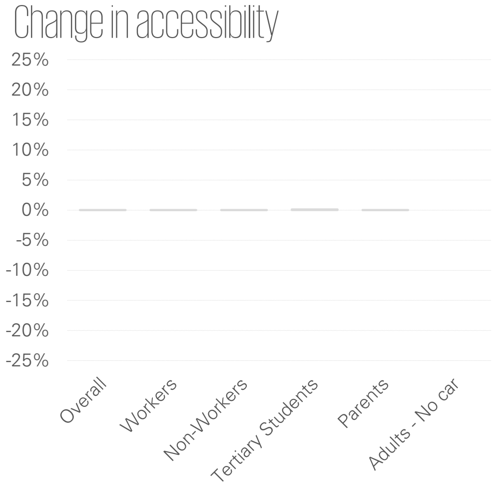


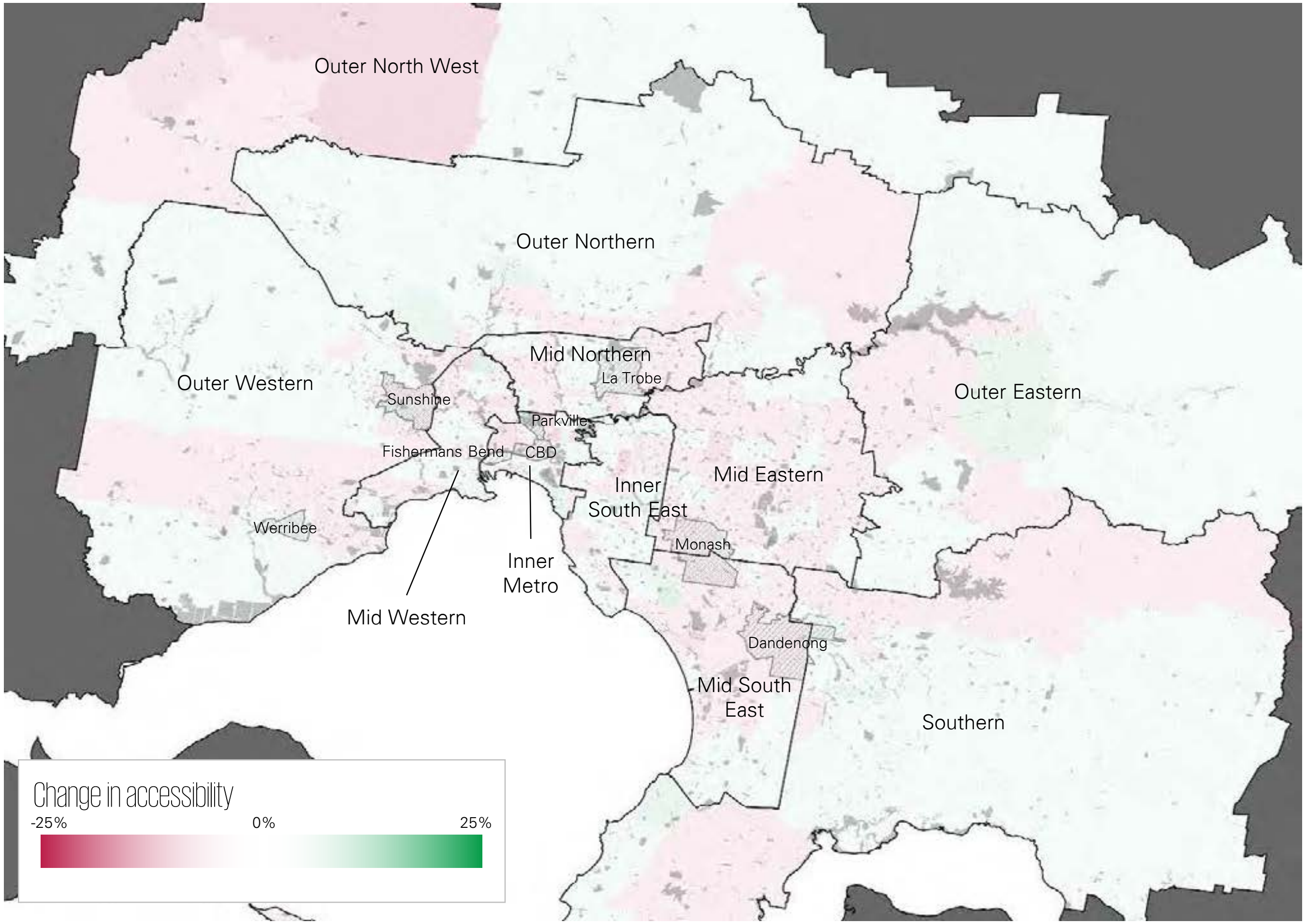


Accessibility: Private drive, Freight to night vs Private drive

The Freight to night variation of the Private drive scenario has negligible impact on accessibility throughout Melbourne relative to the Private drive scenario.

The near-zero change in accessibility for all groups suggests that freight traffic is not a significant impediment to people accessing their daily activities in the Private drive scenario. This is because there is very little congestion in the Private drive scenario.

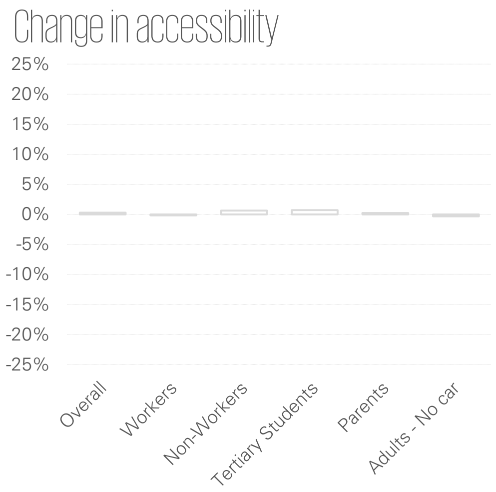


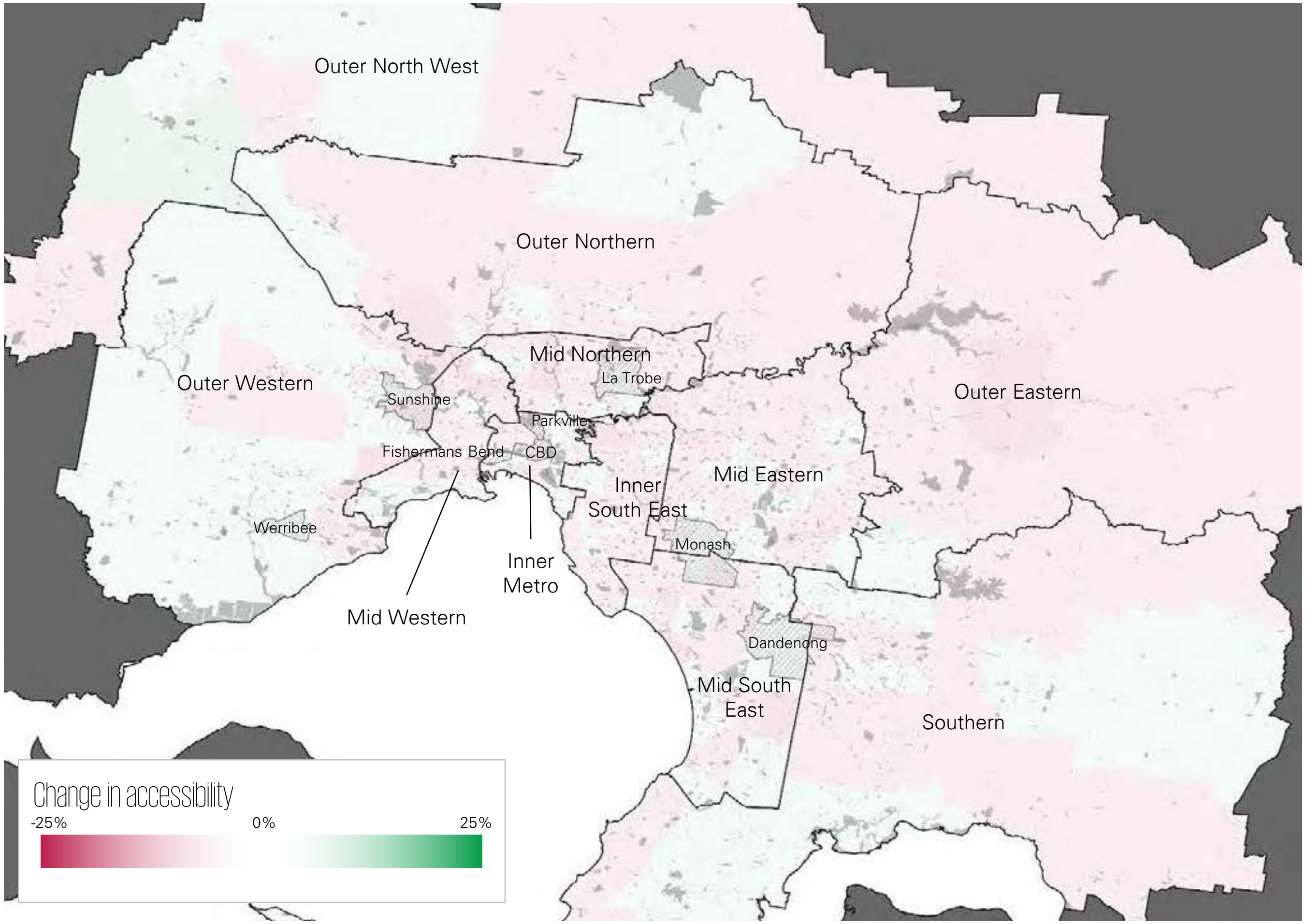


Accessibility: Private drive, Expanded markets vs Private drive, No empty running

The Expanded markets variation of the Private drive scenario has a relatively small impact on accessibility relative to the Private drive scenario without empty running.

A portion of people who were previously unable to drive experience increased accessibility through the use of private AVs. However this affects only a subset of the total population and the additional road traffic they generate has the effect of increasing congestion, which mitigates the accessibility benefits.





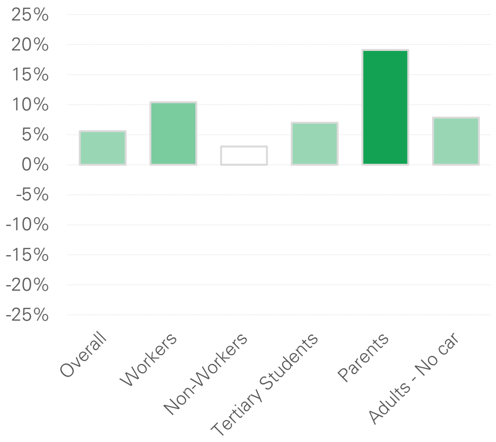
Accessibility: Fleet street, Subscription fare vs Fleet street

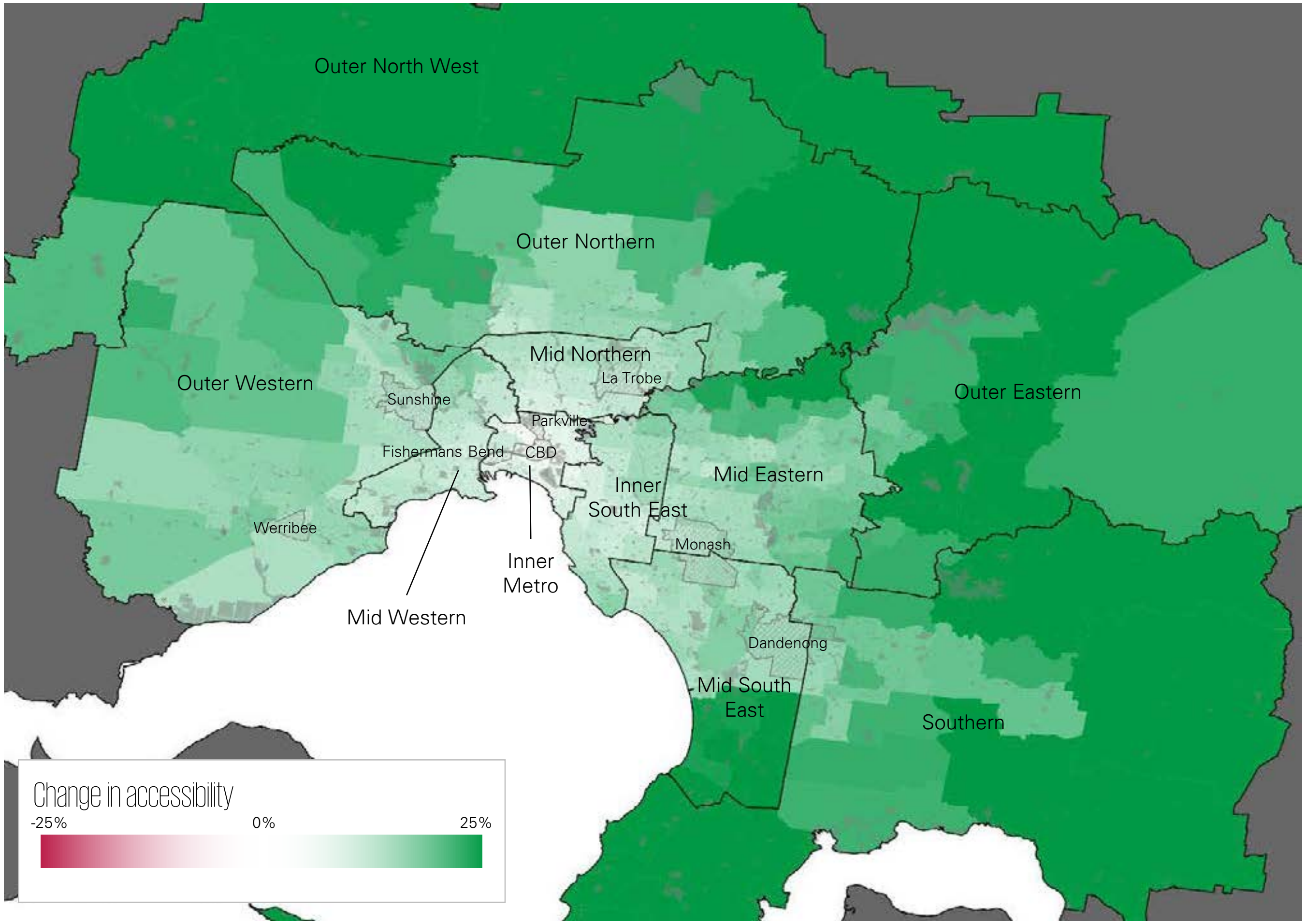
The Fleet street, Subscription fare variation results in significant increases in accessibility, relative to the Fleet street scenario.

The largest increases in accessibility are visible in the outer regions, where trips are longer and if charged based on distance travelled, would have a high perceived cost. For these people a subscription service significantly lowers the marginal cost of an on demand vehicle trip. Conversely, closer to the CBD where trips are shorter, a subscription fare is not as attractive resulting minimal impact on accessibility in these areas.

Parents who drop their children at school benefit significantly, as do workers. These groups are likely to travel longer distances and make more trips than other groups.

Change in accessibility



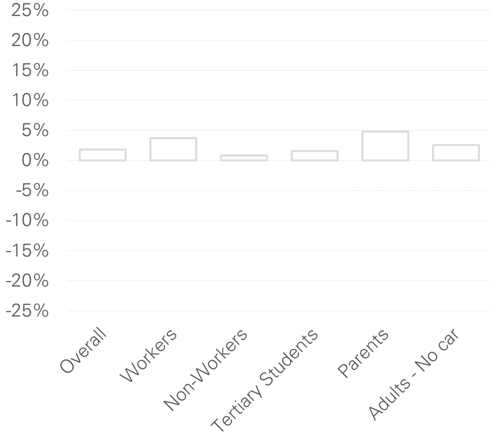


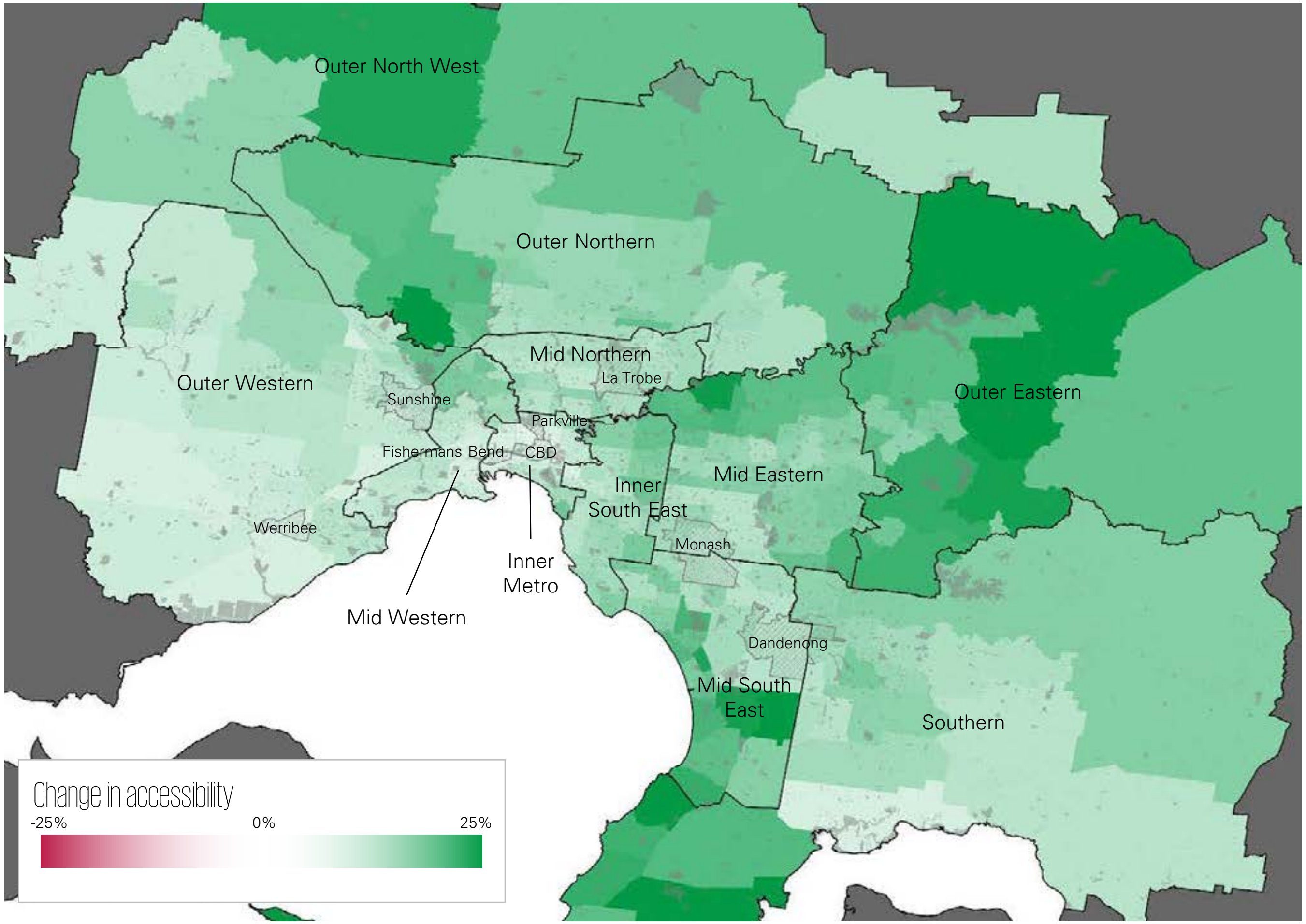
Accessibility: Fleet street, Low MUTT vs Fleet street

The Low MUTT variation of the Fleet street scenario leads to significant accessibility improvements relative to the Fleet street scenario.

This is because people are not as dissatisfied with additional travel time due to the comfort and convenience of AVs, so they perceive greater accessibility. While congestion increases due to induced demand on roads, consumers value the comfort and convenience of their AVs slightly more than they dislike the increases in congestion.

Change in accessibility

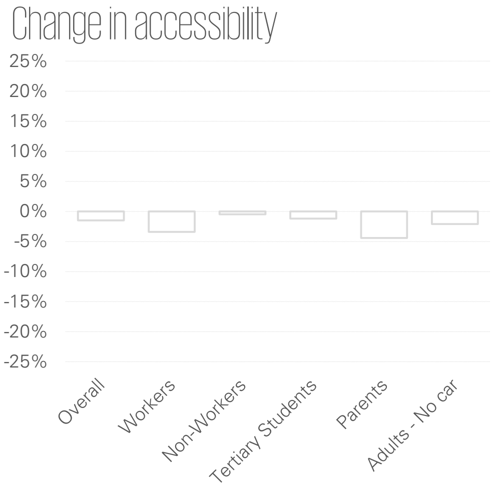


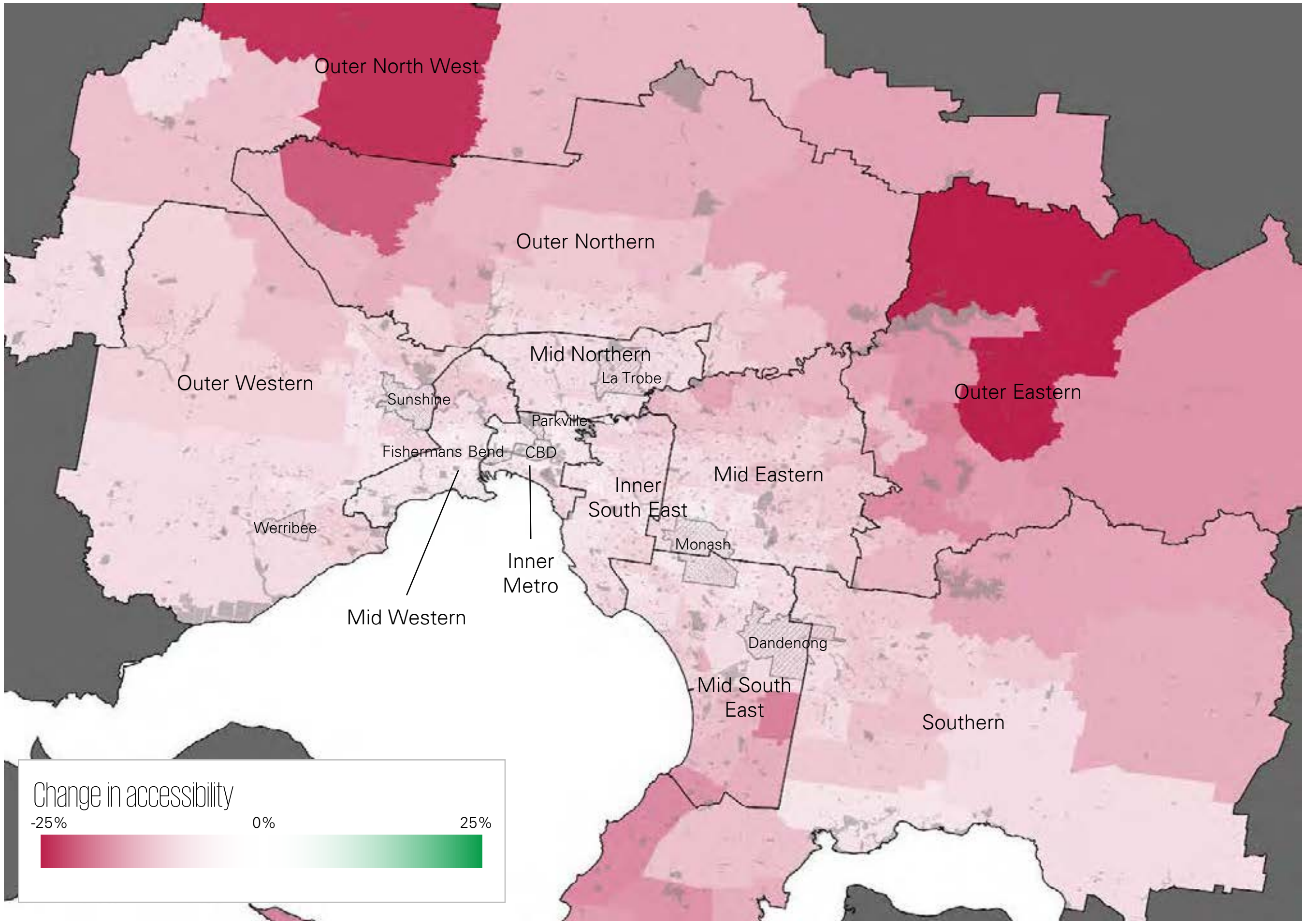


Accessibility: Fleet street, Low flow vs Fleet street

The Low flow variation of the Fleet street scenario leads to slight accessibility reductions relative to the Fleet street scenario.

This is because the benefit of platooning is assumed to be lower in this scenario than in the Fleet street scenario, leading to poorer accessibility. This highlights the benefits of platooning, particularly for residents who live along or at the end of major freeway corridors.

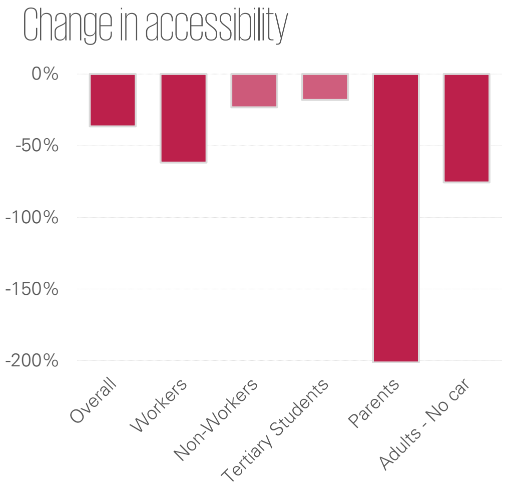




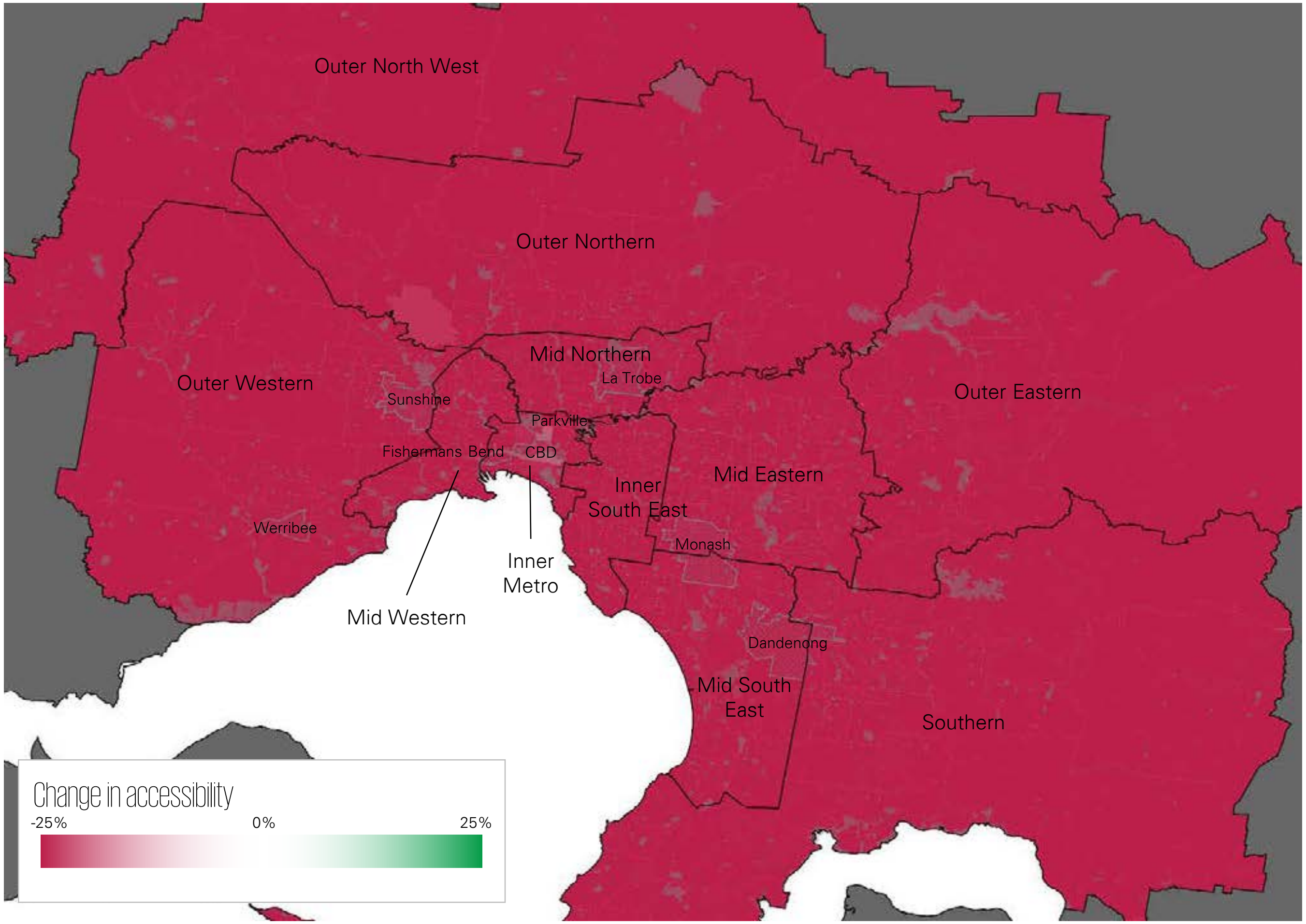
Accessibility: Fleet street, No mode shift vs Fleet street

The No mode shift variation of the Fleet street scenario leads to major accessibility reductions relative to the Fleet street scenario.

This is because people would like to shift away from vehicles on demand and towards public transport and active modes avoid the fares. However they are constrained from doing so in this model run, leading to dissatisfaction and therefore poorer accessibility.



Change in accessibility



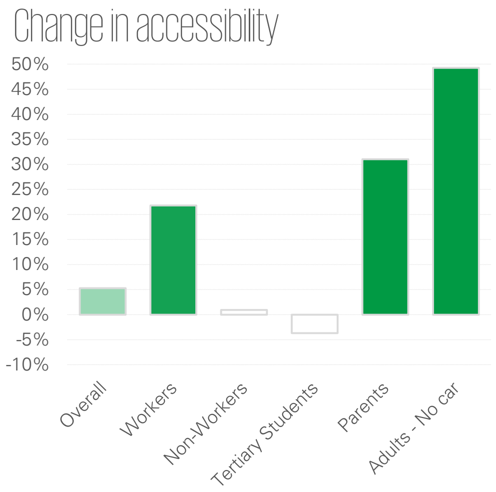
Accessibility: Fleet street, No mode shift, with DRTs vs Fleet street, No mode shift

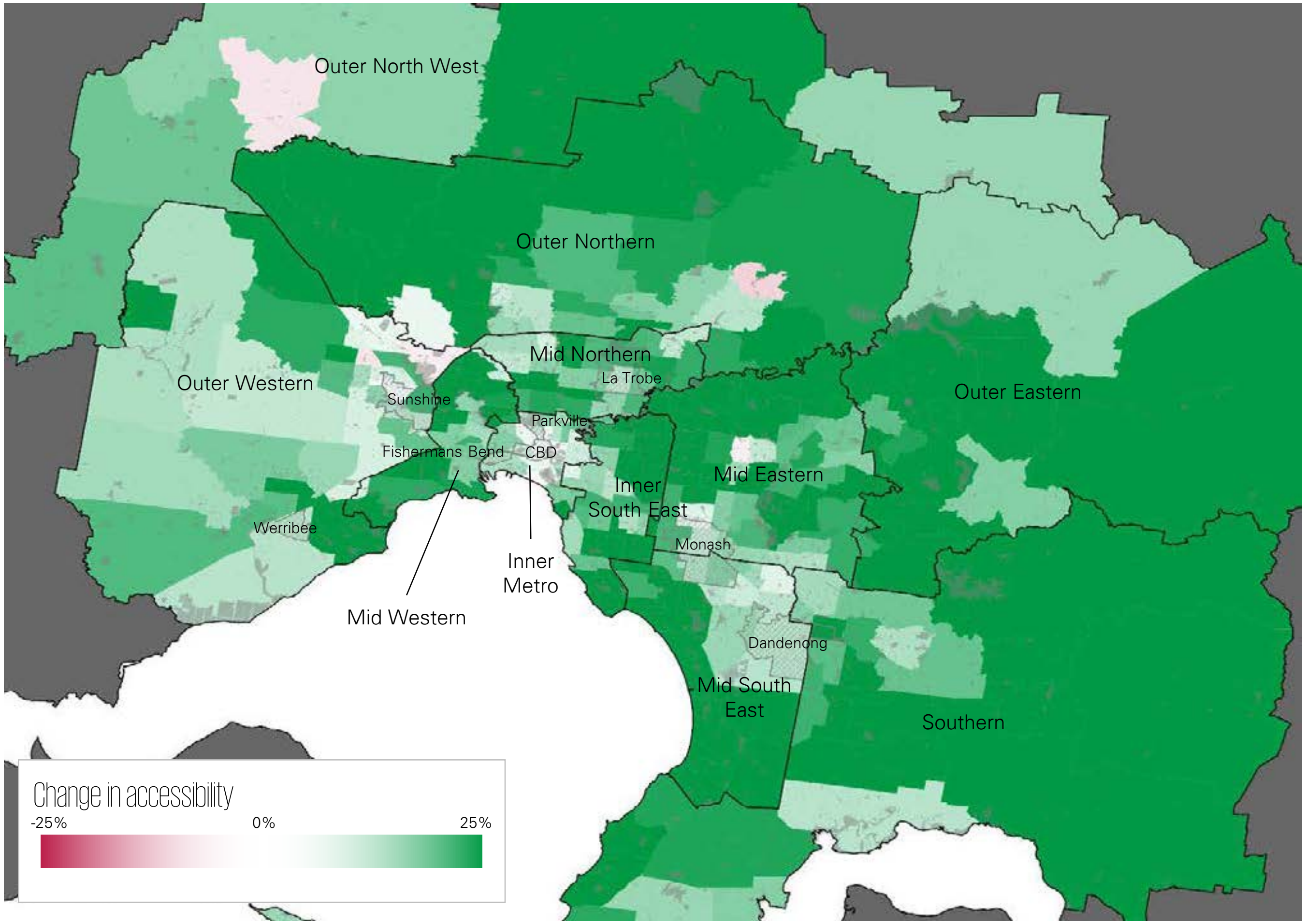
The No mode shift, with pooling variation of the Fleet street scenario significantly increases accessibility relative to the Fleet street, no mode shift scenario.

In this scenario, bus services are replaced with a fleet with an on demand shared AV service. Users pay a lower fare than if they would if they travelled alone.

Compared to the Fleet Street, no mode shift scenario, more users are able to access AVs and at a low cost. This creates a significant uplift in accessibility. Areas with

Parents and Adults with no cars are the groups that benefit the most as a result of pooling.





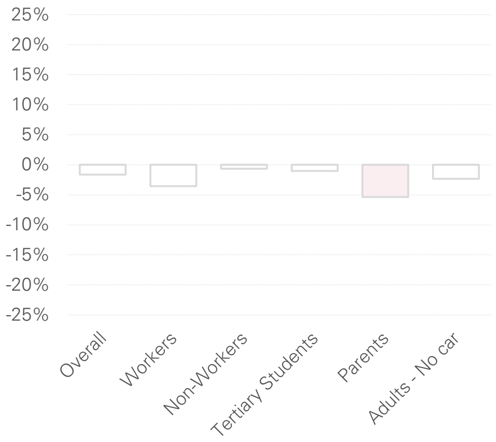
Accessibility: Fleet street, Calibrated fleet size vs Fleet street

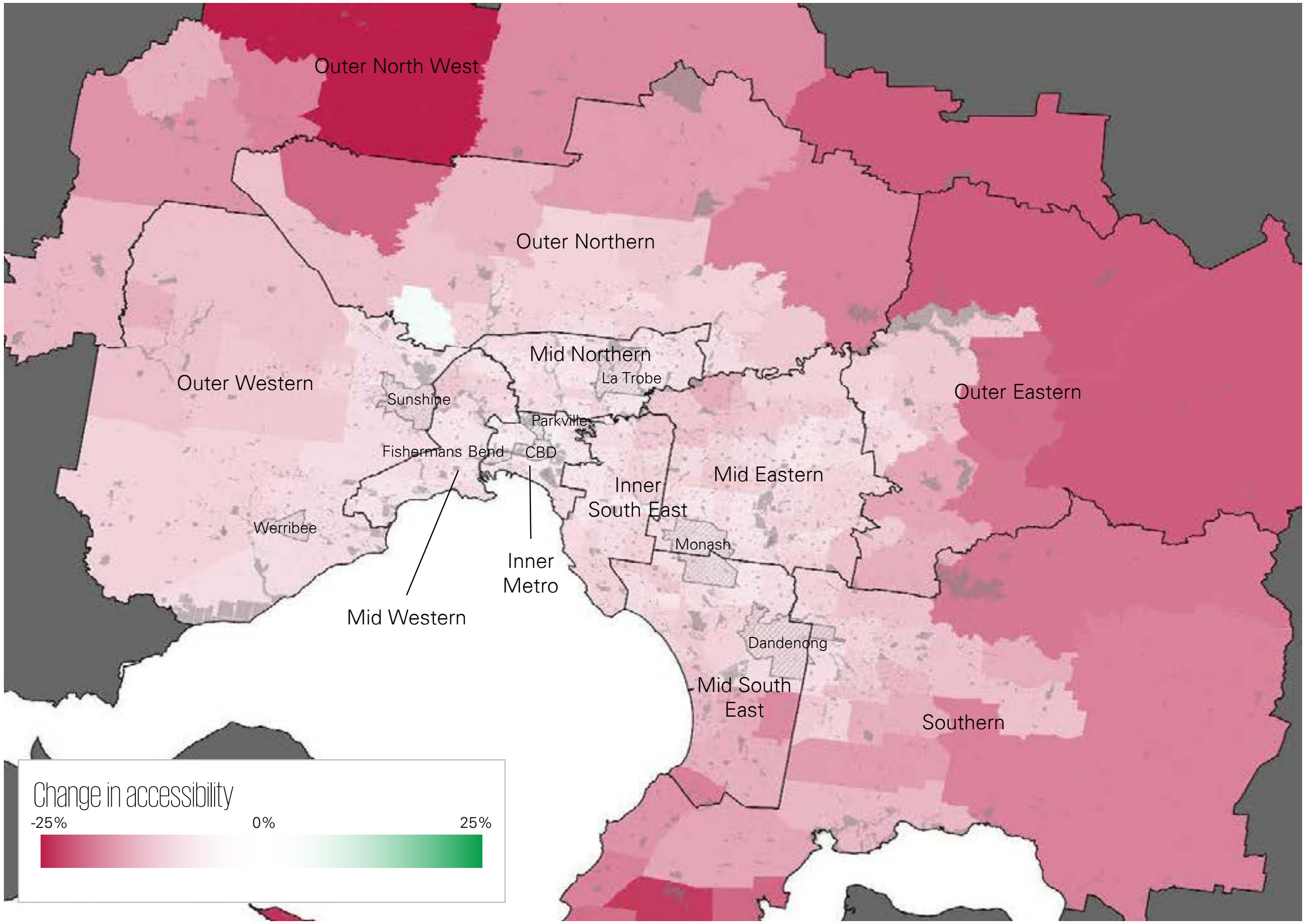
The calibrated Fleet street scenario has longer wait times for on-demand AVs due to a smaller fleet servicing the same demand as in Fleet street. Overall, accessibility is marginally worse than Fleet street due to the poorer service provided by the on-demand fleet. Parents are the most affected as they tend to travel more frequently and further than other user groups.

There is a strong geographic component to the change in accessibility, with residents of outer areas seeing the largest reductions in accessibility, as these low density outer areas are not serviced as easily by the on-demand fleet.

There is little change in accessibility in the dense inner areas as these residents are well served, even by the smaller fleet.

Change in accessibility

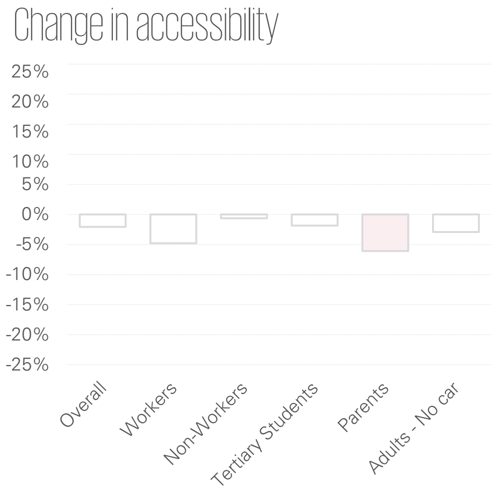


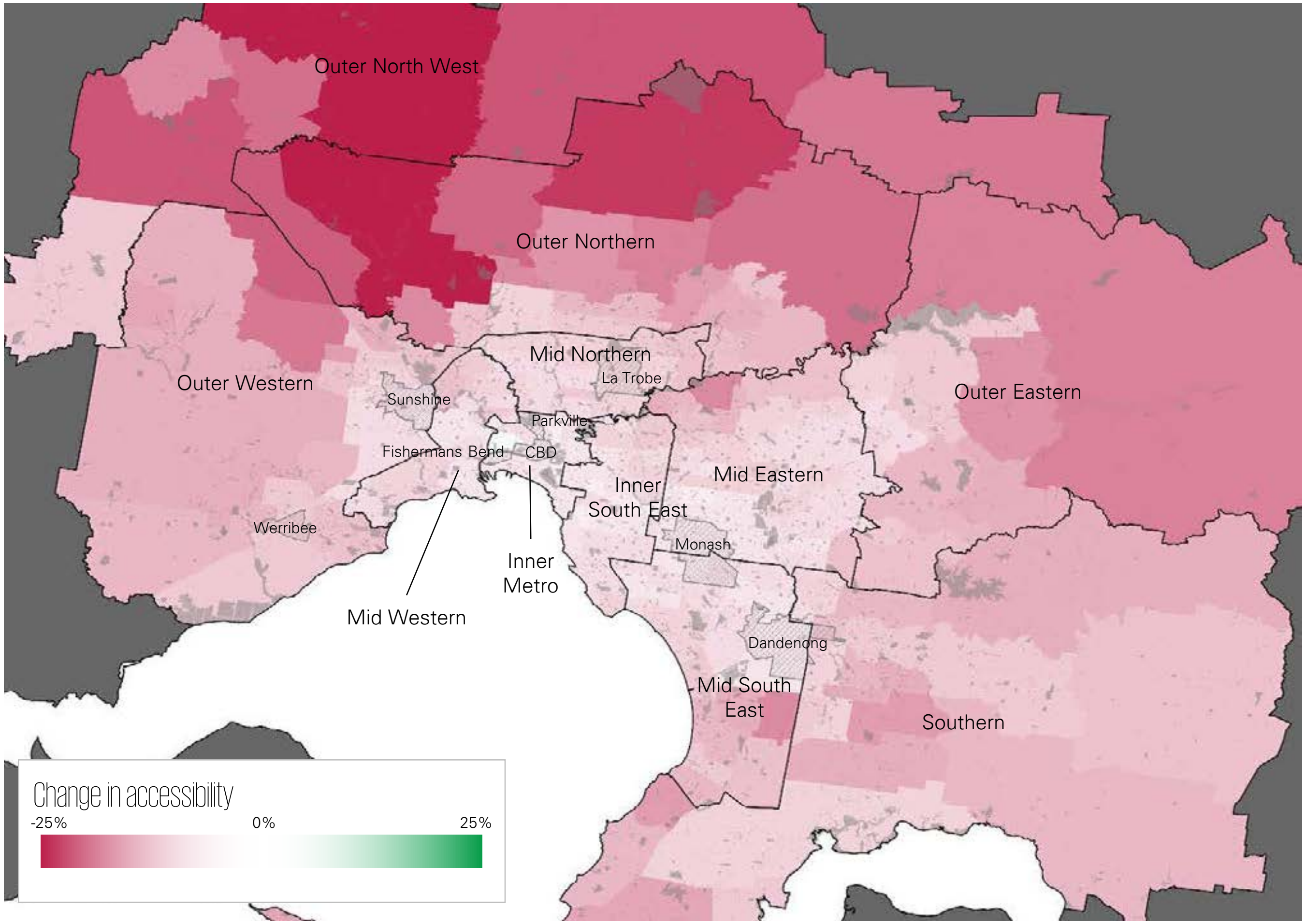


Accessibility: Fleet street, No new (pre-construction) major road projects vs Fleet street

The No new (pre-construction) major roads scenario has a general reduction in accessibility due to less available road infrastructure. The change is relatively modest overall, but has larger influences on certain areas.

The Outer North West and Outer Northern sub-regions are the most negatively affected by this scenario. This is due to the removal of the Outer Metropolitan Ring Road and North East Link in those areas. There are also modest reductions in accessibility in the south-east sub-regions and the Outer Western sub-region, which forego various freeway and arterial road upgrades. Parents are the most negatively impacted user group.



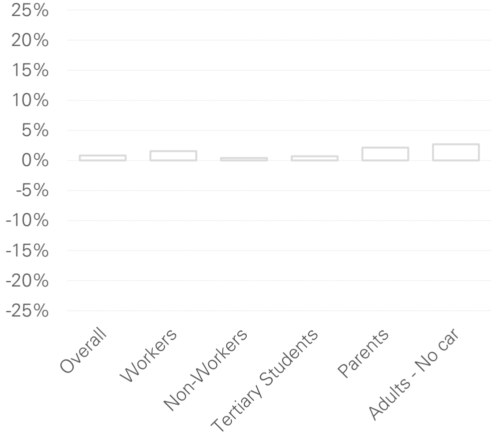


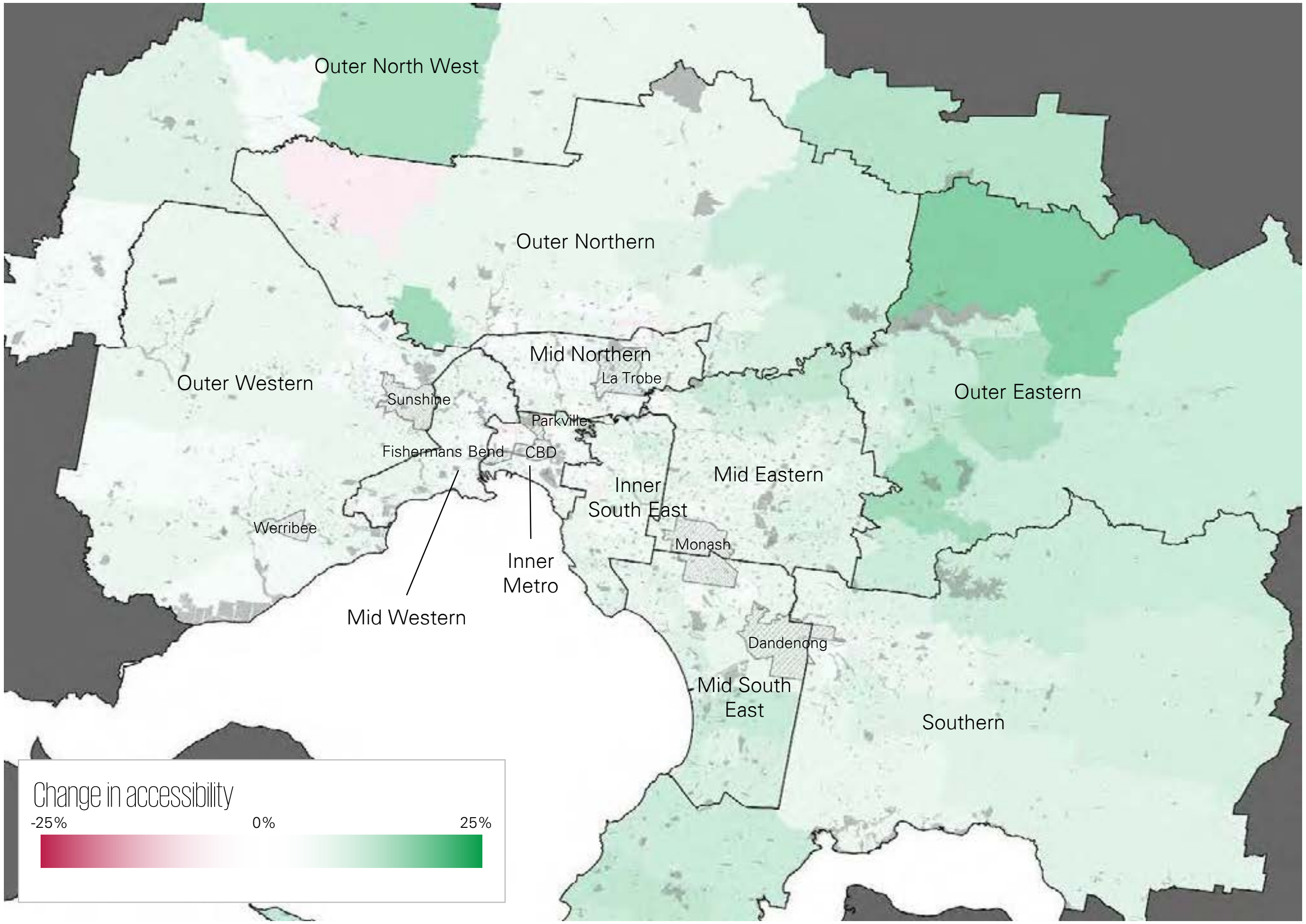
Accessibility: Slow lane, Low MUTT vs Slow lane

The Low MUTT variation of the Slow lane scenario leads to significant accessibility improvements relative to the Slow lane scenario.

This is because people are not as dissatisfied with additional travel time due to the comfort and convenience of AVs, so they perceive greater accessibility. While congestion increases due to induced demand on roads, consumers value the comfort and convenience of their AVs slightly more than they dislike the increases in congestion.

Change in accessibility

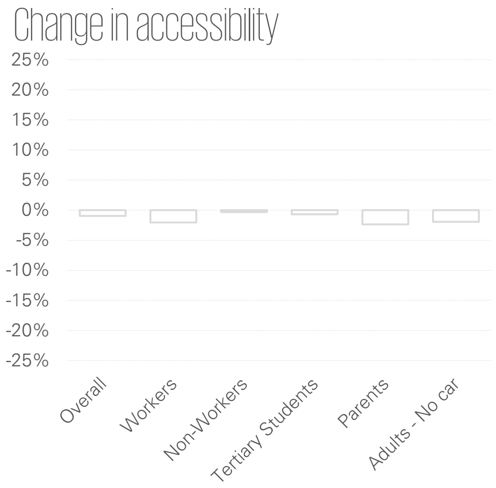


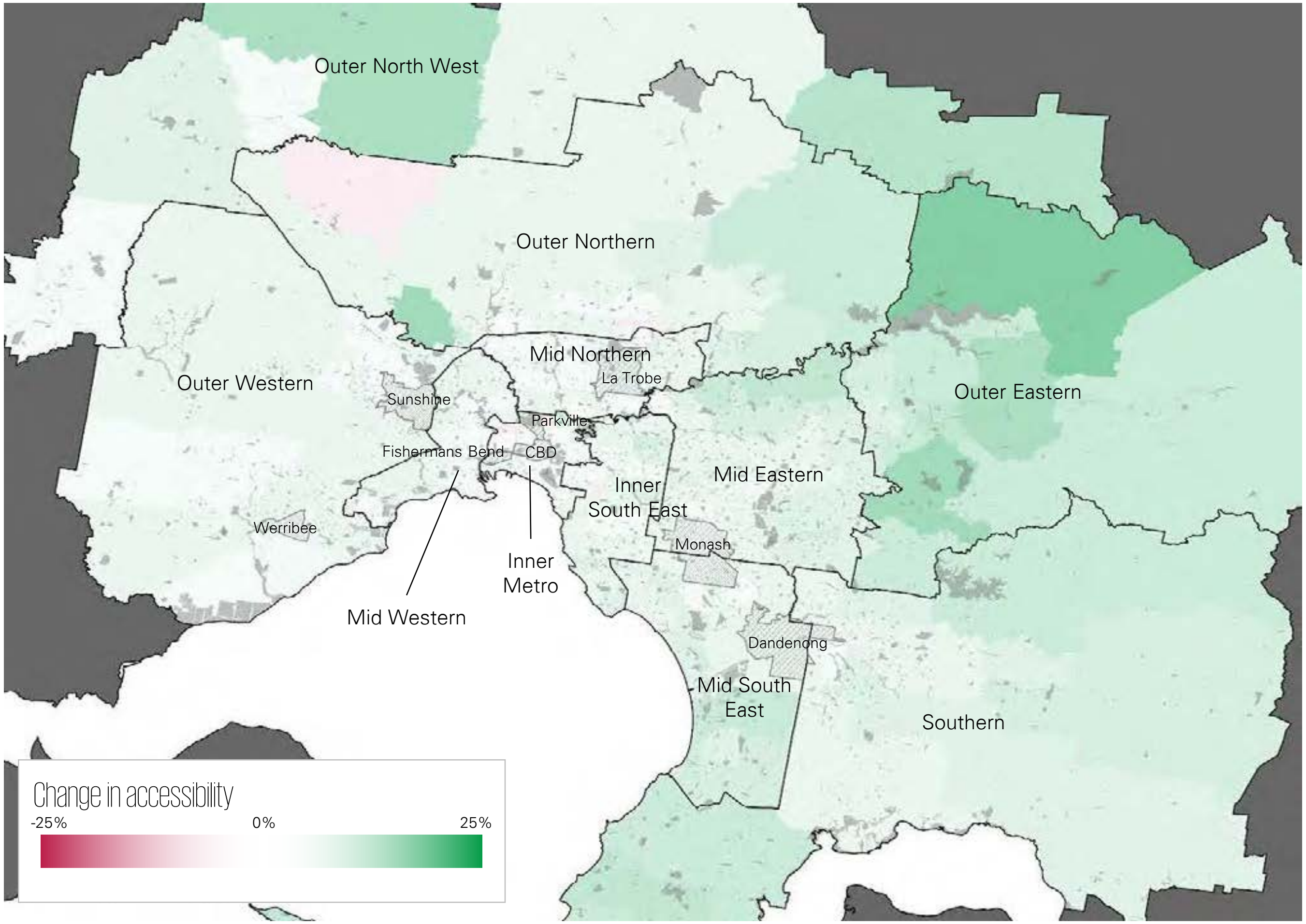


Accessibility: Slow lane, Low flow vs Slow lane

The Low flow variation of Slow lane scenario leads to slight accessibility reductions relative to the Slow lane scenario.

This is because the benefit of platooning is assumed to be lower in this scenario than in the Slow lane scenario, leading to poorer accessibility. This highlights the benefits of platooning, particularly for residents who live along or at the end of major freeway corridors.

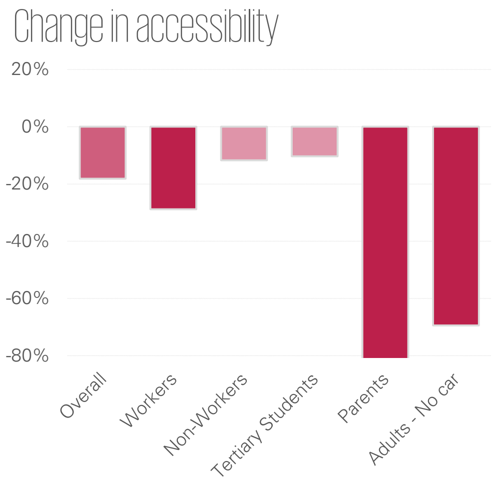


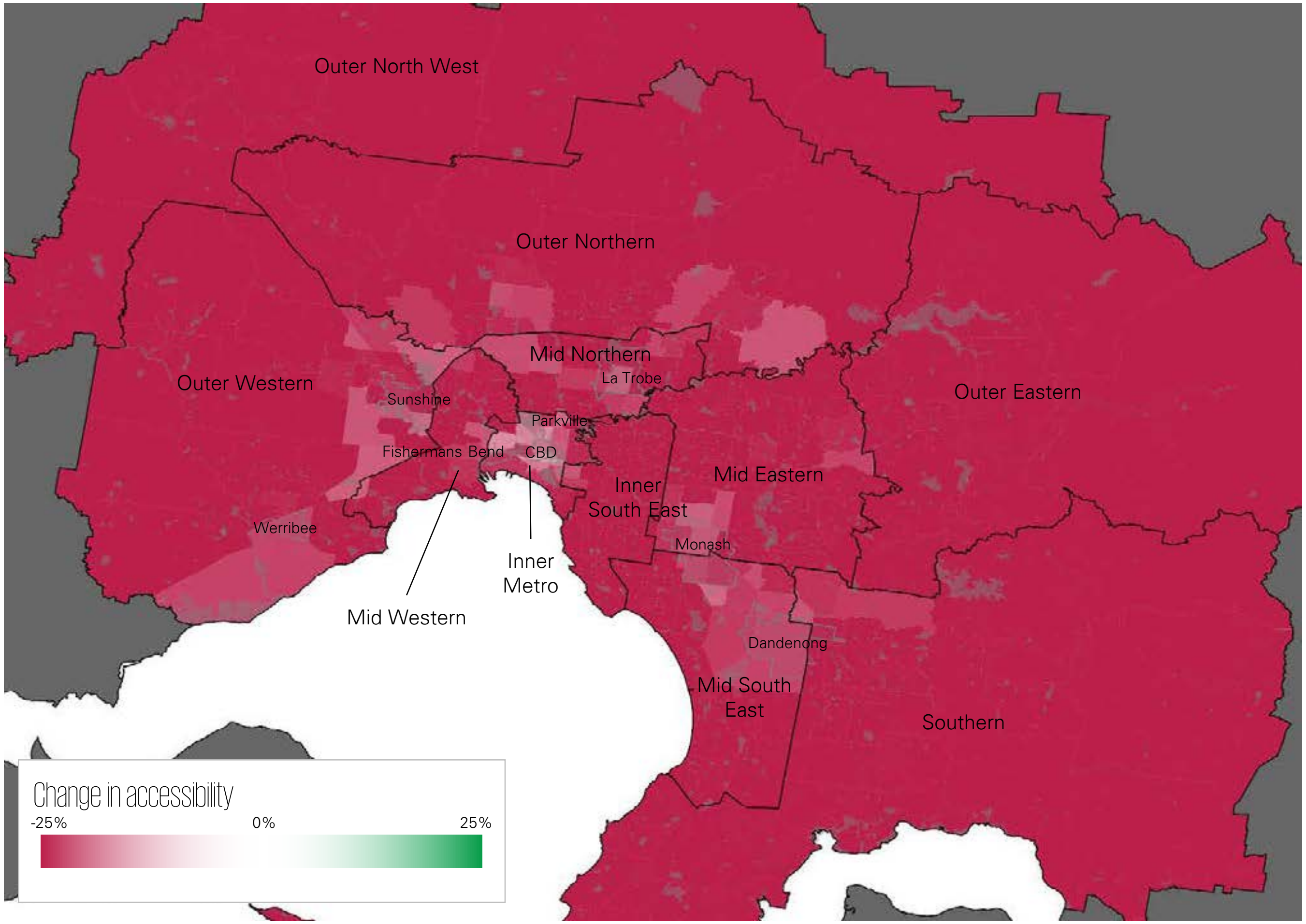


Accessibility: Slow lane, No mode shift vs Slow lane

The No mode shift variation of the Slow lane scenario leads to major accessibility reductions relative to the Slow lane scenario.

This is because people would like to shift away from vehicles on demand and towards public transport and active modes avoid the fares. However they are constrained from doing so in this model run, leading to dissatisfaction and therefore poorer accessibility.



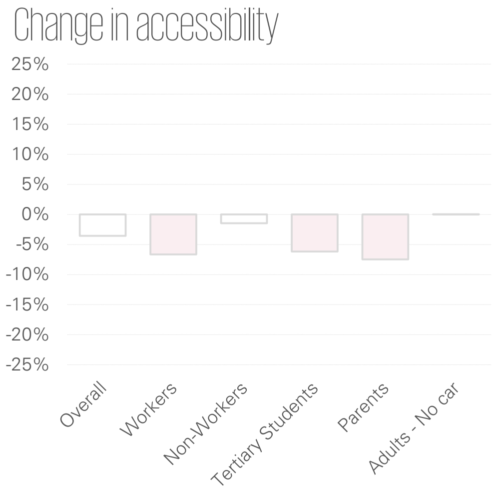


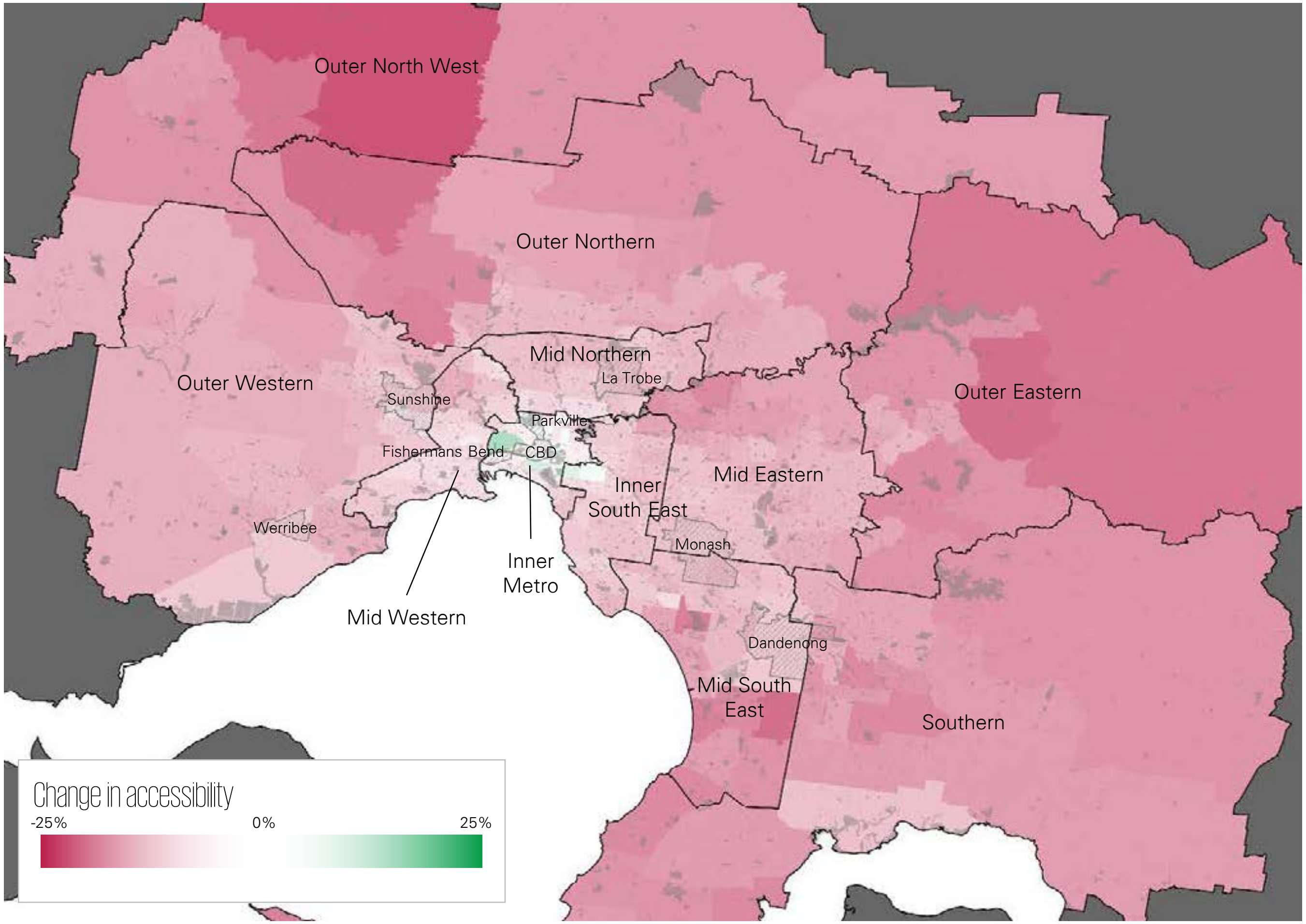
Accessibility: Slow lane, Private slow lane vs Private drive

The Slow lane, Private AV scenario sees a reduction in accessibility across most of the city. This is because the traditional cars are unable to platoon, meaning road capacity is effectively decreased and congestion is worse.

The exception to this is the CBD and inner areas. Because traditional cars can not be sent home empty to avoid parking, they generate less congestion in the inner city than the Private drive scenario.

Workers, tertiary students and parents are the user groups most affected.





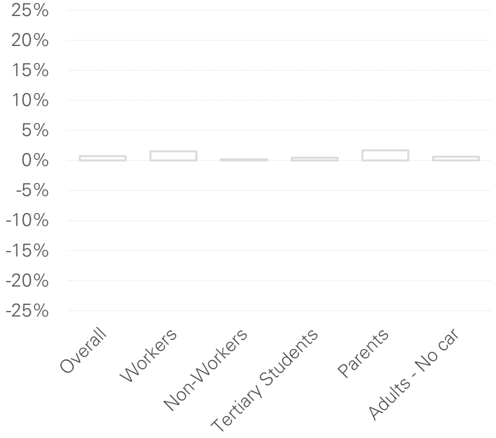
Accessibility: Hydrogen highway, No empty running vs Hydrogen highway

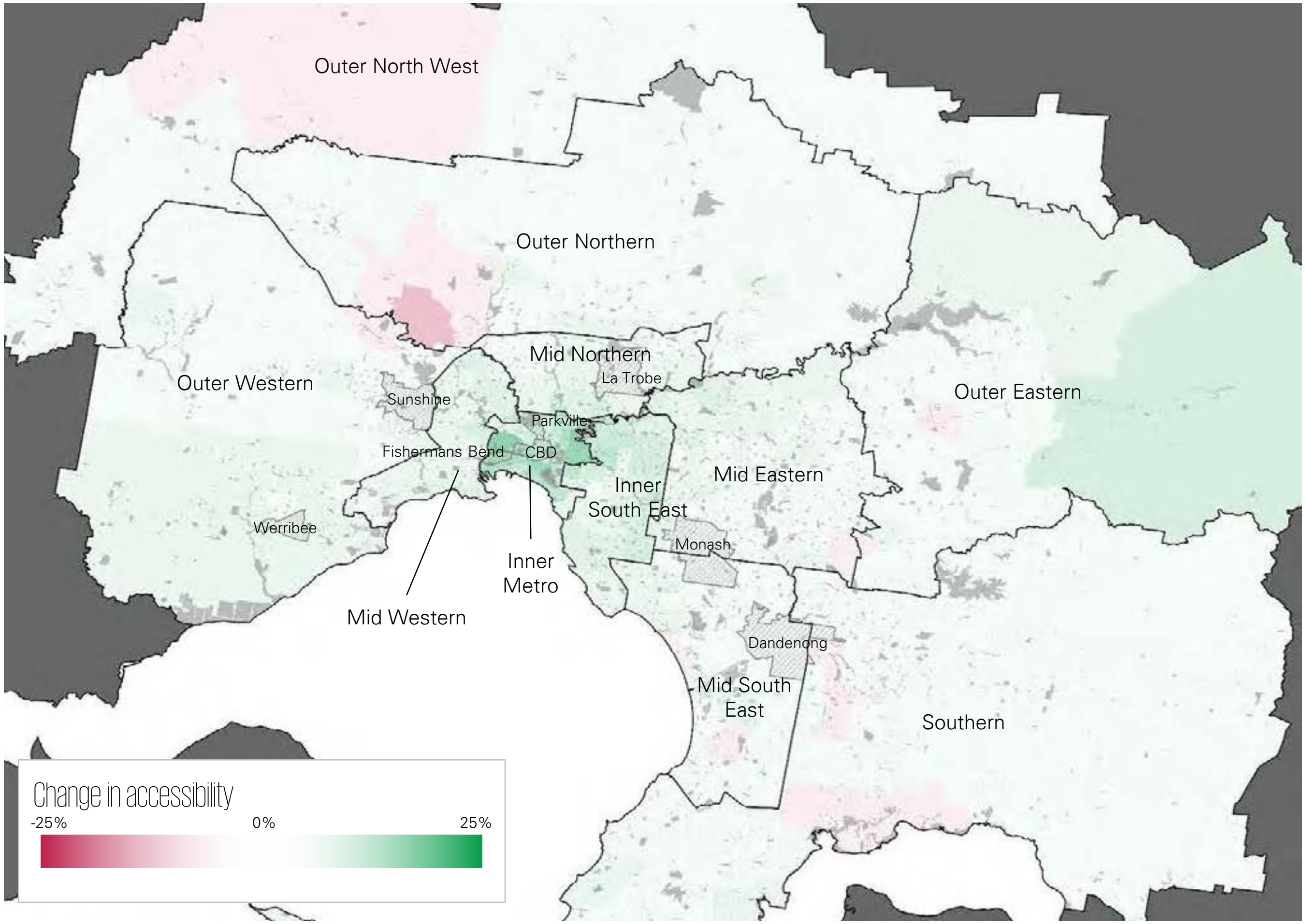
The No Empty Running variation of the Hydrogen Highway scenario leads to accessibility improvements for those living in the inner suburbs, and small changes elsewhere.

When empty running is allowed, AV owners send their cars back home to avoid inner city parking charges. These empty vehicles create congestion in inner areas which reduces accessibility for residents.

Removing empty running reduces this extra traffic and also discourages some people from choosing to drive due to the cost of parking. This improves accessibility for residents of the inner city where parking is a significant deterrent from driving.

Change in accessibility





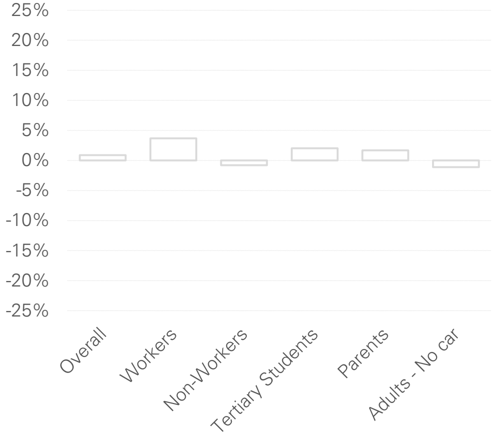
Accessibility: Mix of scenarios vs Dead end

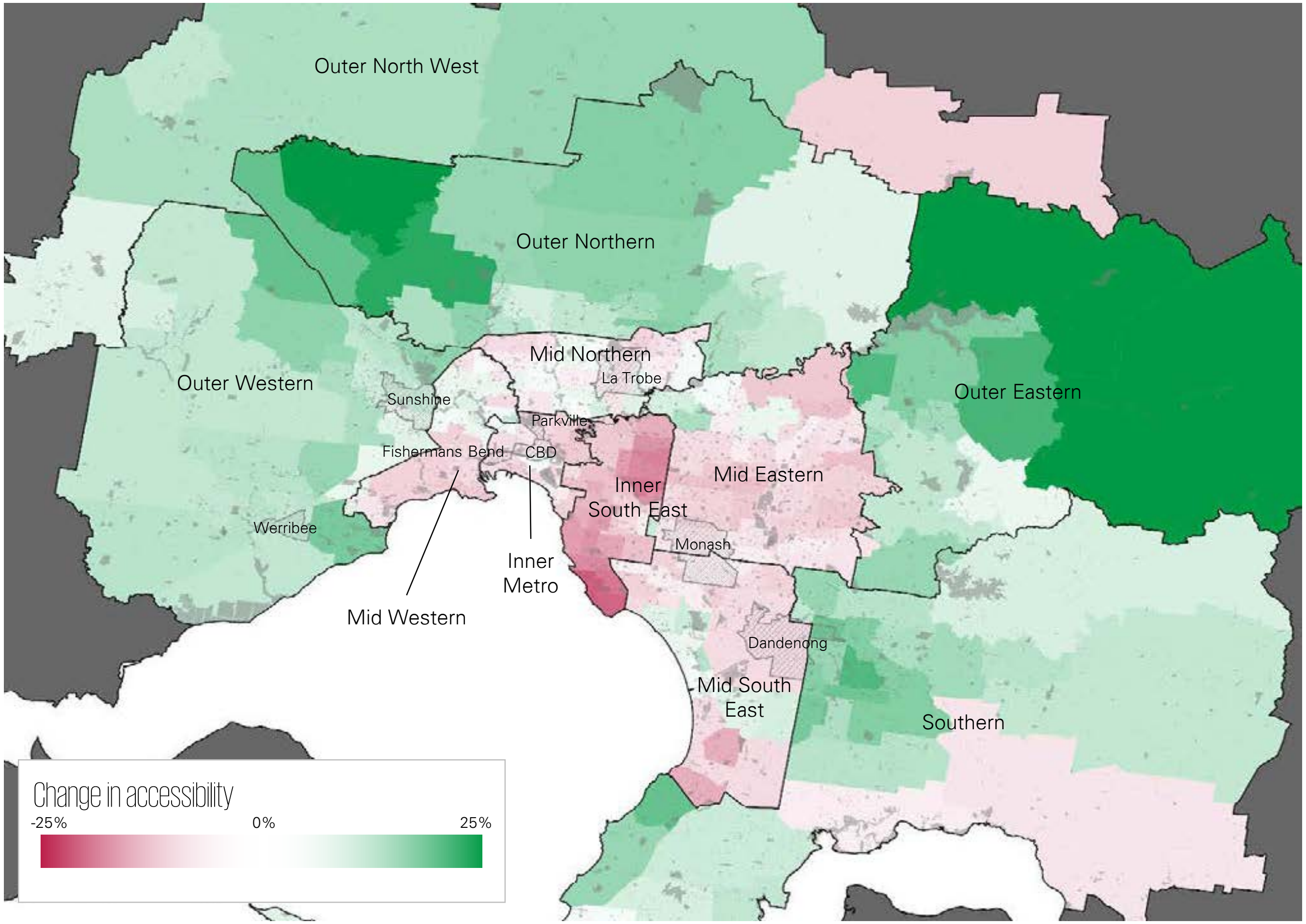
The Mixed fleet scenario has different impacts in different areas of Melbourne. Overall, accessibility is similar to Dead end on average, with workers benefitting the most of all user groups.

Accessibility is generally, lower in the inner and middle sub-regions as more of these residents (75% and 50% respectively) need to rely on on-demand AVs instead of private cars. This comes with wait times and perceived on-demand fares, reducing accessibility.

Accessibility is higher in the outer areas, as 75% of residents retain their private cars, and congestion is low for trips in the inner and middle sub-regions due to the higher use of public transport by those residents.

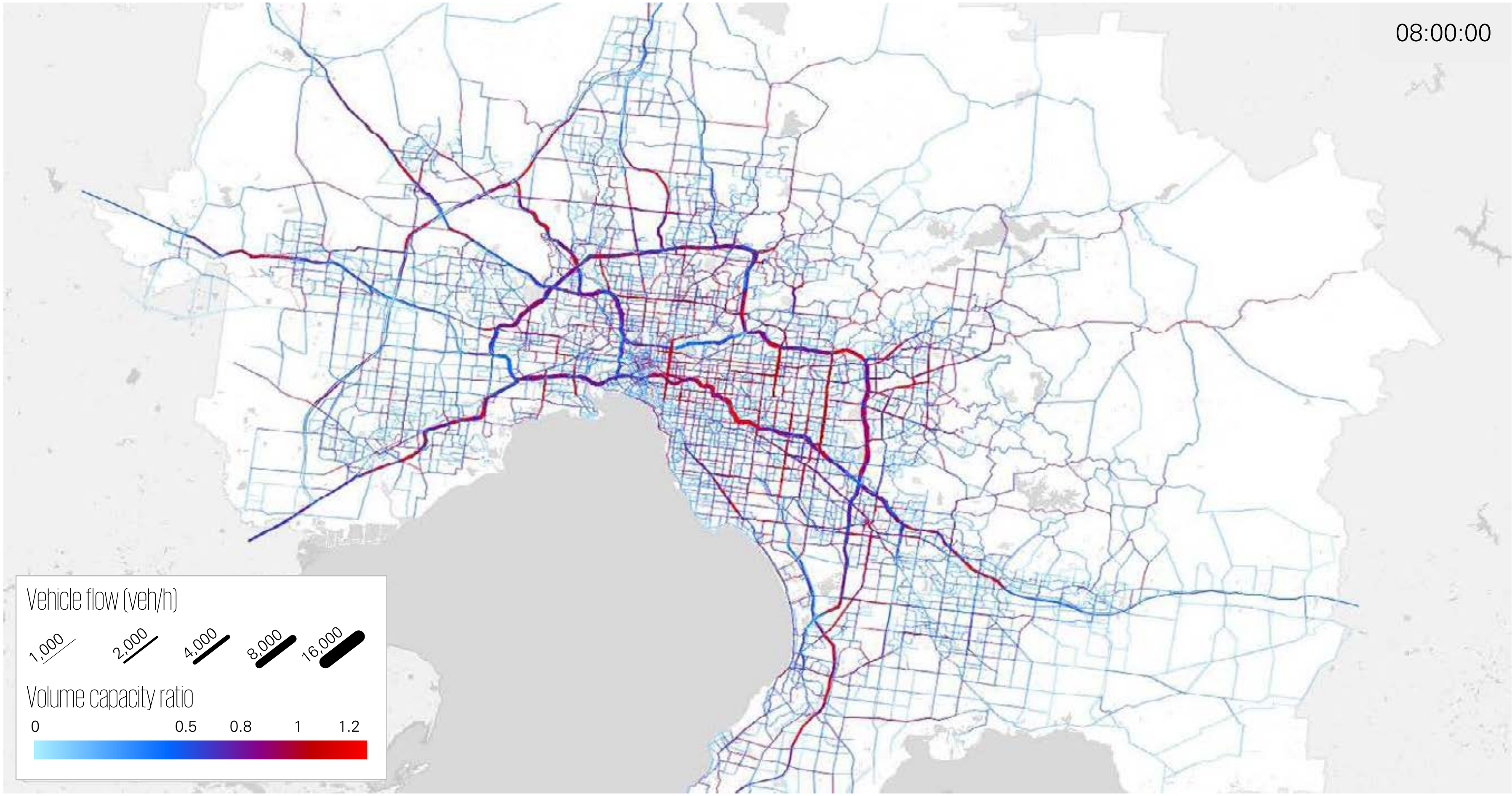
Change in accessibility





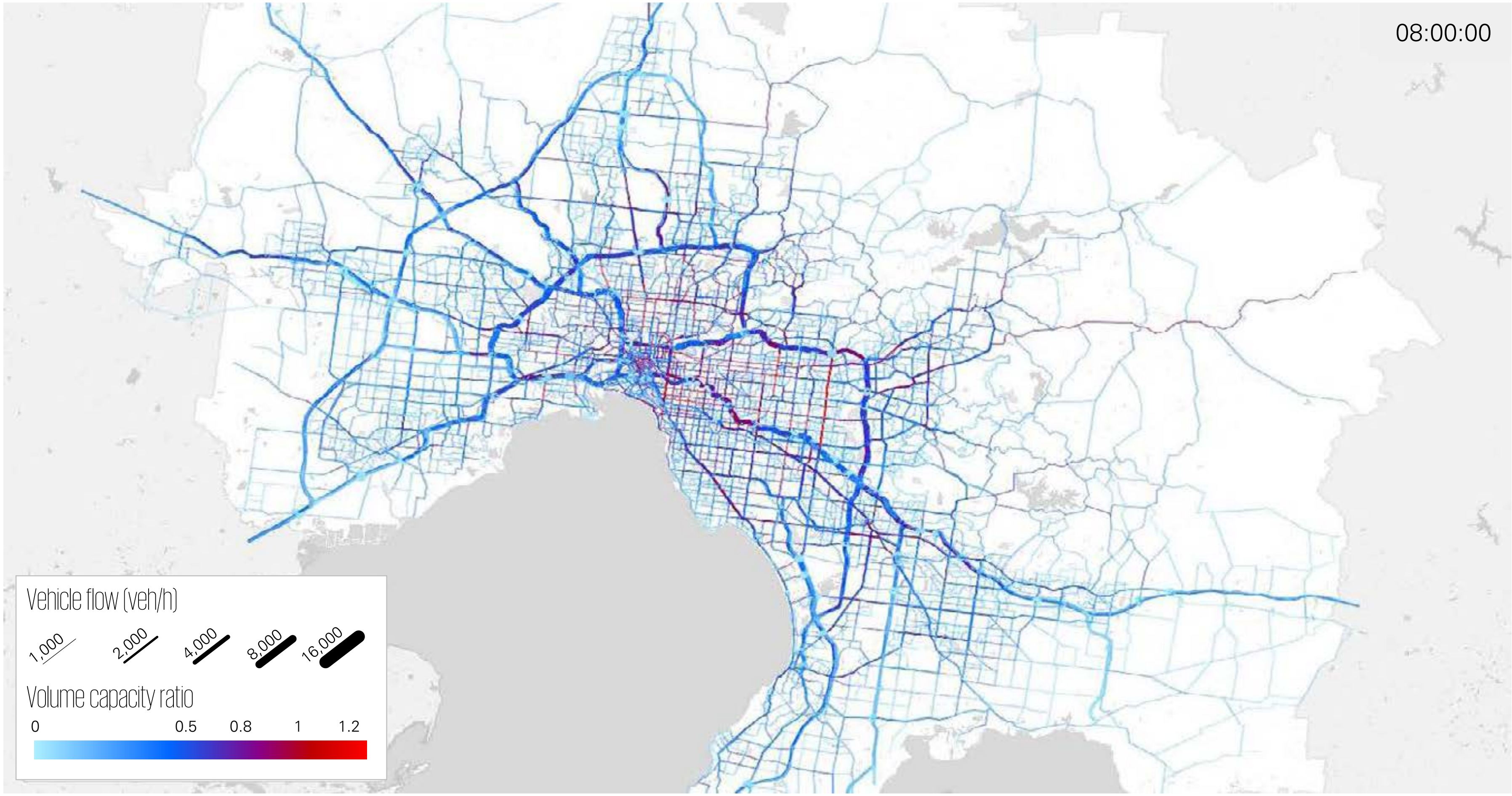
Appendix D: Volume capacity ratio plots

Volume capacity ratio: Dead end, morning peak



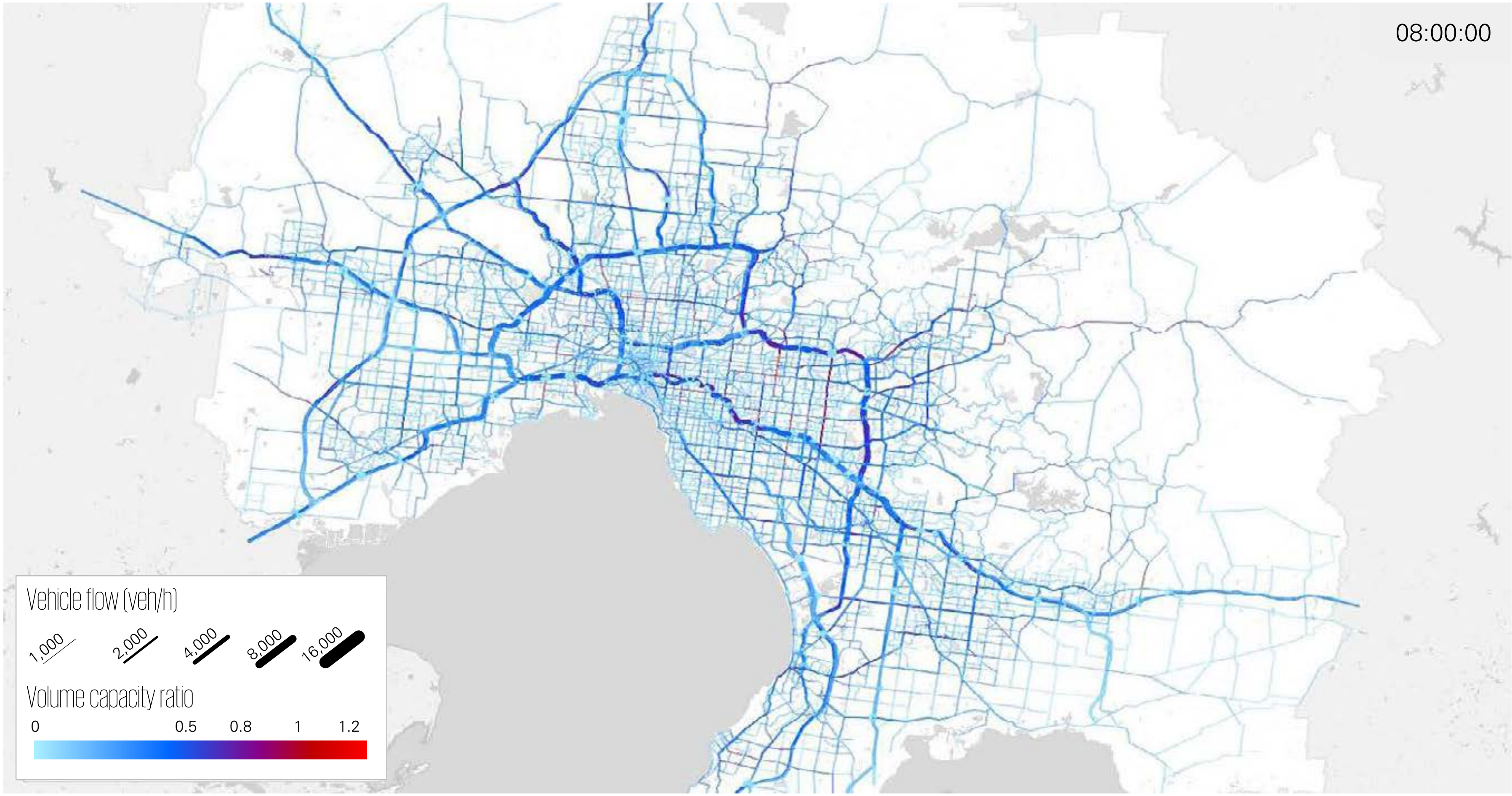
Source: MABM

Volume capacity ratio: Private drive, morning peak



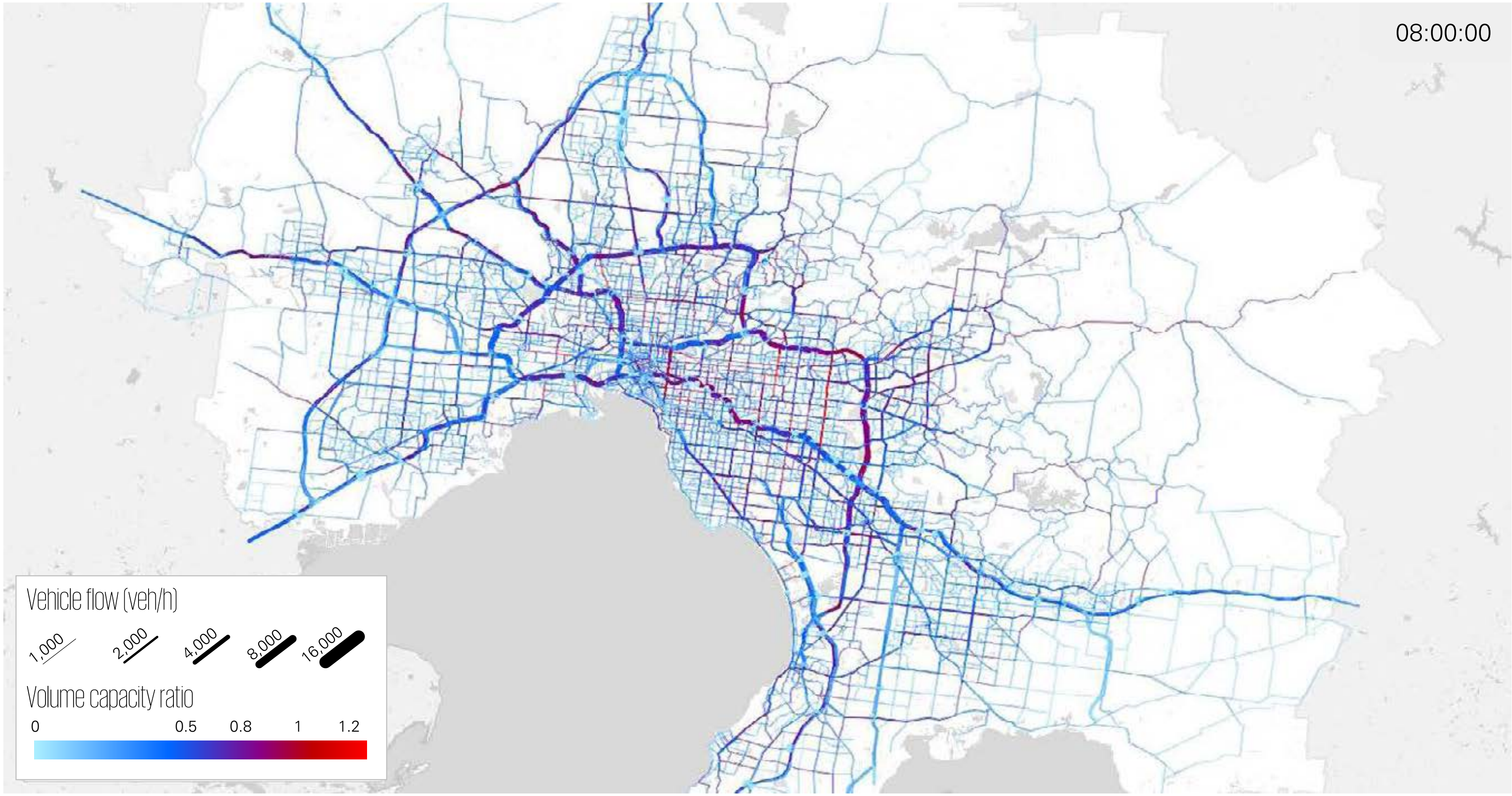
Source: MABM

Volume capacity ratio: Fleet street, morning peak



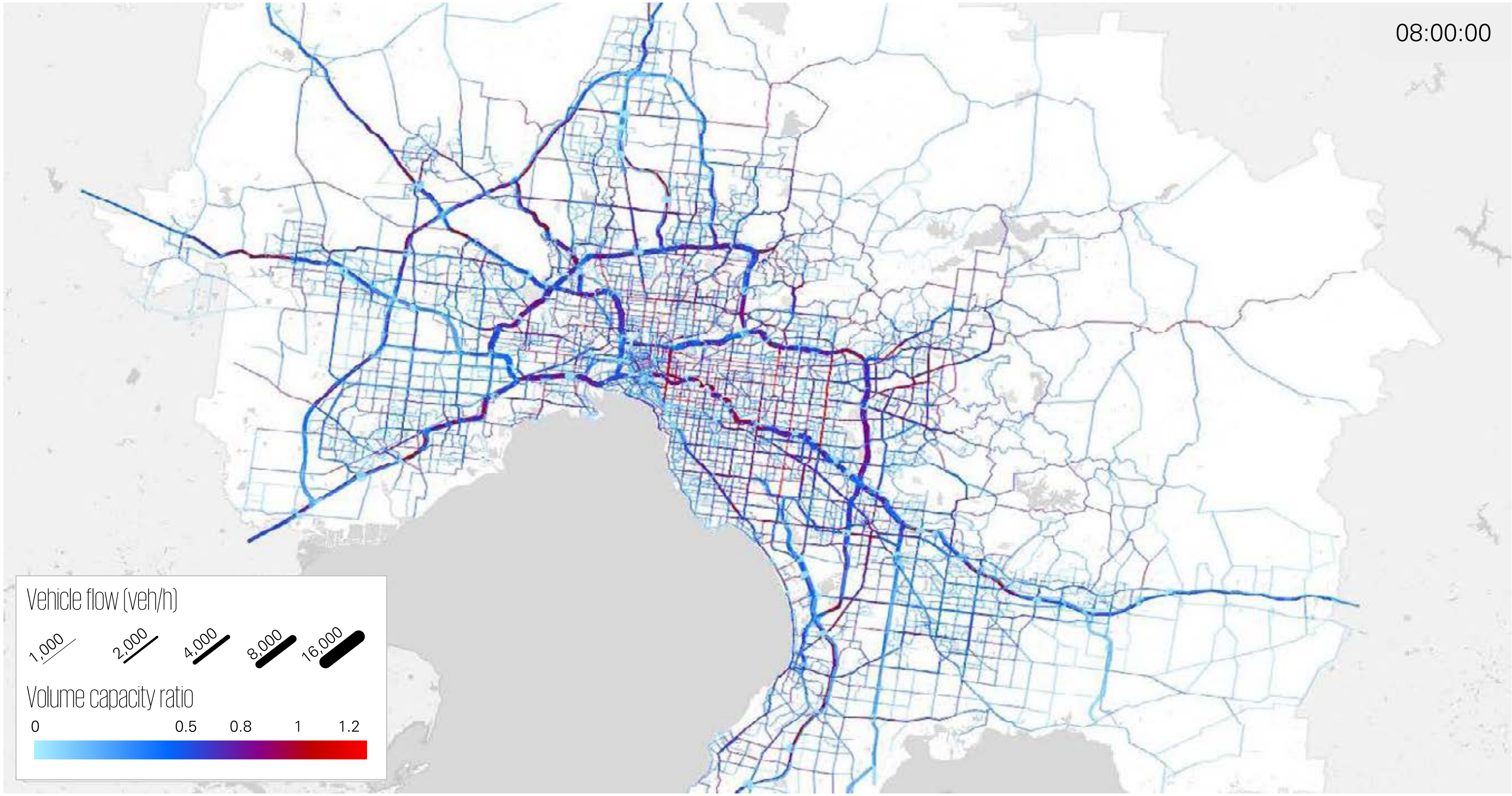
Source: MABM

Volume capacity ratio: Slow lane, morning peak



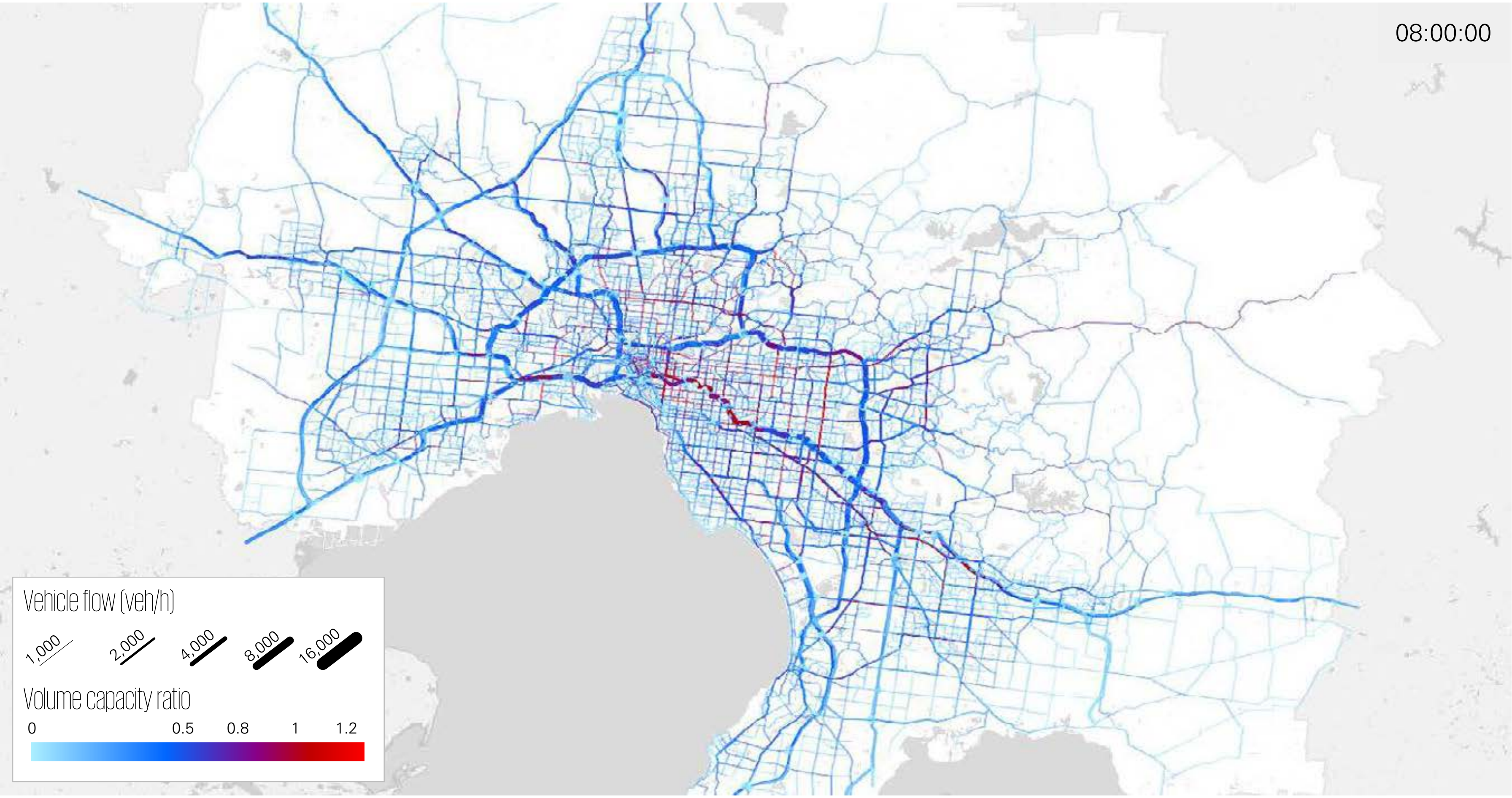
Source: MABM

Volume capacity ratio: Electric avenue, morning peak



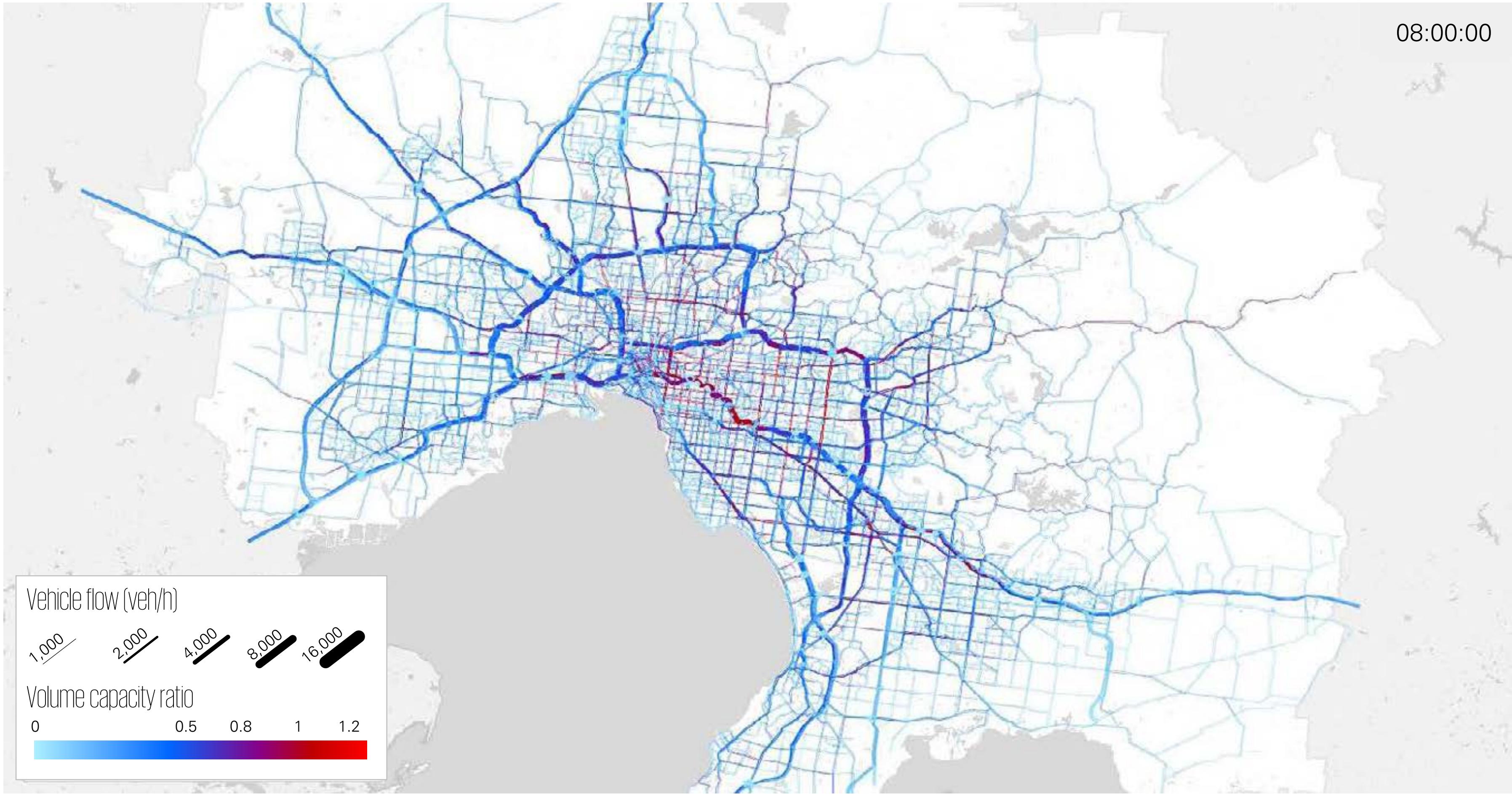
Source: MABM

Volume capacity ratio: Hydrogen highway, morning peak



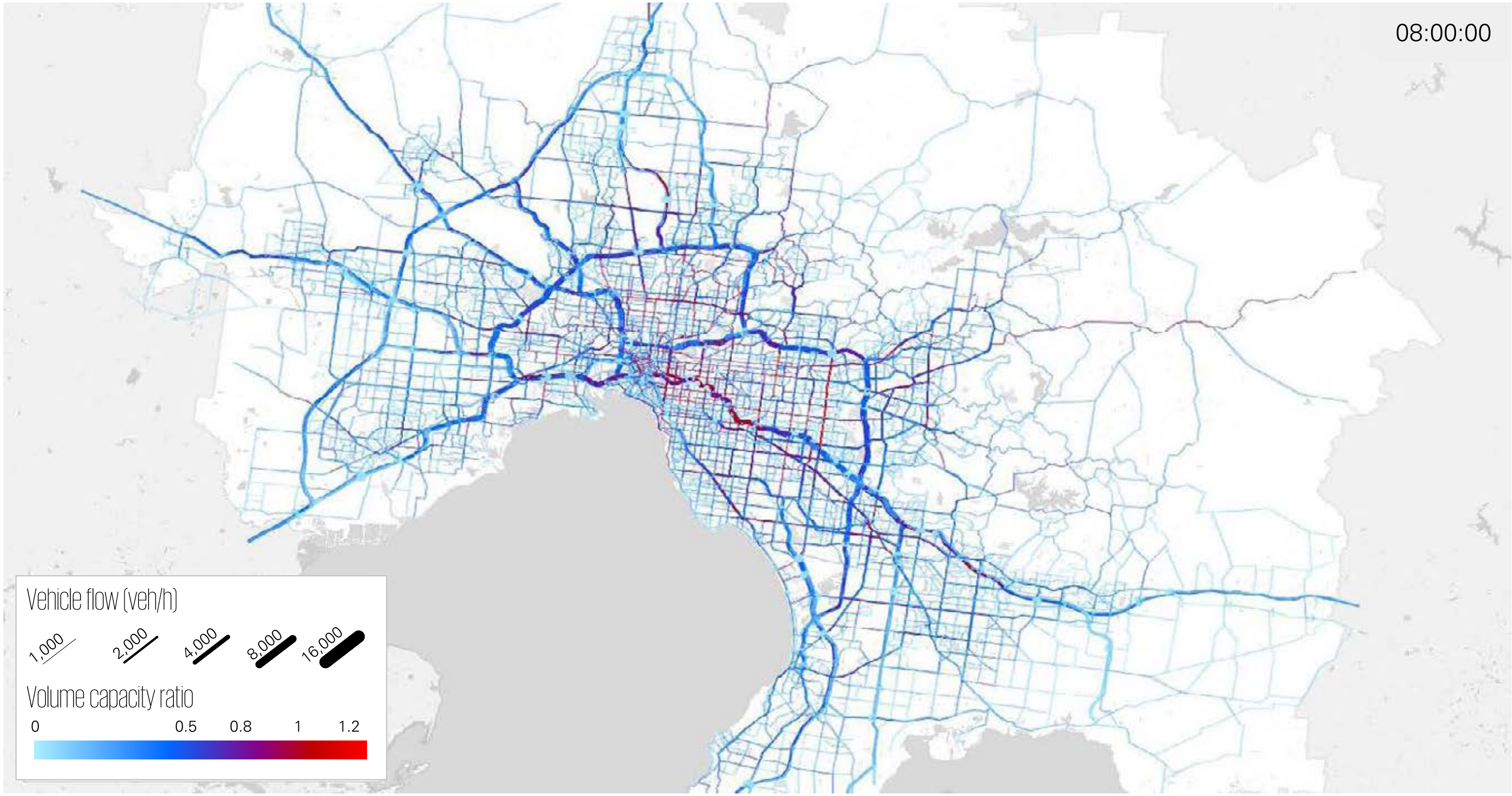
Source: MABM

Volume capacity ratio: Private drive, No empty running, morning peak



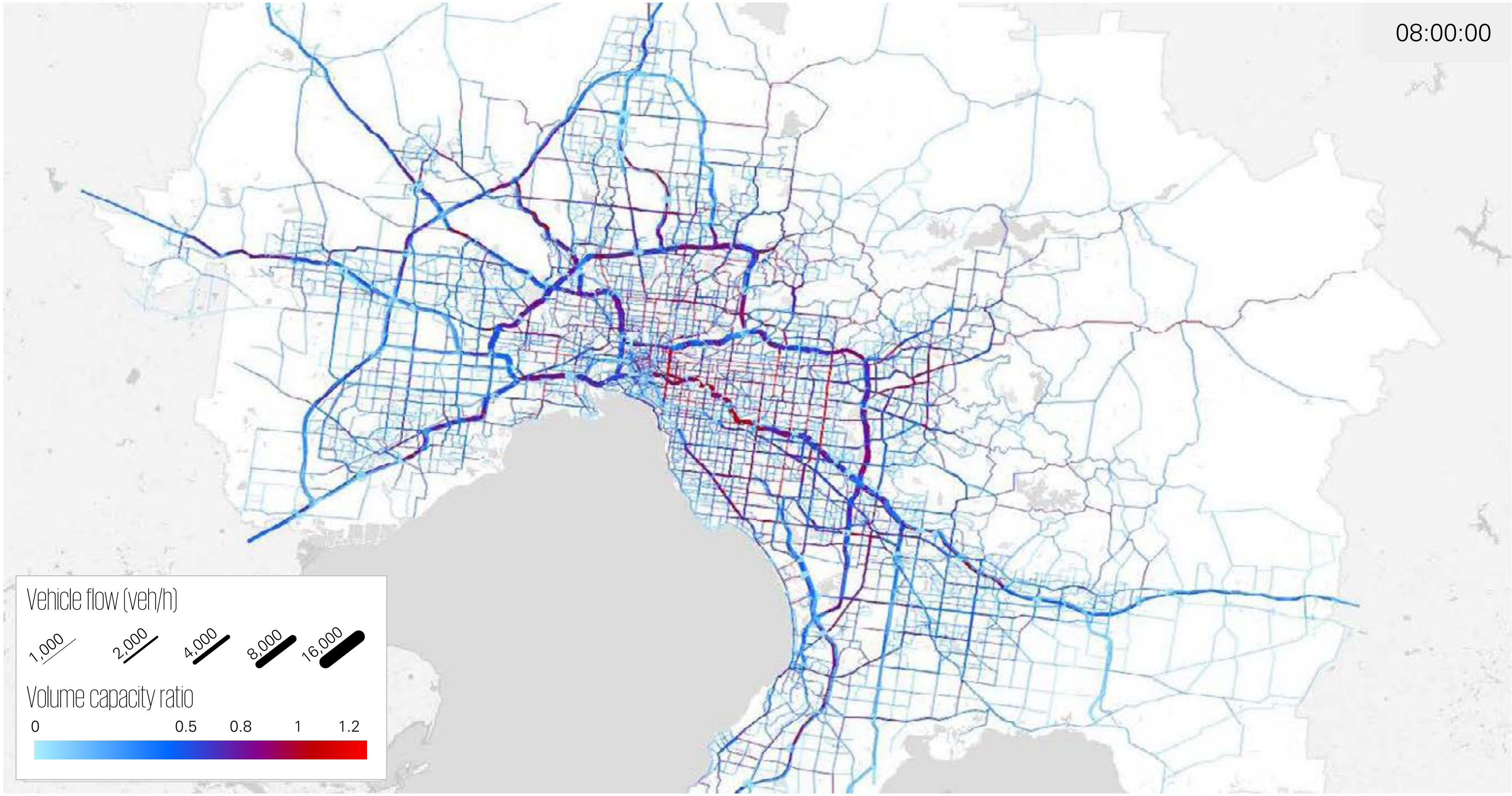
Source: MABM

Volume capacity ratio: Private drive, Low MUTT, morning peak



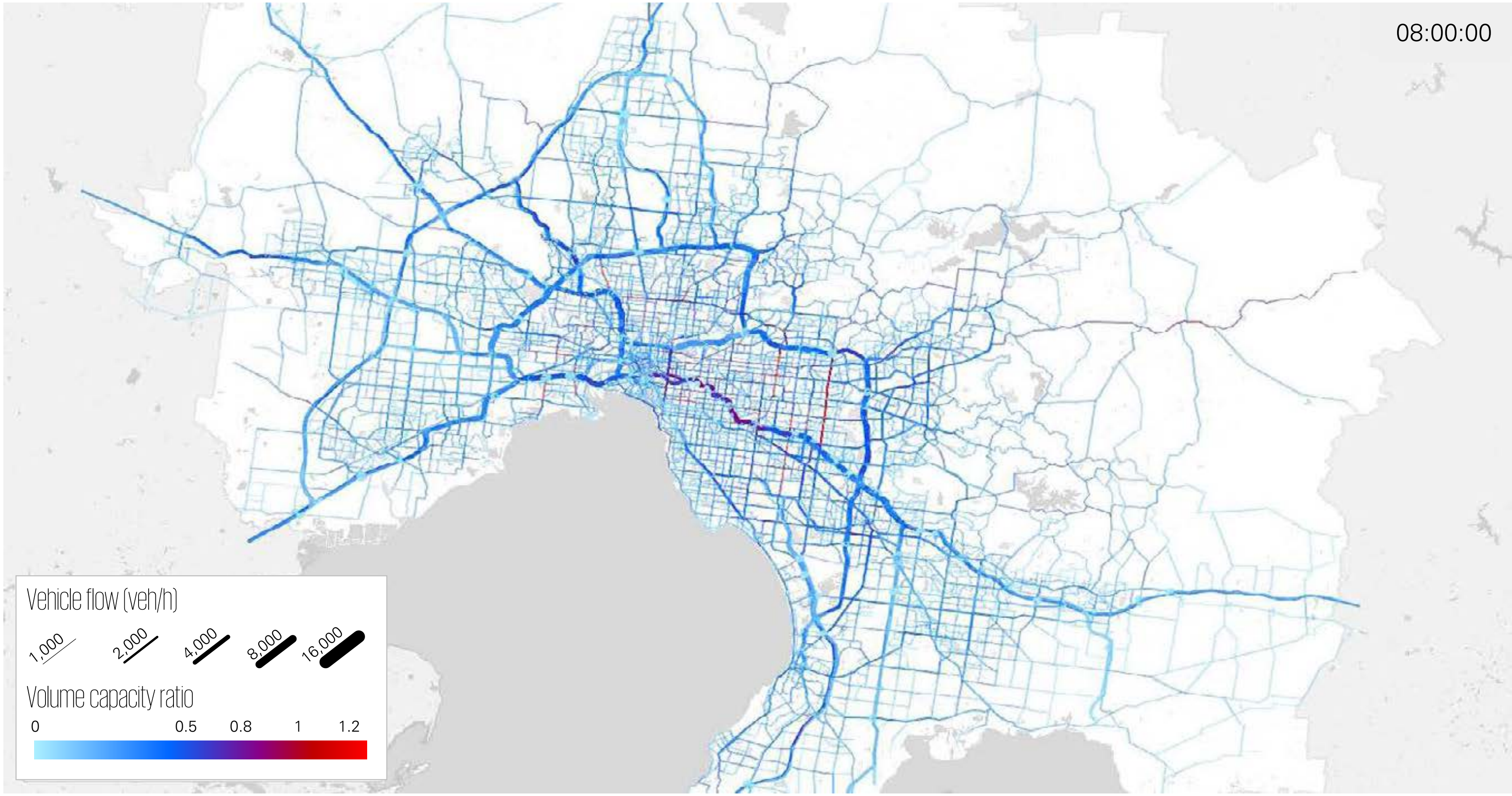
Source: MABM

Volume capacity ratio: Private drive, Low flow, morning peak



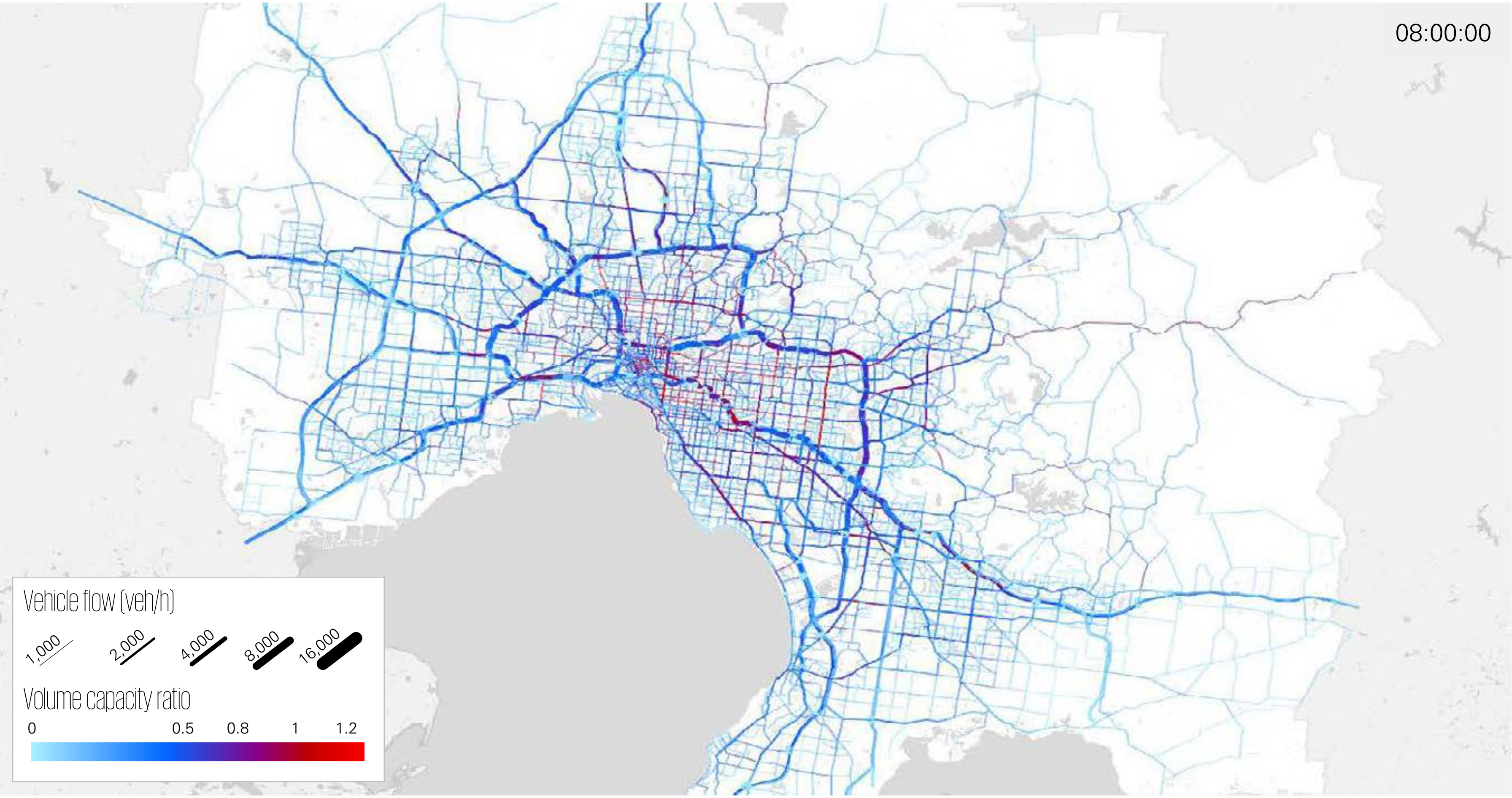
Source: MABM

Volume capacity ratio: Private drive, No mode shift, morning peak



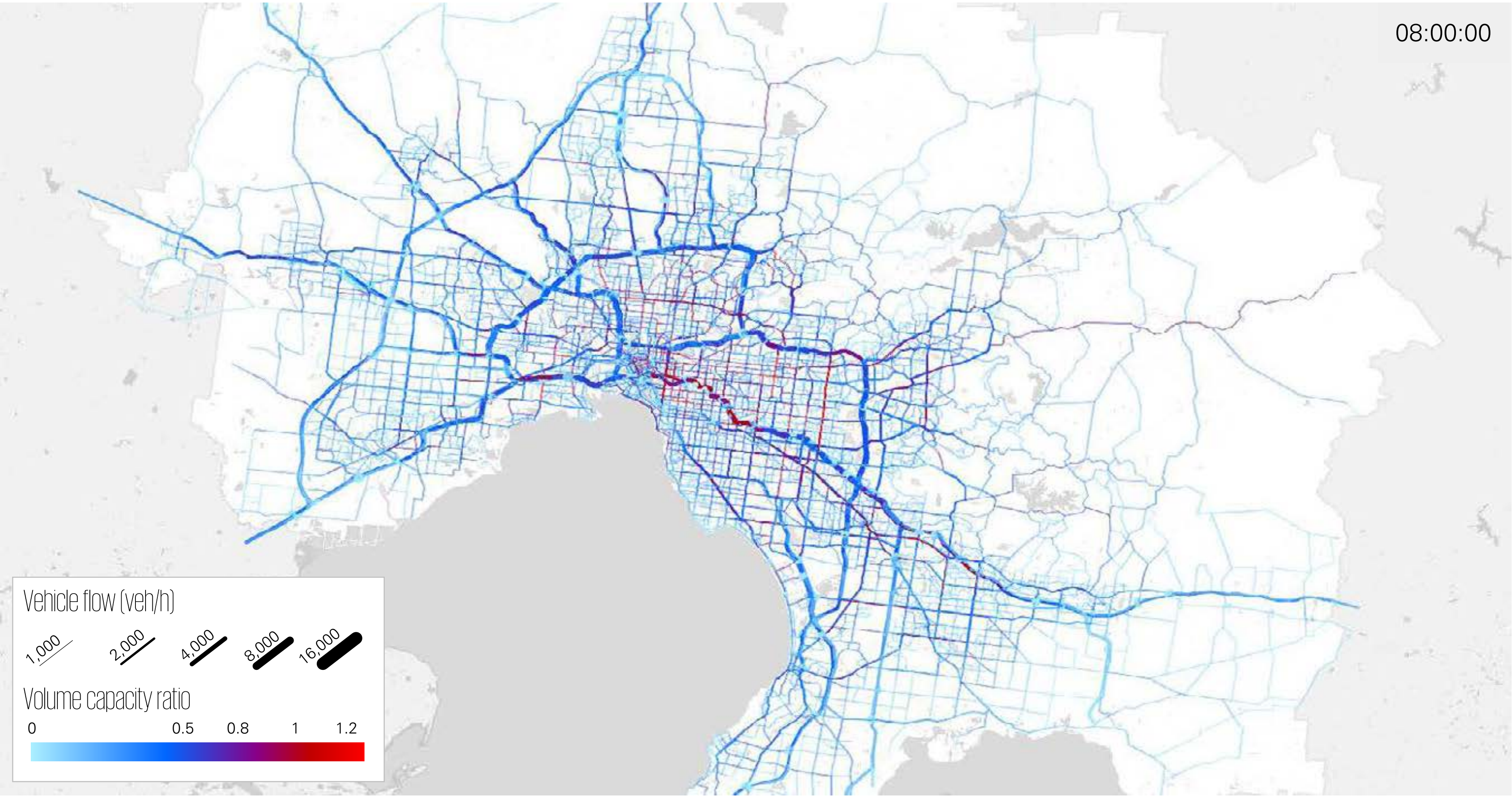
Source: MABM

Volume capacity ratio: Private drive, Area based charge, morning peak



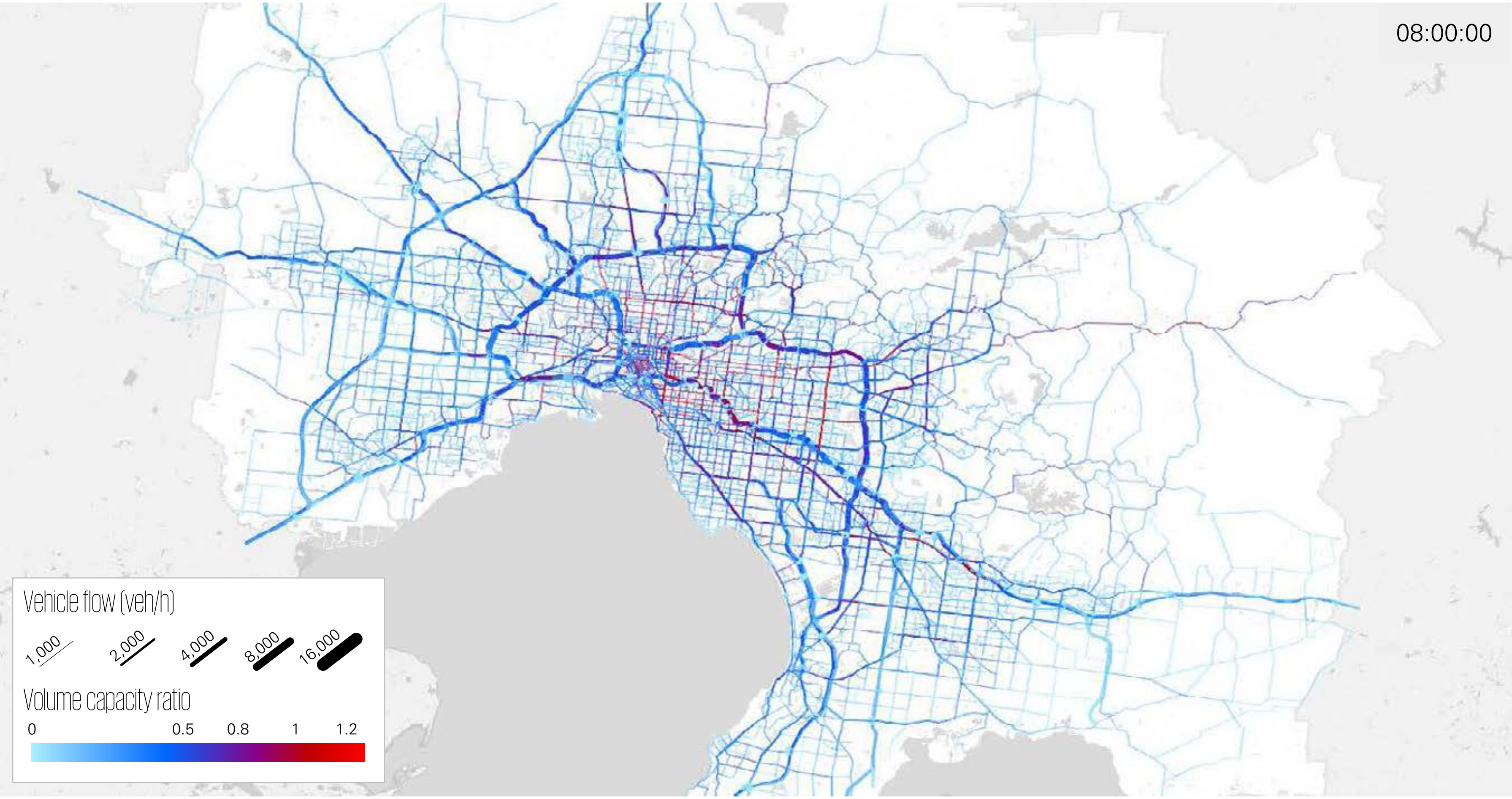
Source: MABM

Volume capacity ratio: Private drive, Distance based charge, morning peak



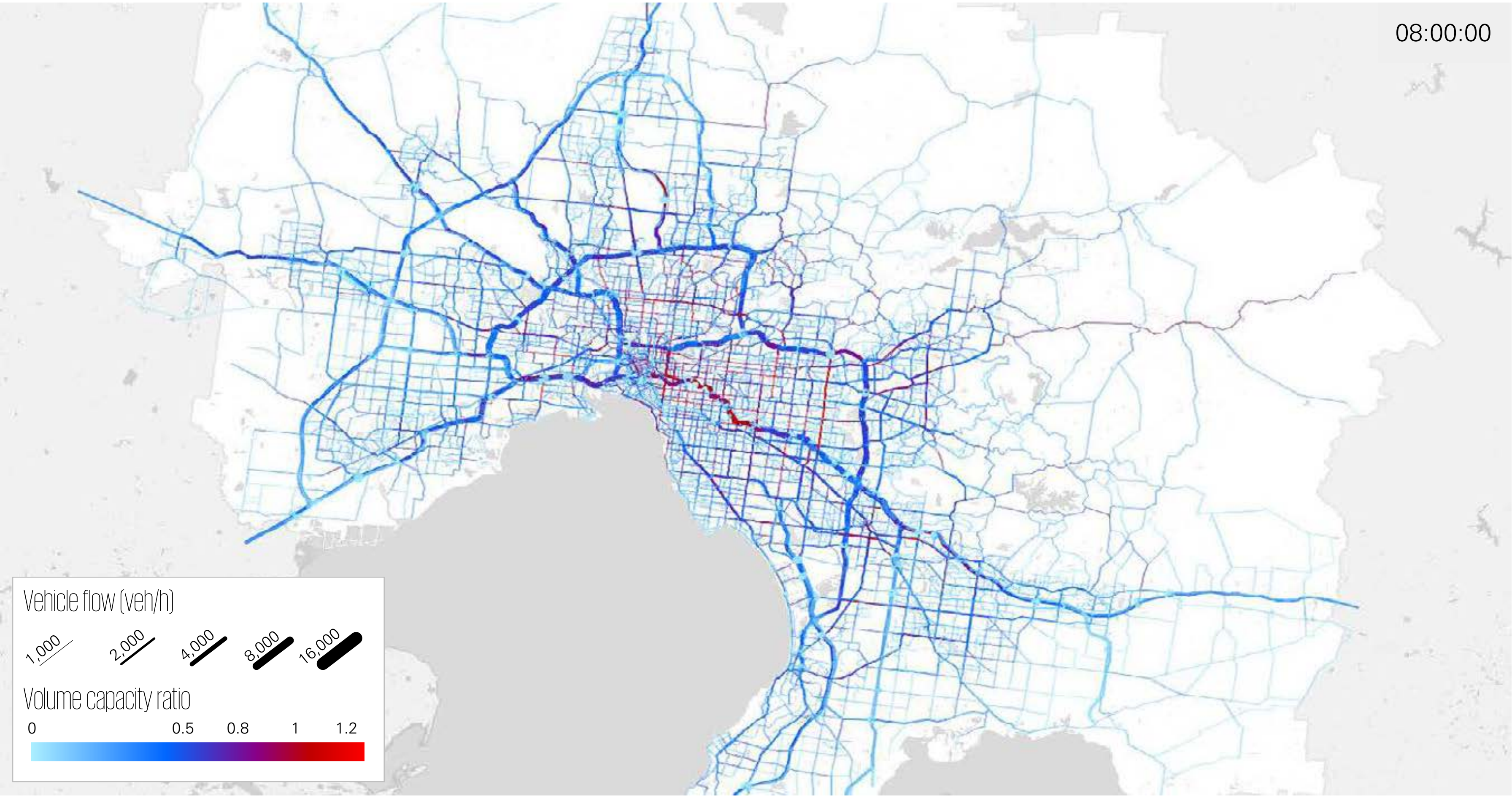
Source: MABM

Volume capacity ratio: Private drive, Freight to night, morning peak



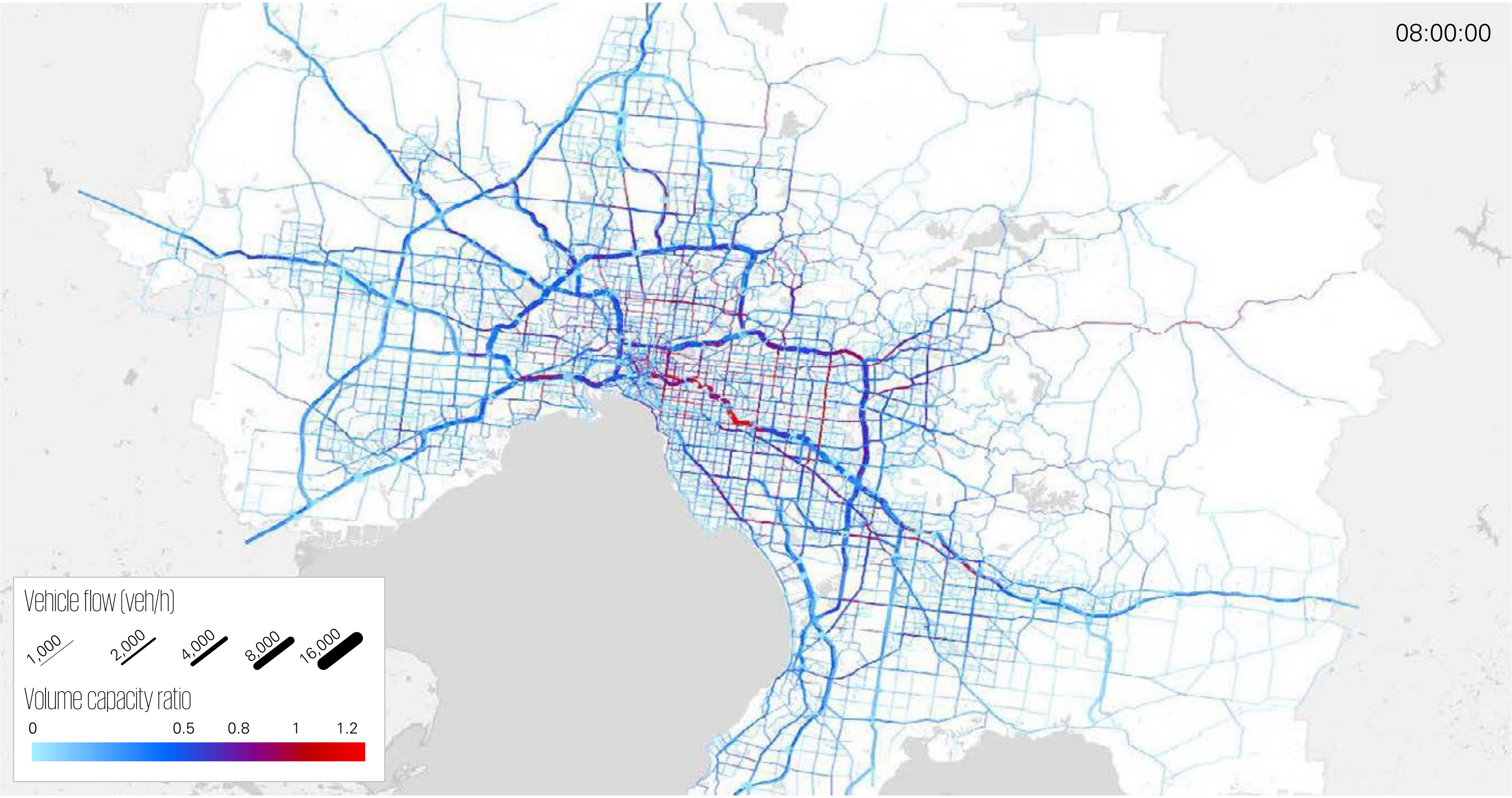
Source: MABM

Volume capacity ratio: Private drive, Expanded markets, morning peak



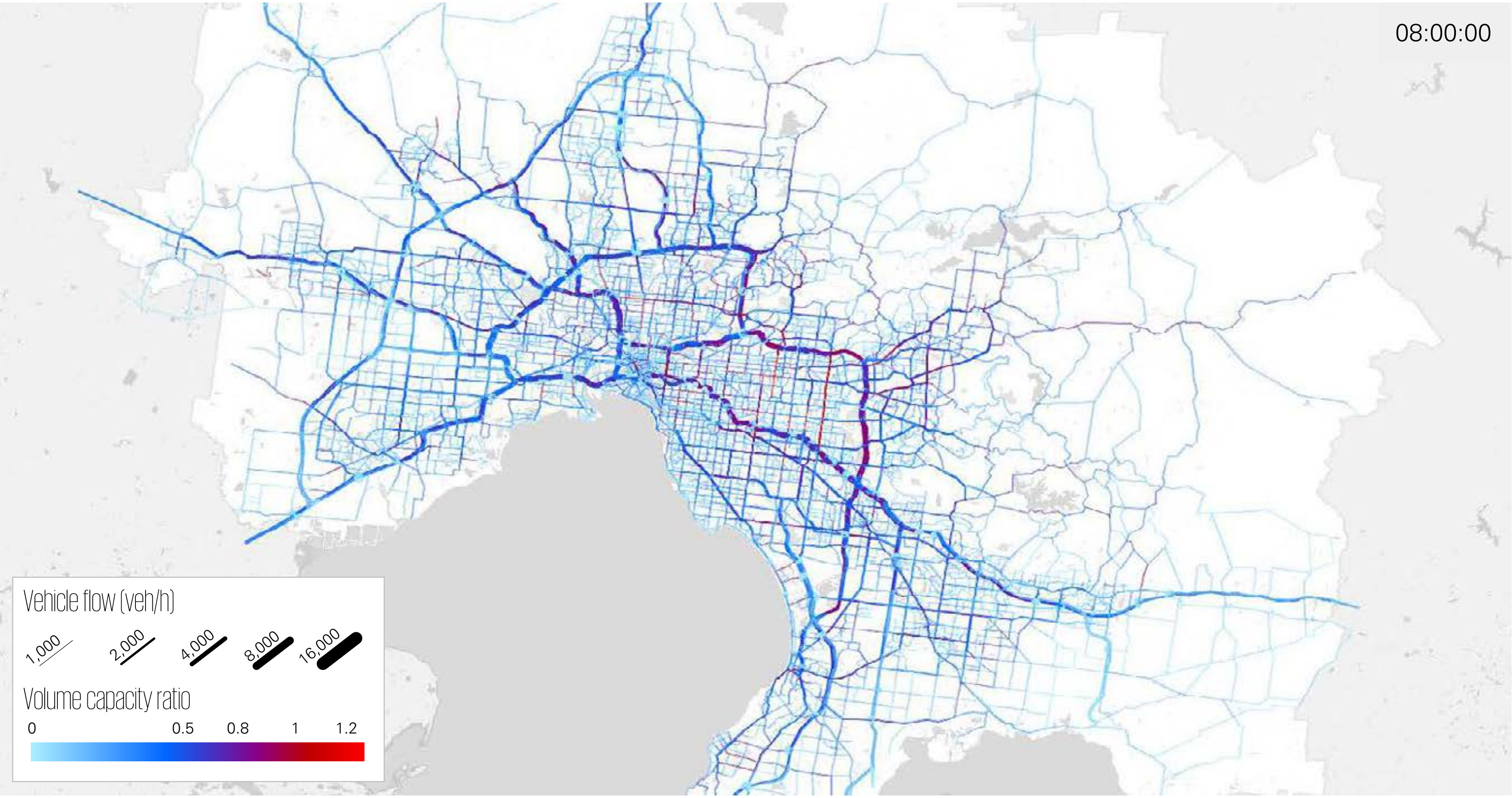
Source: MABM

Volume capacity ratio: Private drive, Station drop-off and pick-up, morning peak



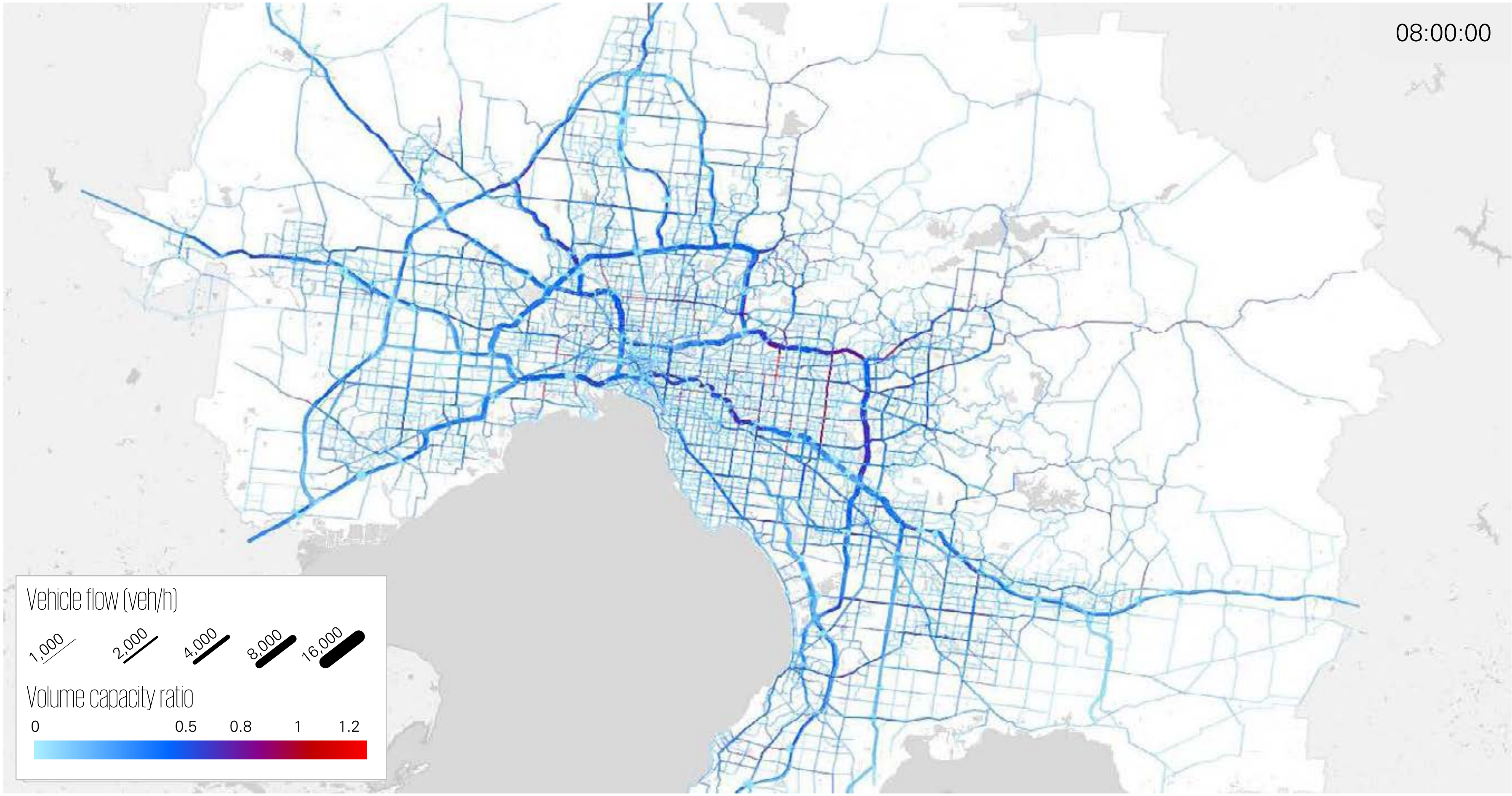
Source: MABM

Volume capacity ratio: Fleet street, Subscription fare, morning peak



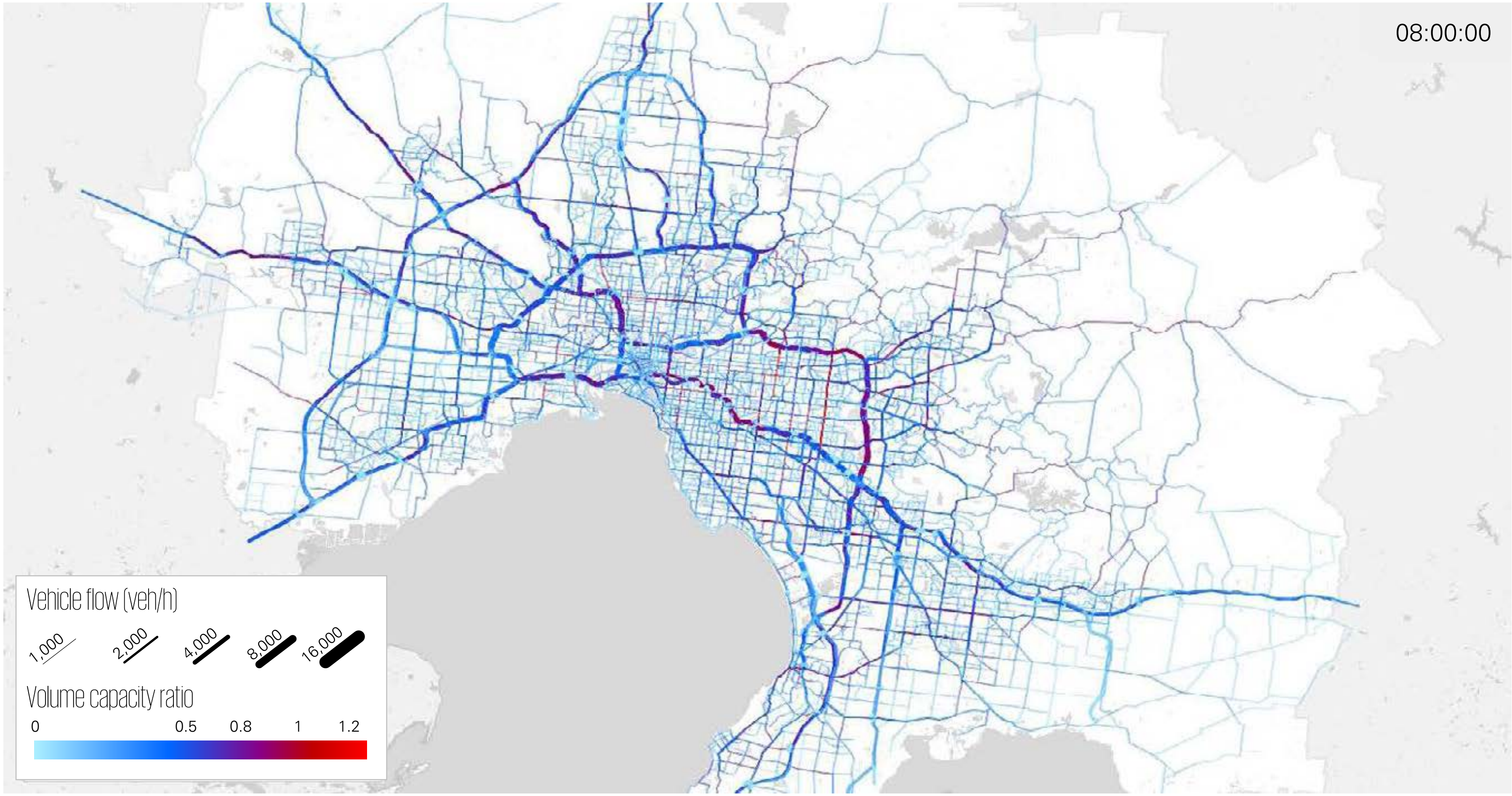
Source: MABM

Volume capacity ratio: Fleet street, Low MUTT, morning peak



Source: MABM

Volume capacity ratio: Fleet street, Low flow, morning peak



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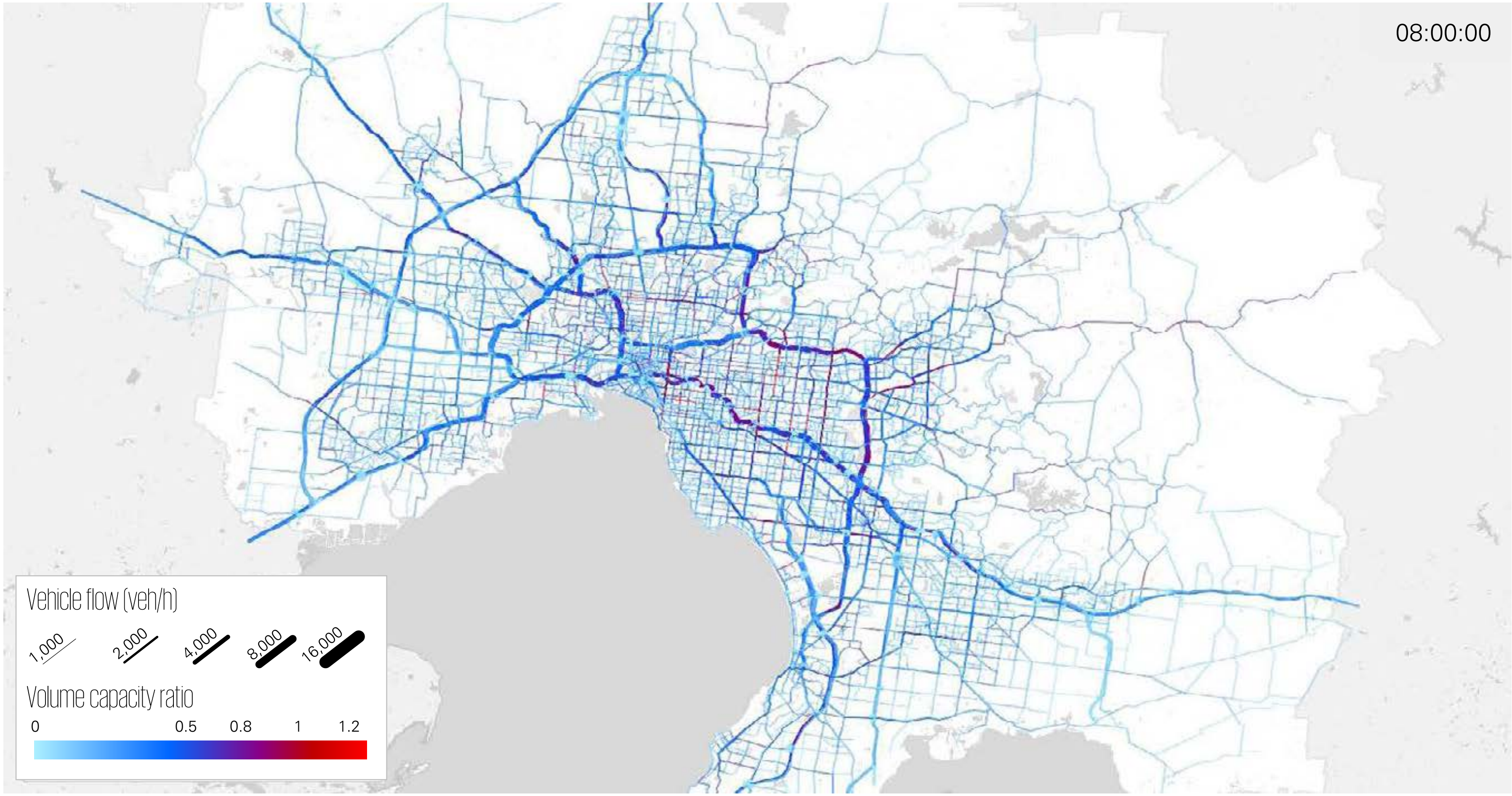
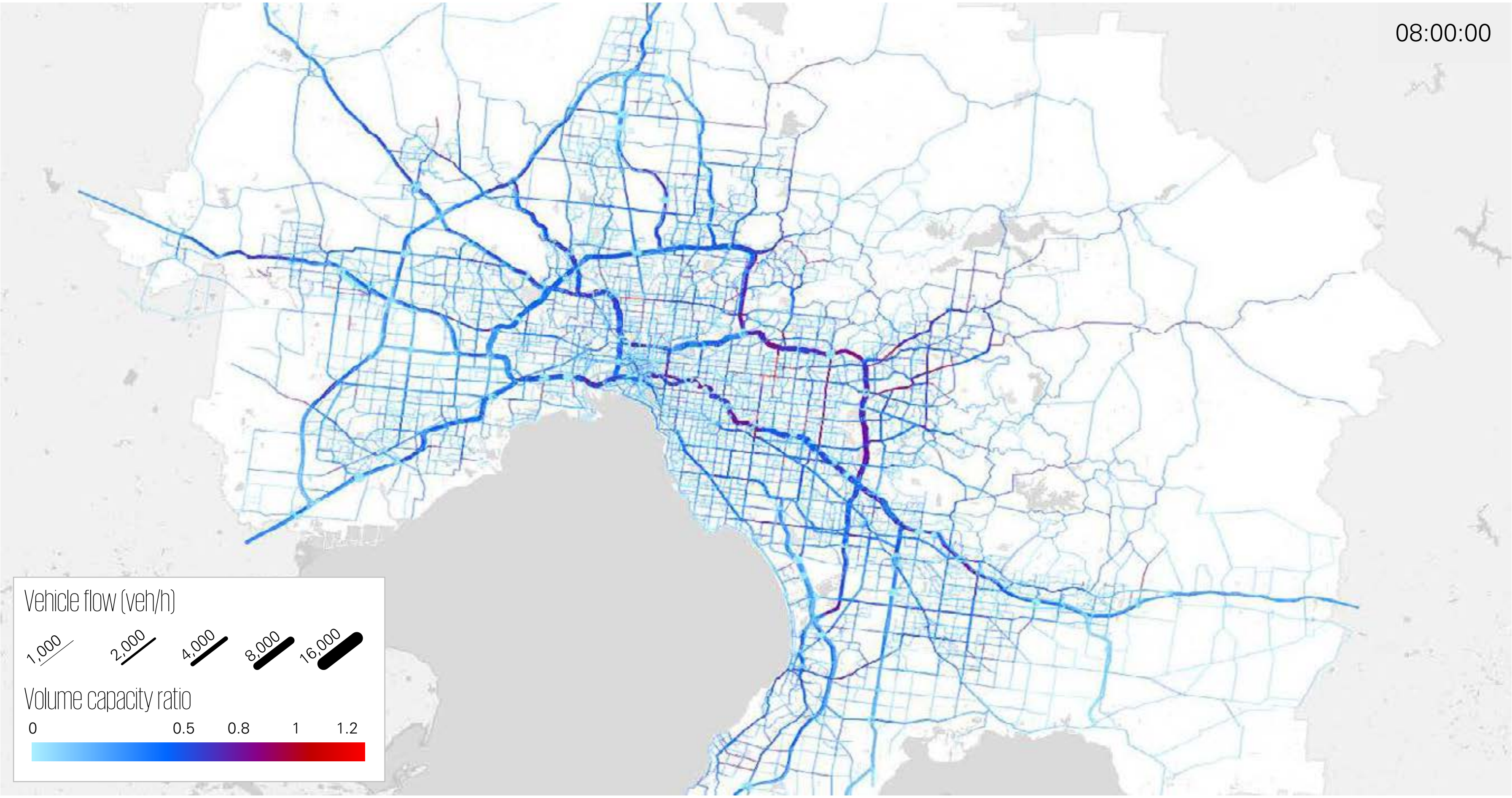
Volume capacity ratio: Fleet street, No mode shift, morning peak



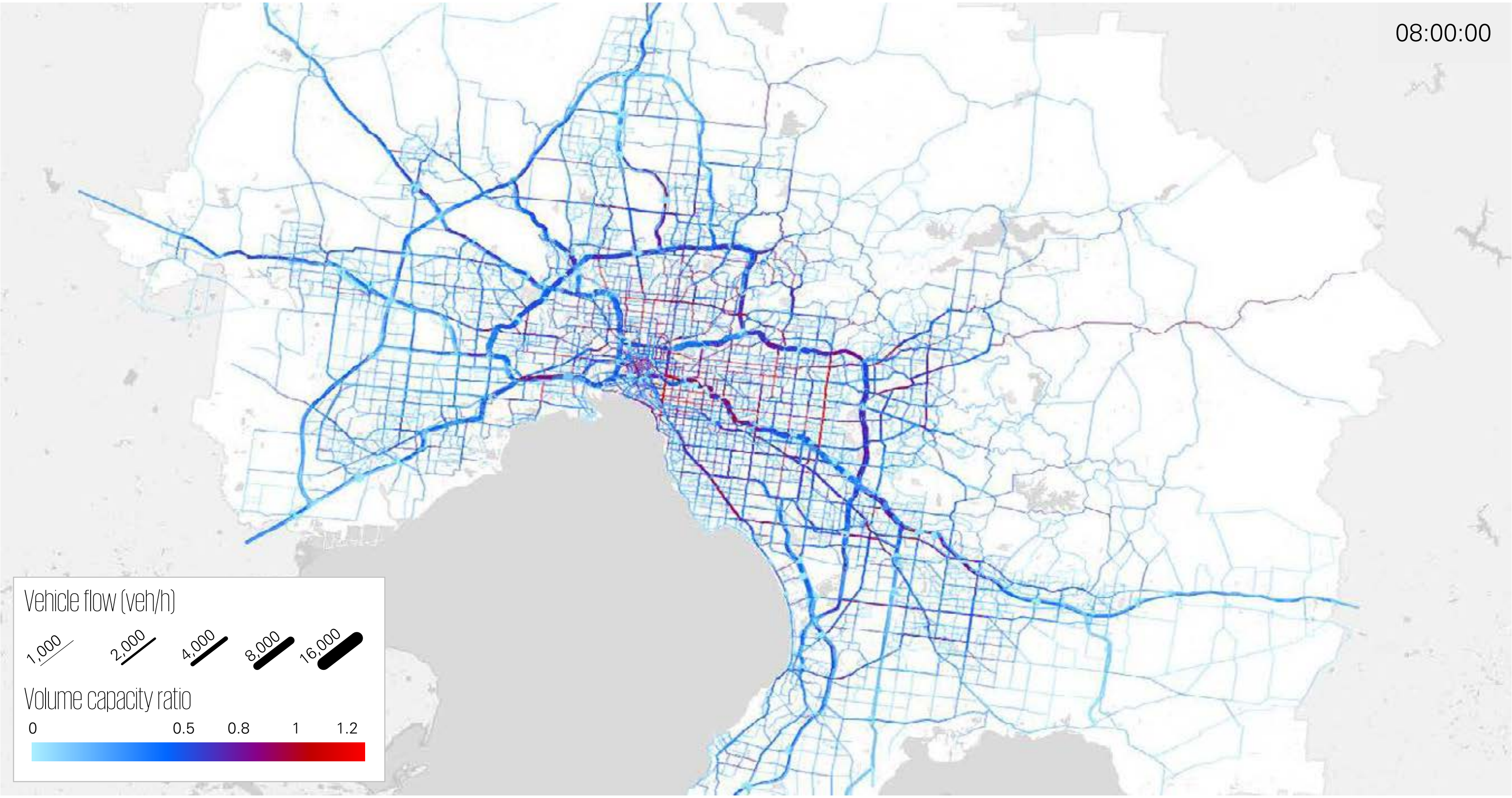
Source: MABM

Volume capacity ratio: Fleet street, Calibrated fleet size, morning peak



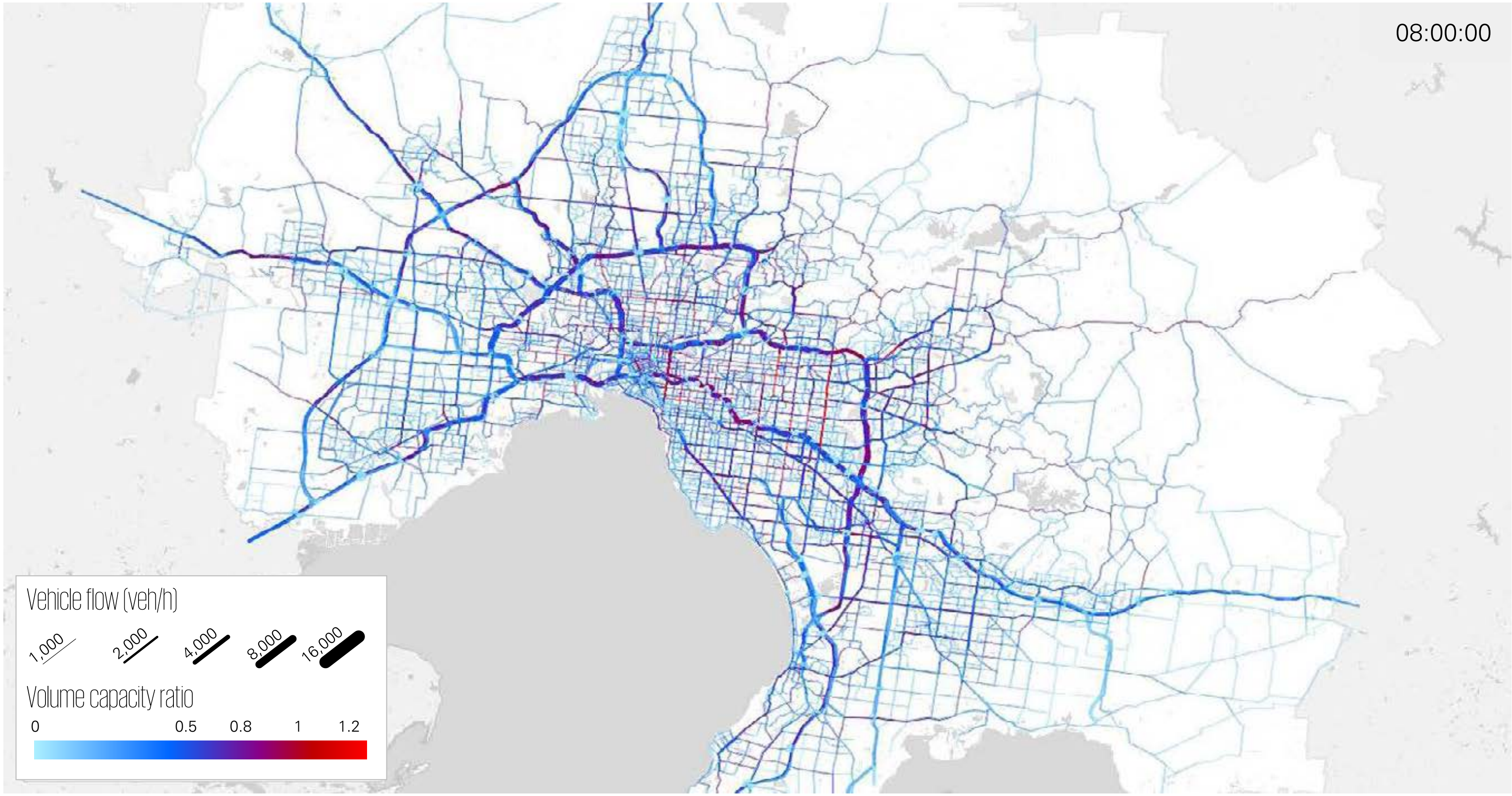
Source: MABM

Volume capacity ratio: Fleet Street, No new (pre-construction) major road projects, morning peak



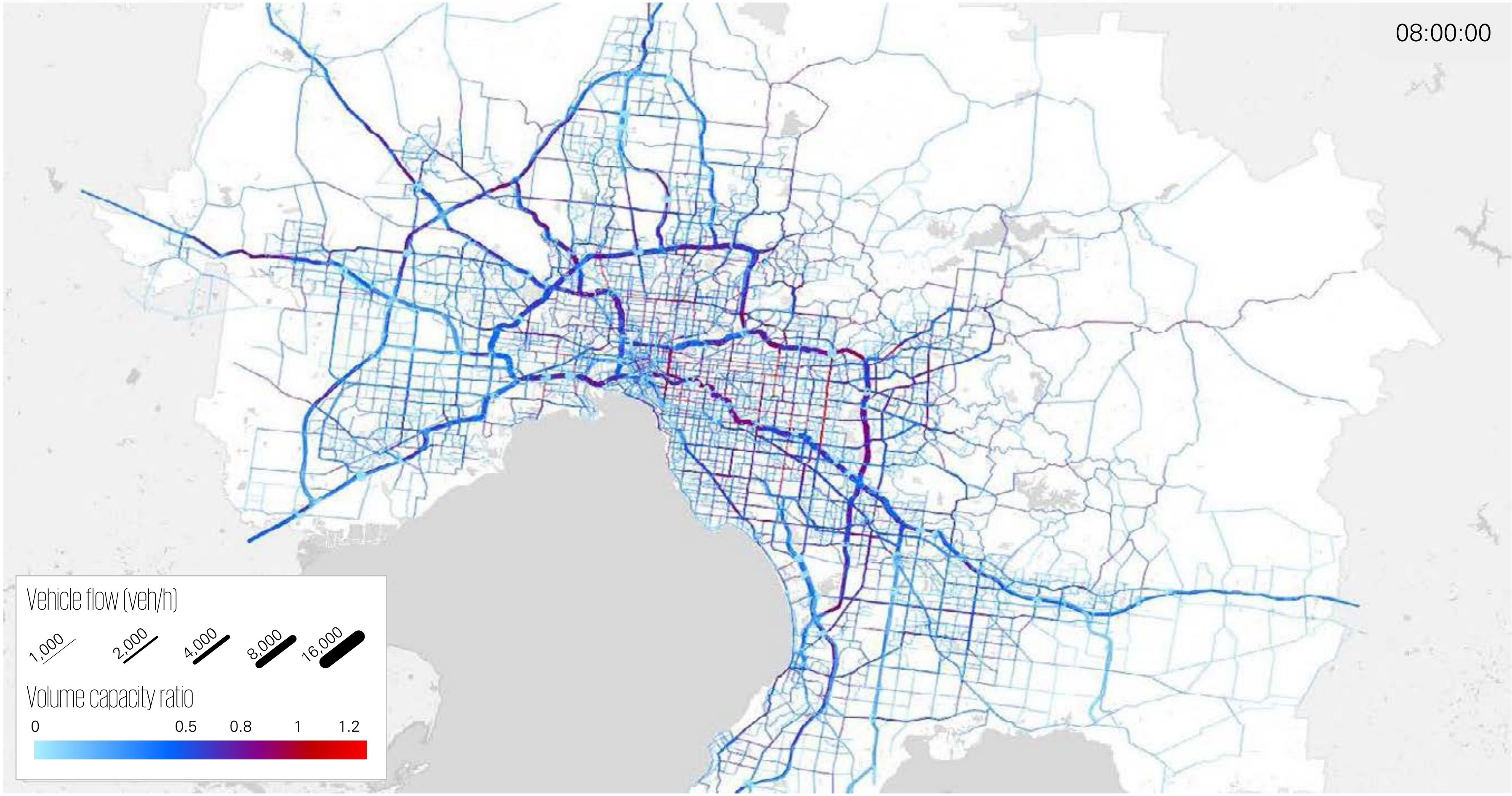
Source: MABM

Volume capacity ratio: Slow lane, Low MUTT, morning peak



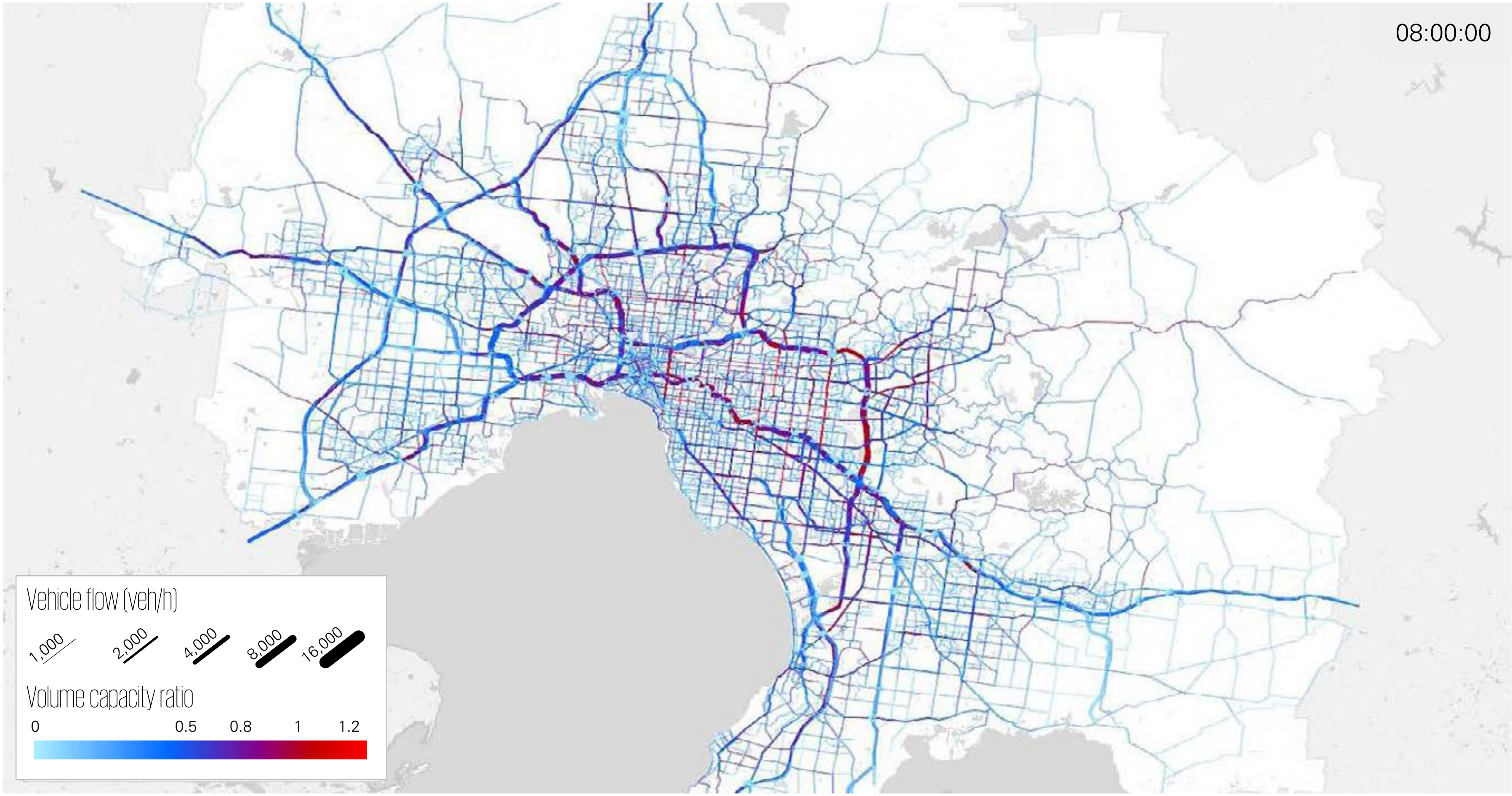
Source: MABM

Volume capacity ratio: Slow lane, Low flow, morning peak



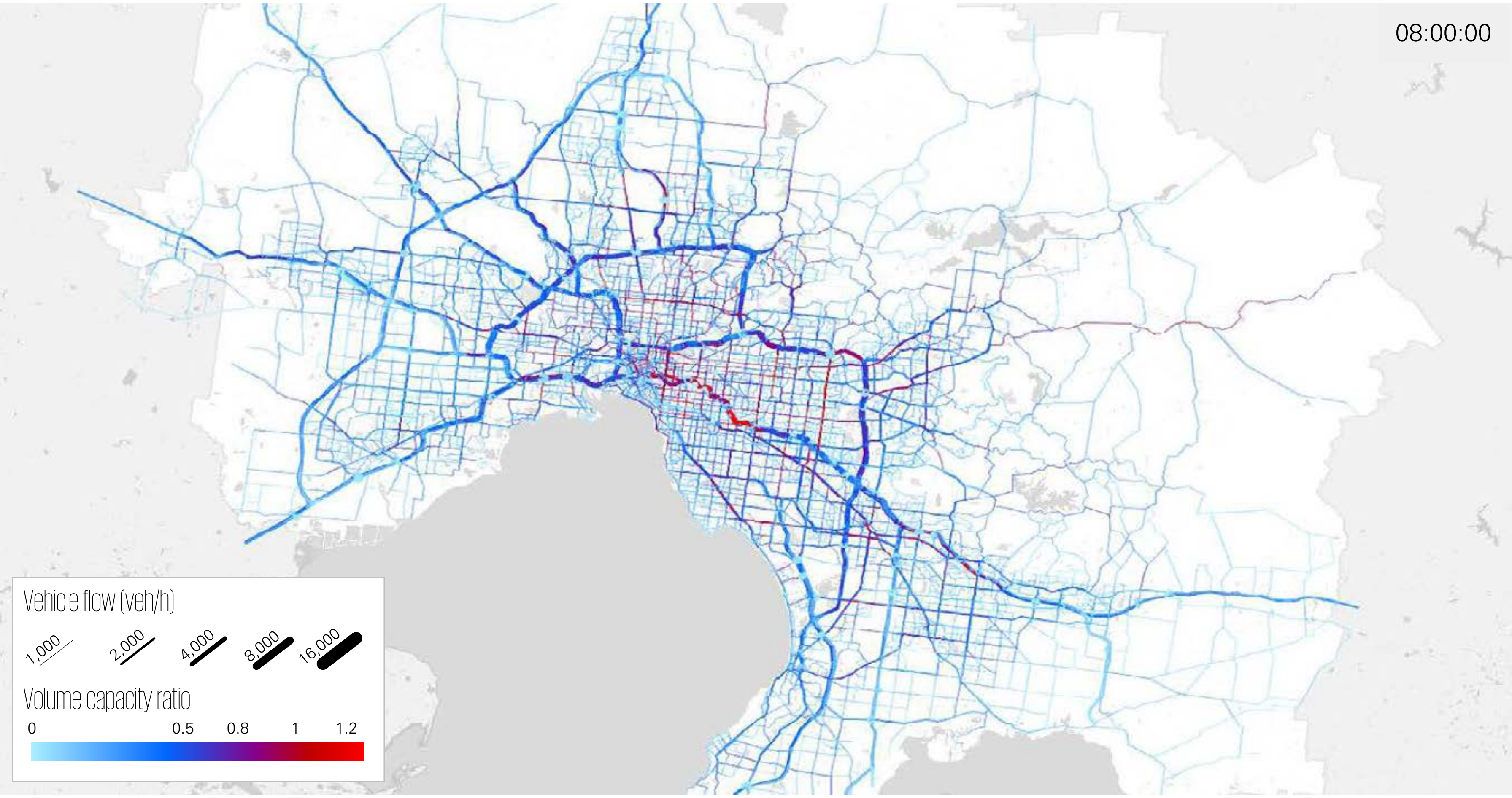
Source: MABM

Volume capacity ratio: Slow lane, No mode shift, morning peak



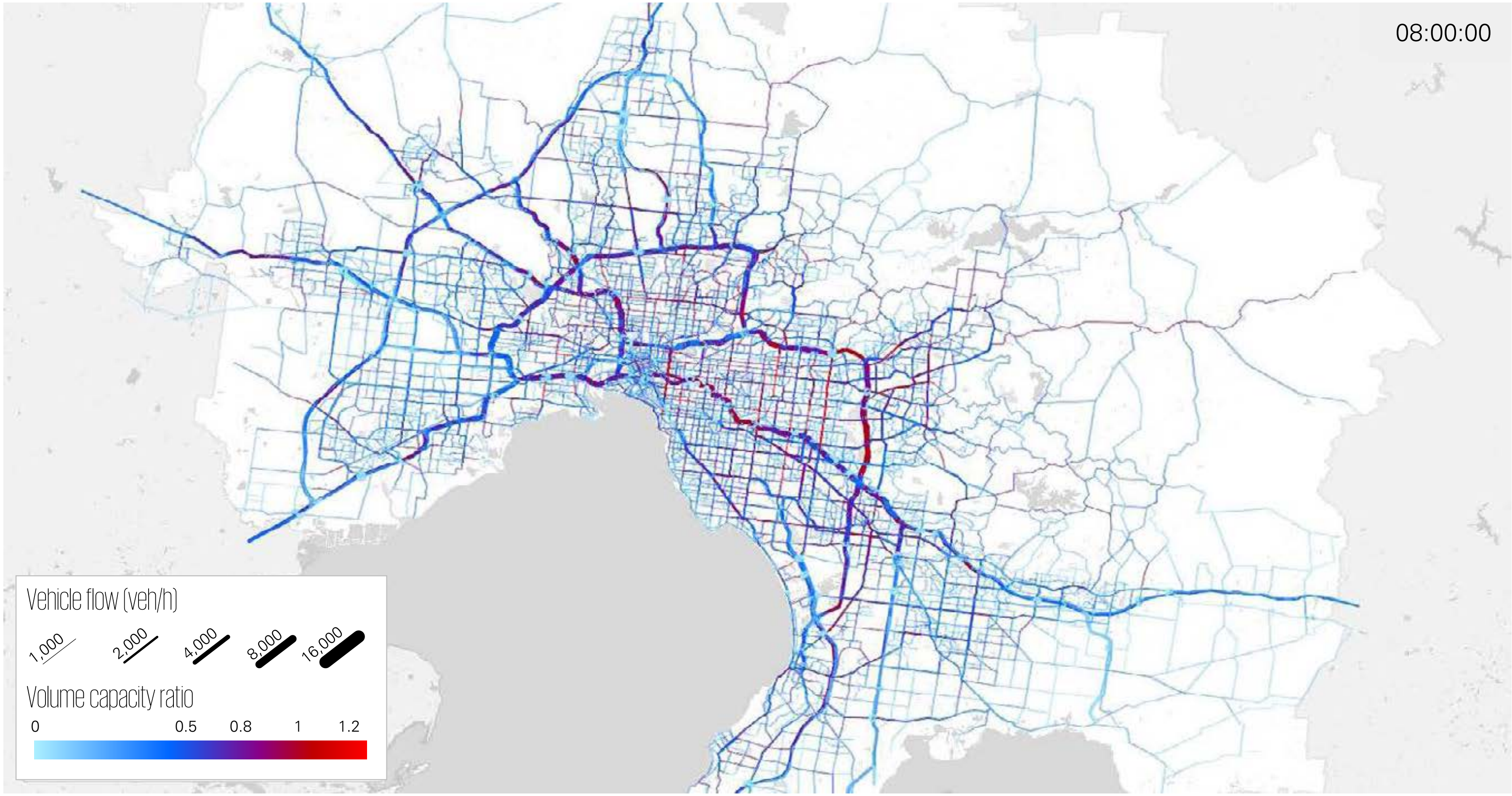
Source: MABM

Volume capacity ratio, road: Private slow lane, Slow lane, morning peak



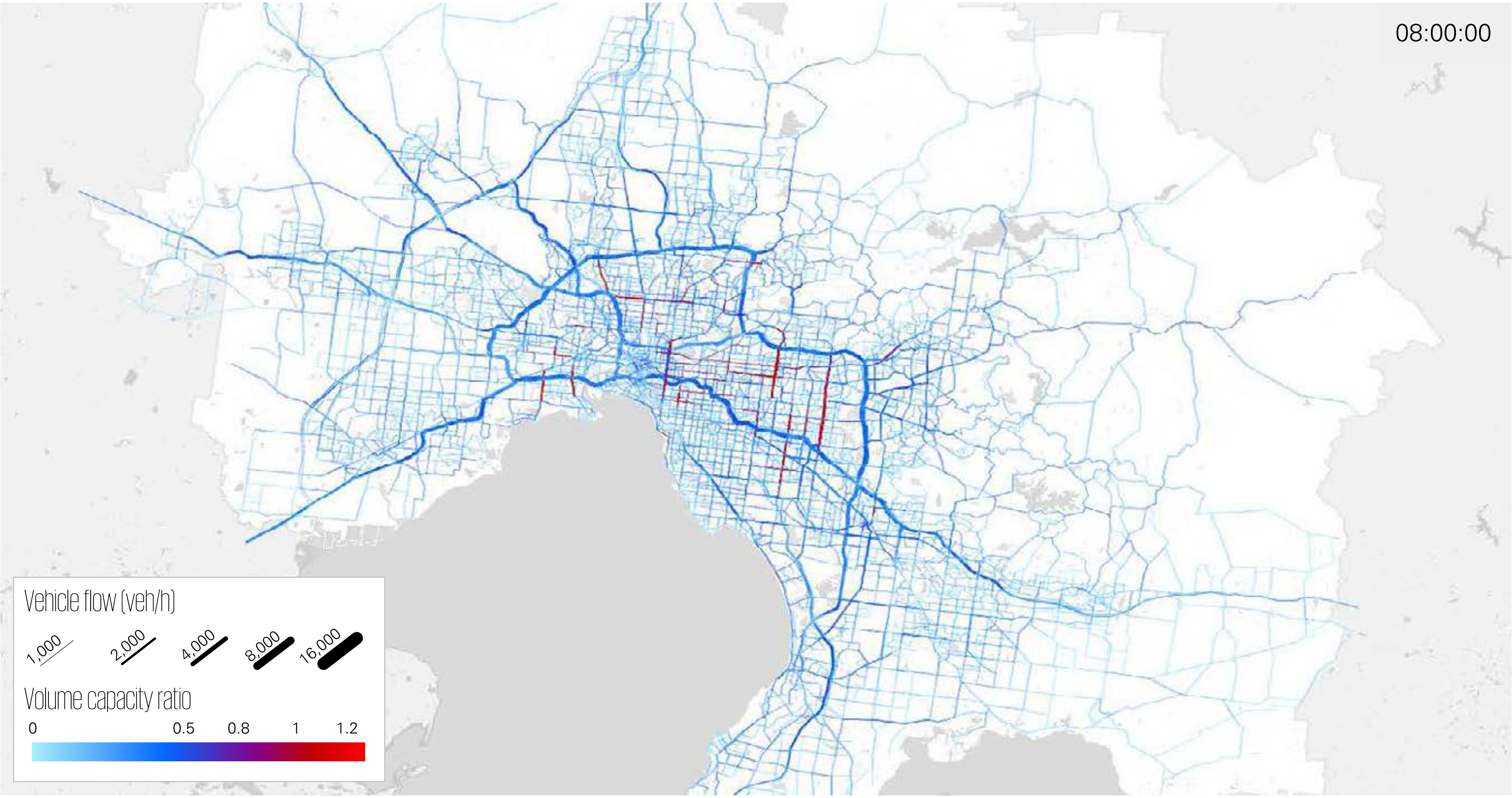
Source: MABM

Volume capacity ratio: Hydrogen highway, No empty running, morning peak



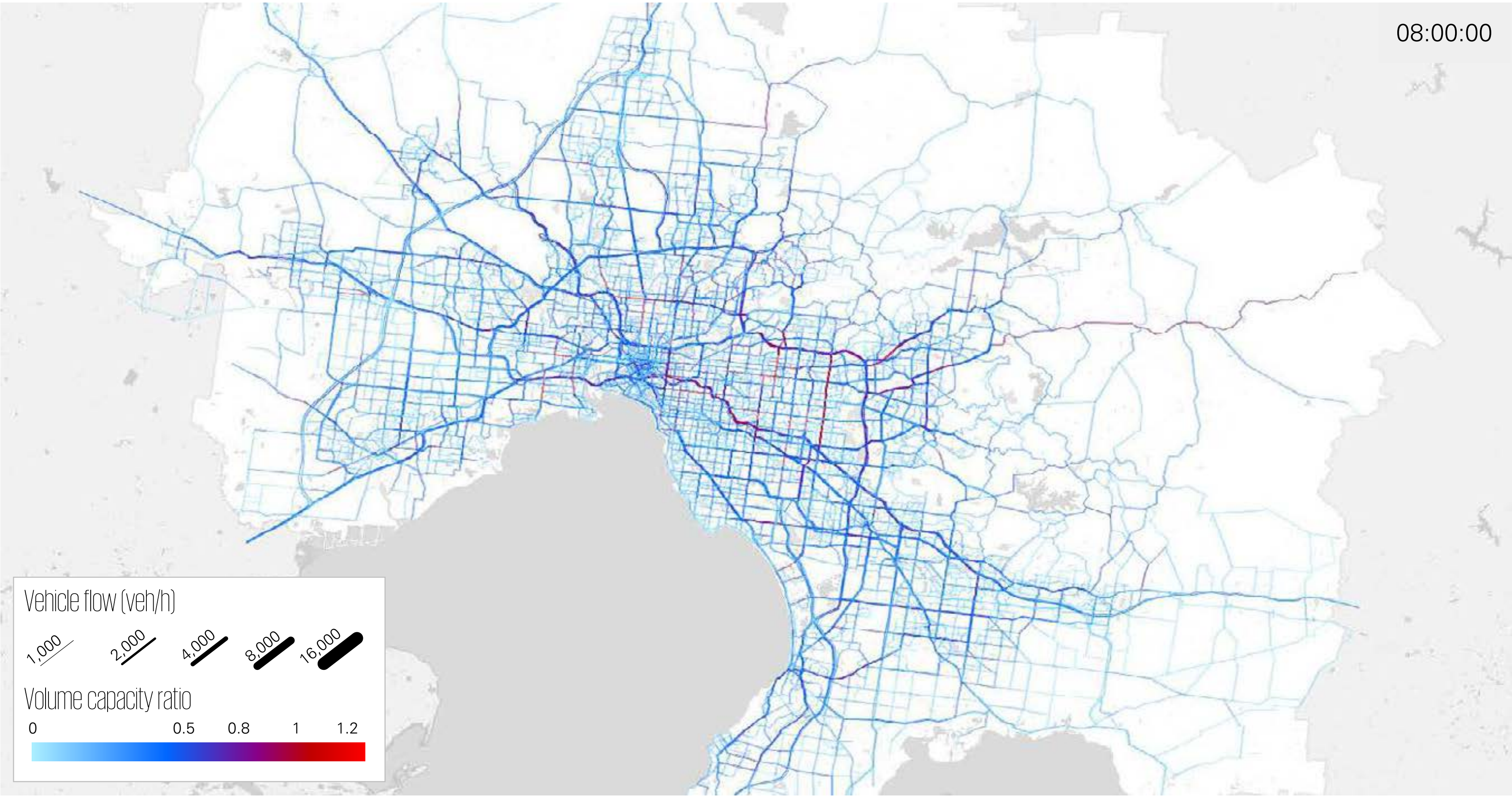
Source: MABM

Volume capacity ratio: Mix of scenarios, morning peak



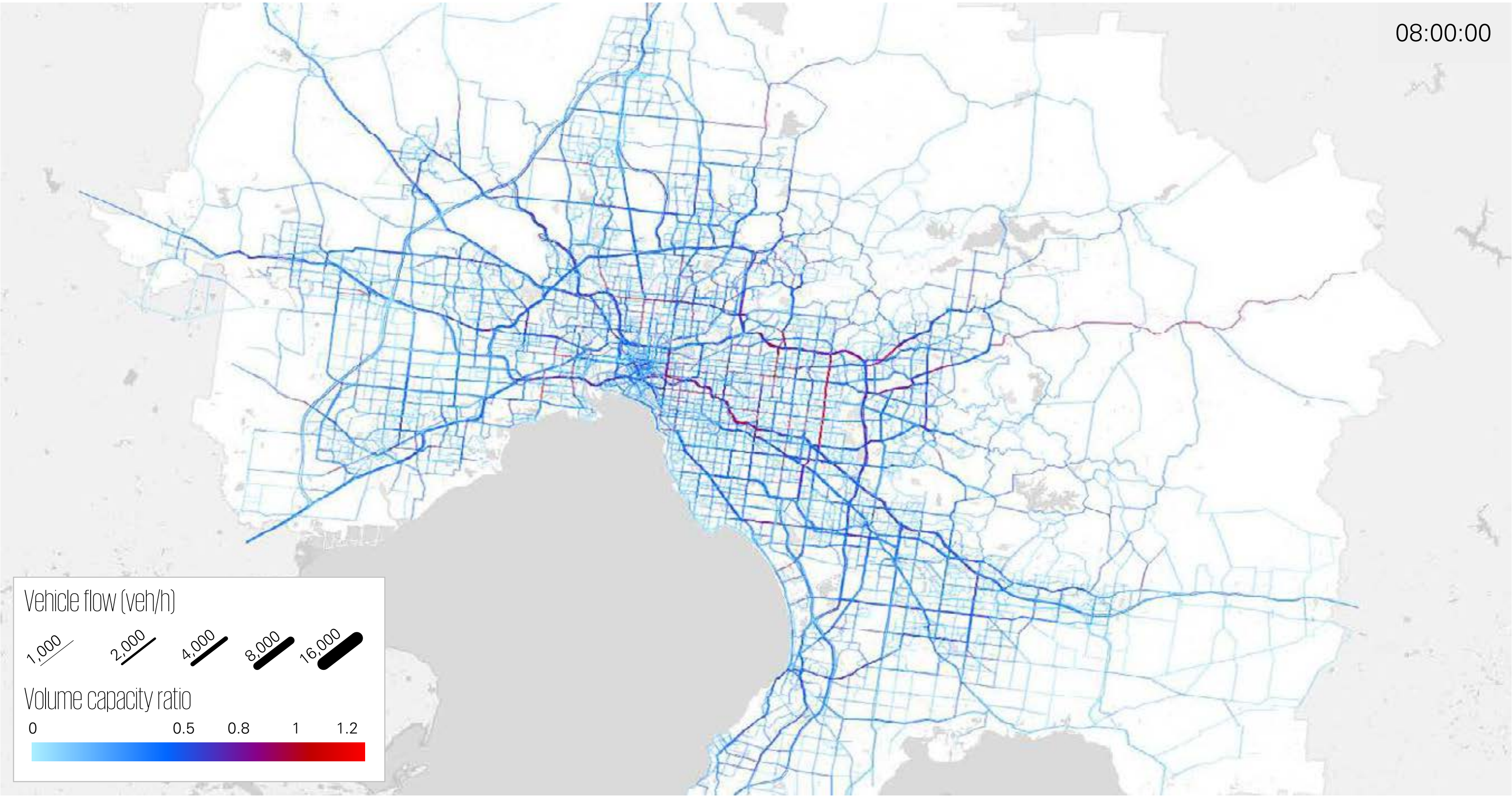
Source: MABM

Volume capacity ratio: Mix of scenarios, Centralised land use, morning peak



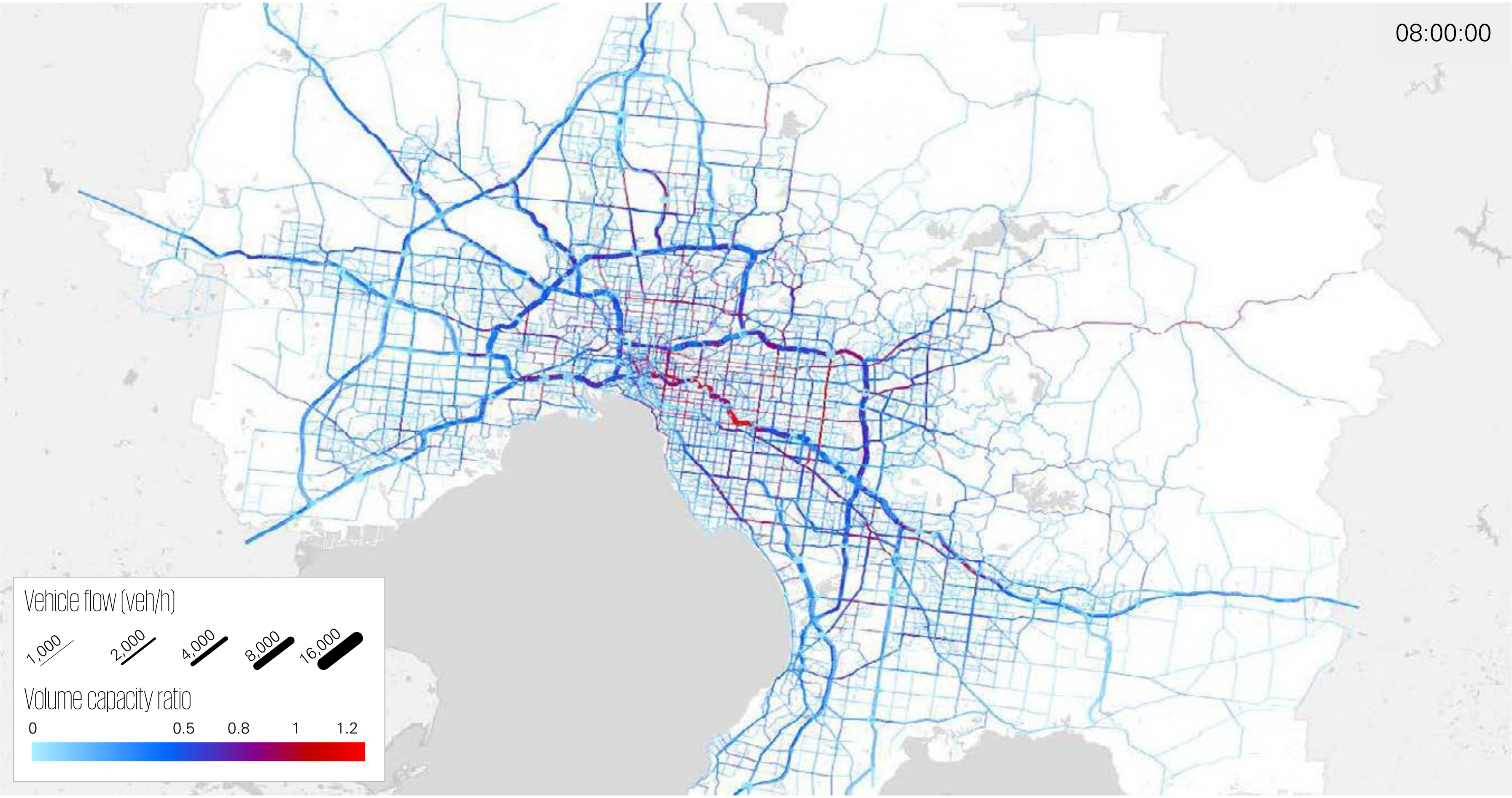
Source: MABM

Volume capacity ratio: Mix of scenarios, Expanded land use, morning peak



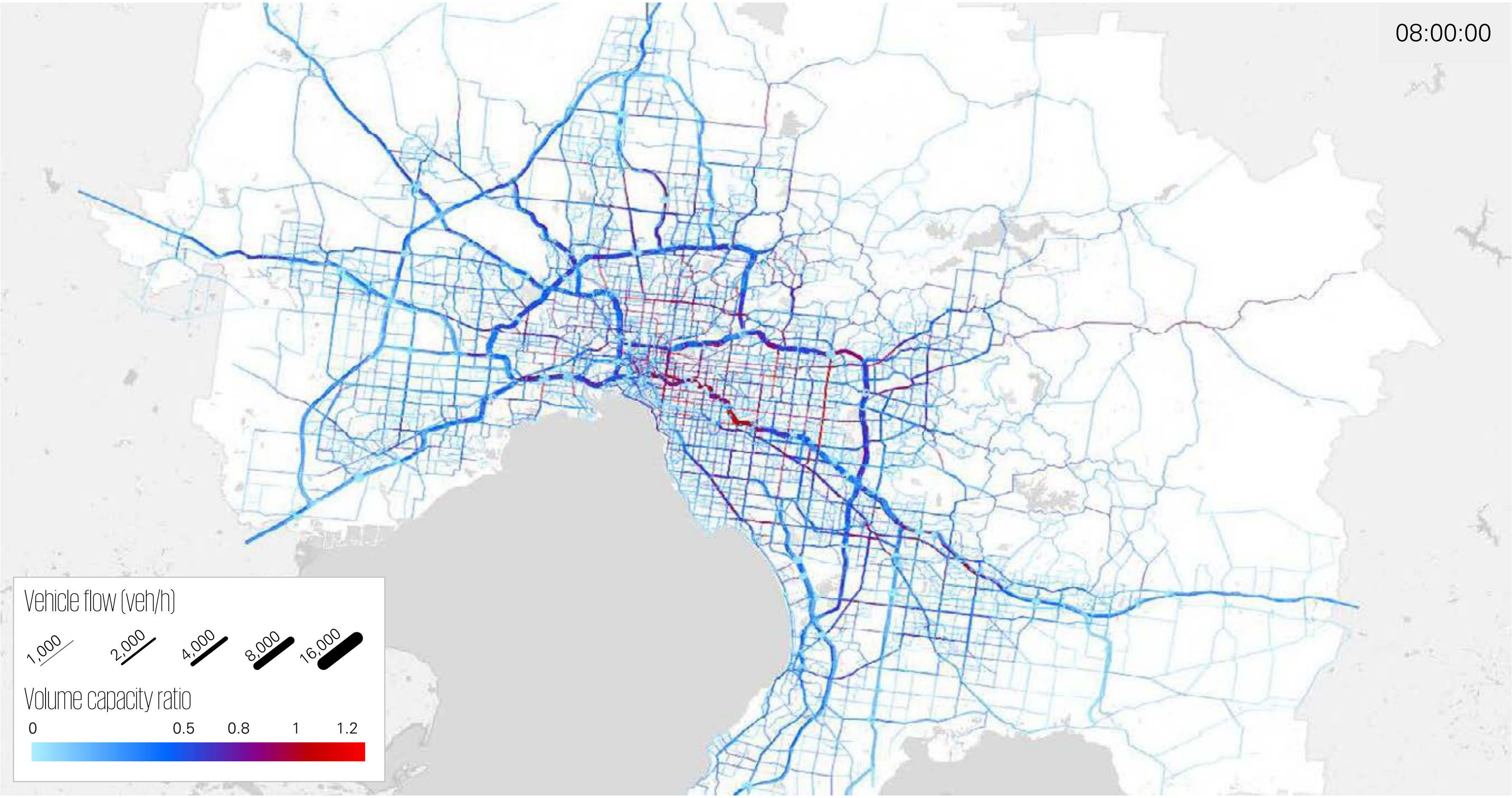
Source: MABM

Volume capacity ratio: Private drive, Centralised land use, morning peak



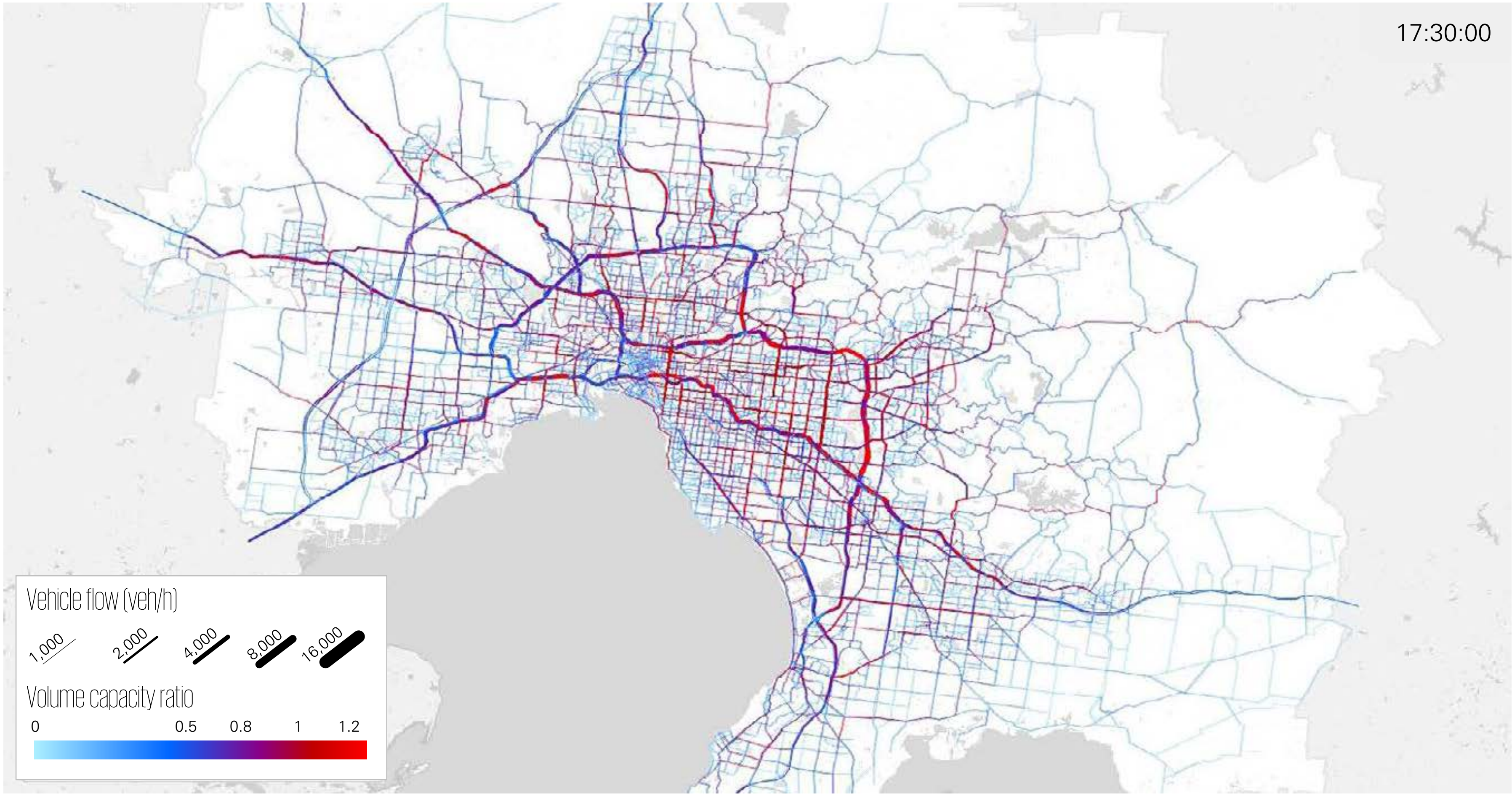
Source: MABM

Volume capacity ratio: Private drive, Expanded land use, morning peak



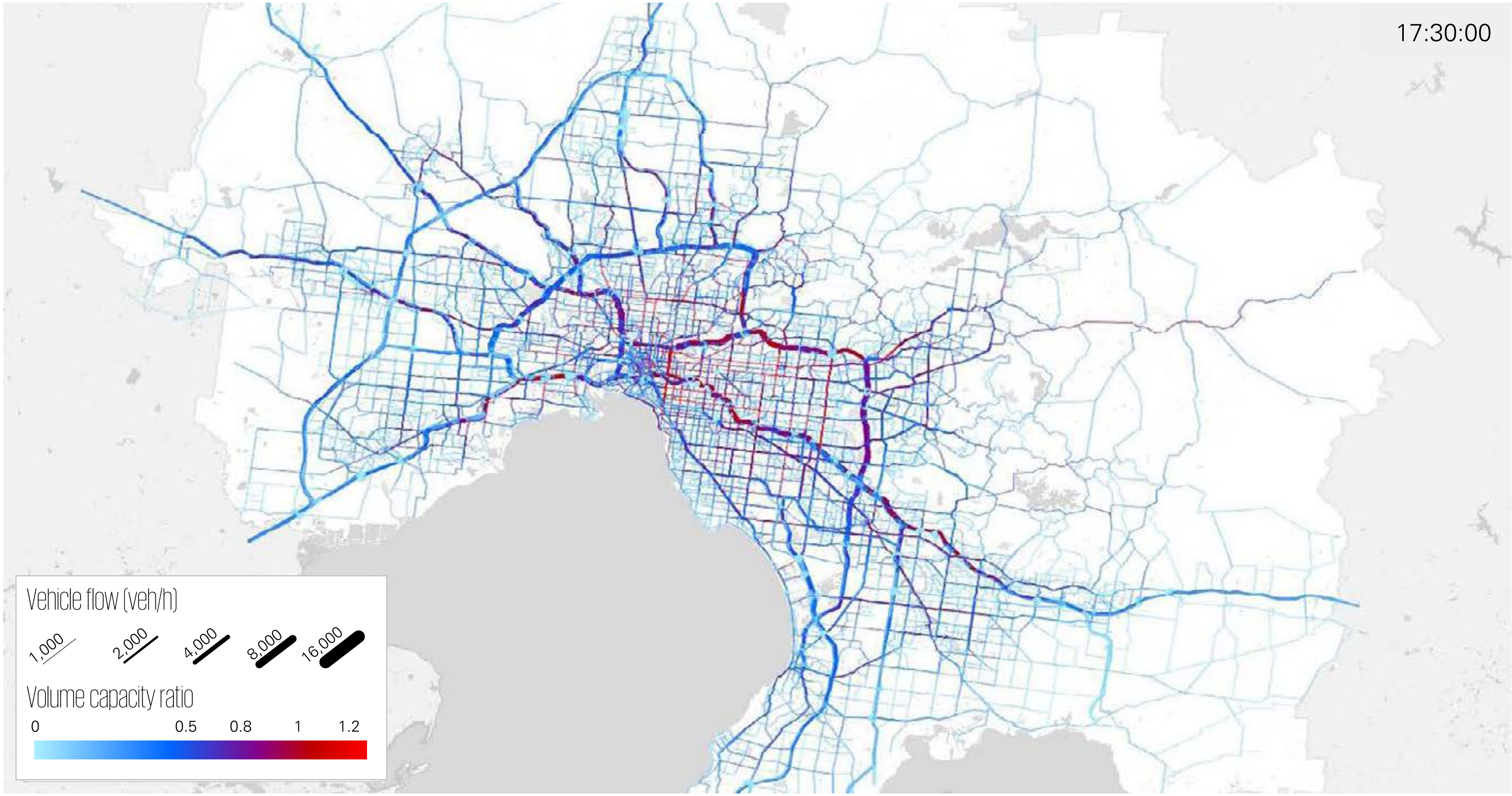
Source: MABM

Volume capacity ratio: Dead end, afternoon peak



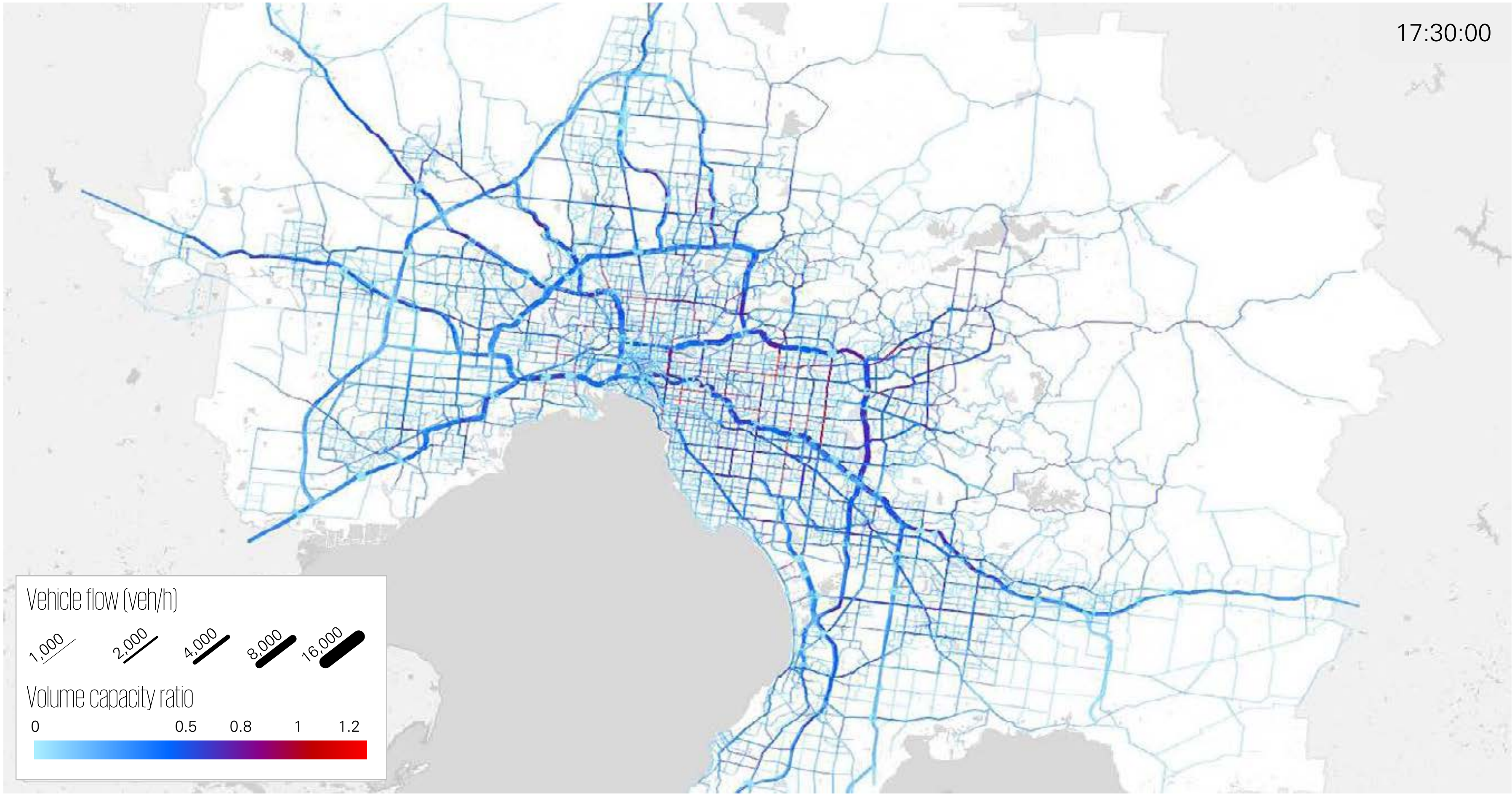
Source: MABM

Volume capacity ratio: Private drive, afternoon peak



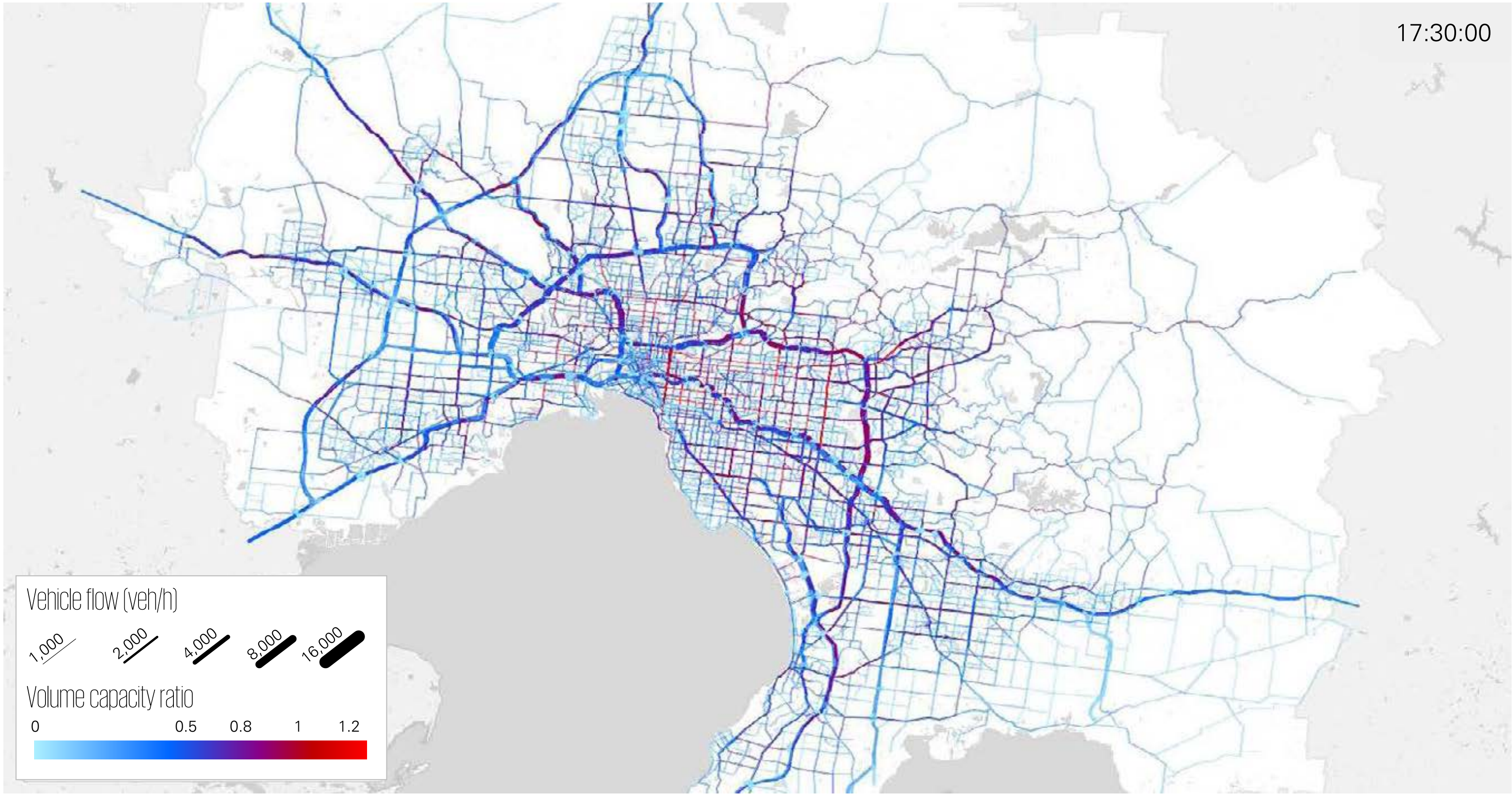
Source: MABM

Volume capacity ratio: Fleet street, afternoon peak



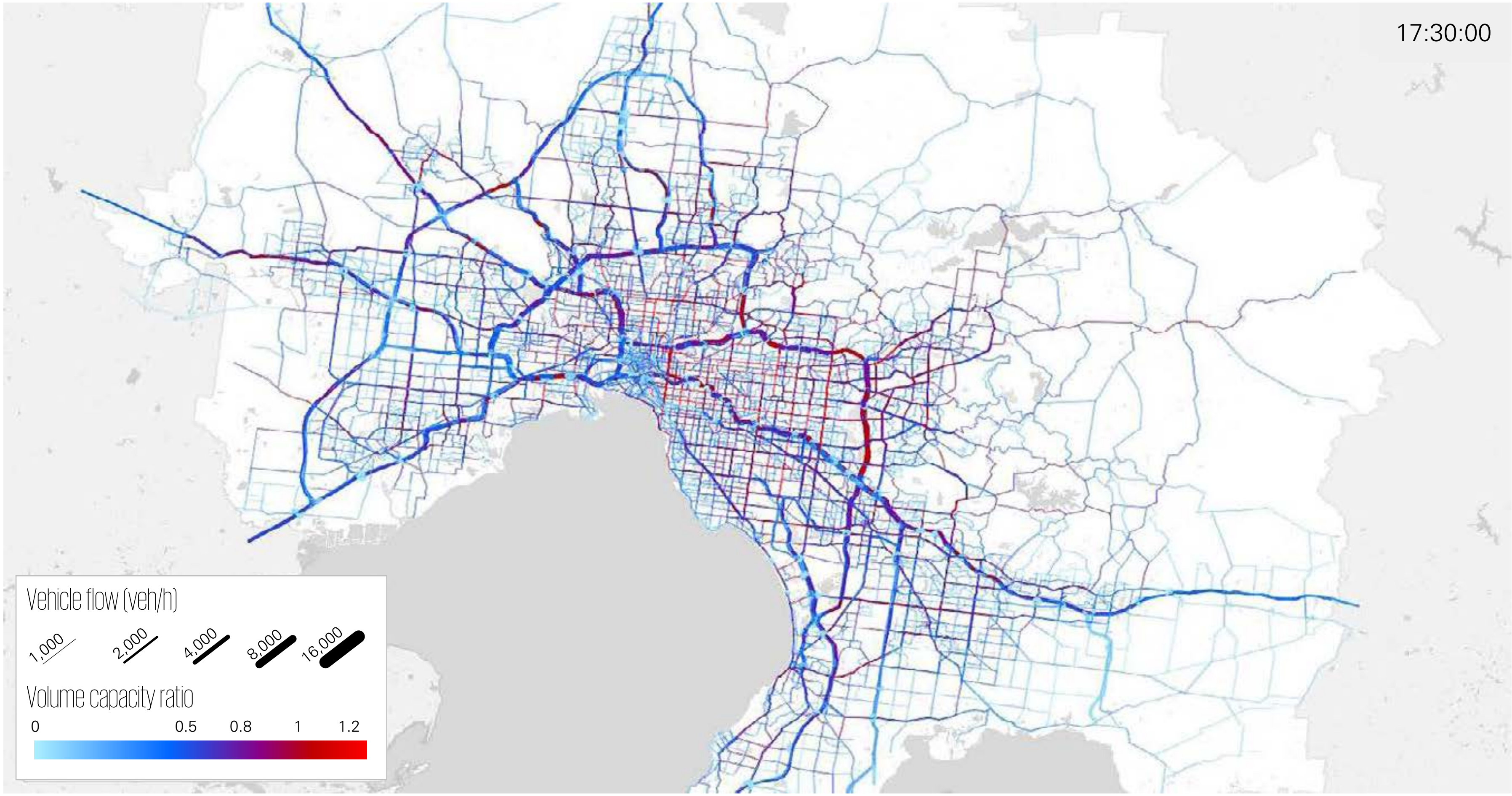
Source: MABM

Volume capacity ratio: Slow lane, afternoon peak



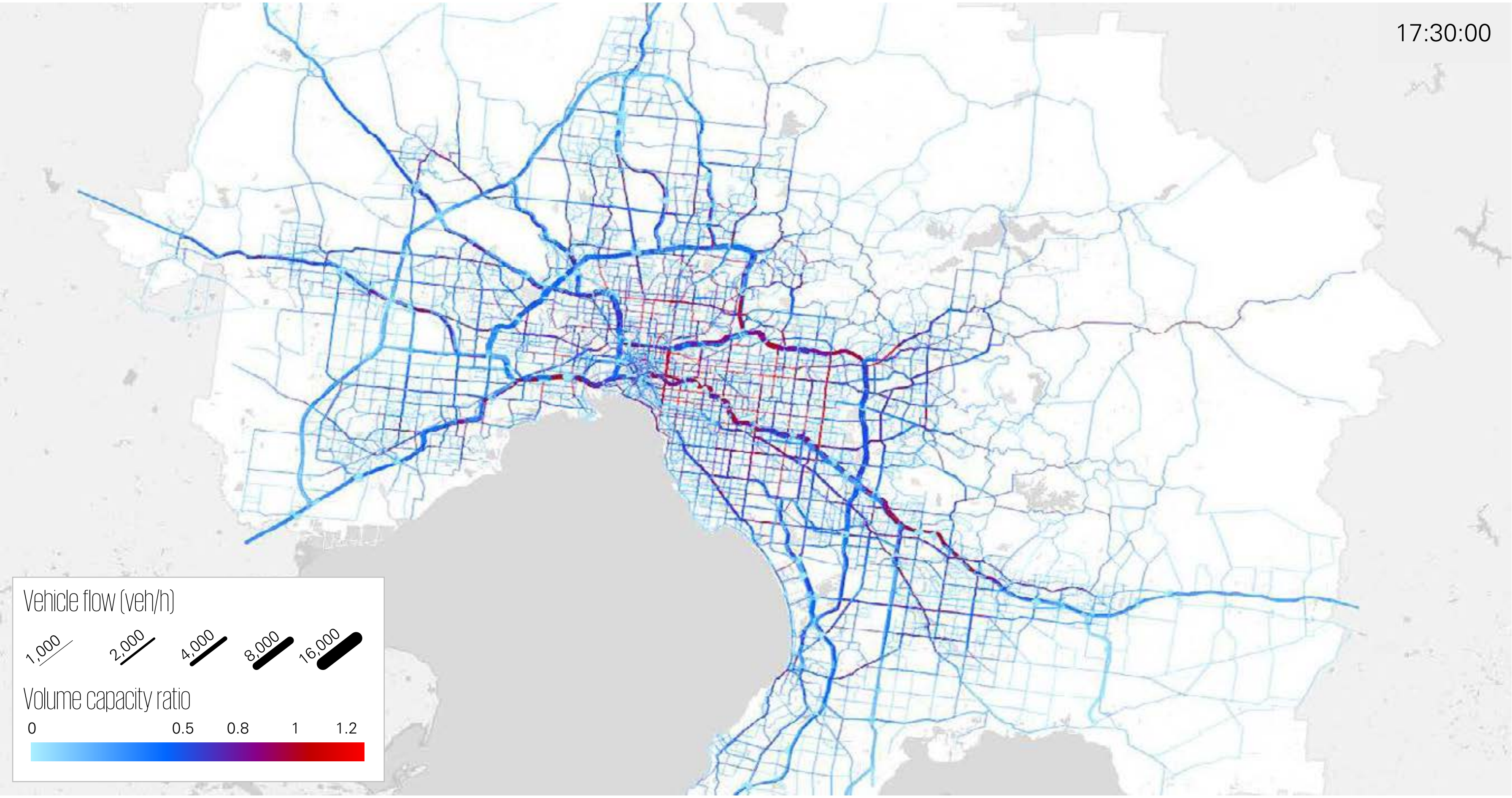
Source: MABM

Volume capacity ratio: Electric avenue, afternoon peak



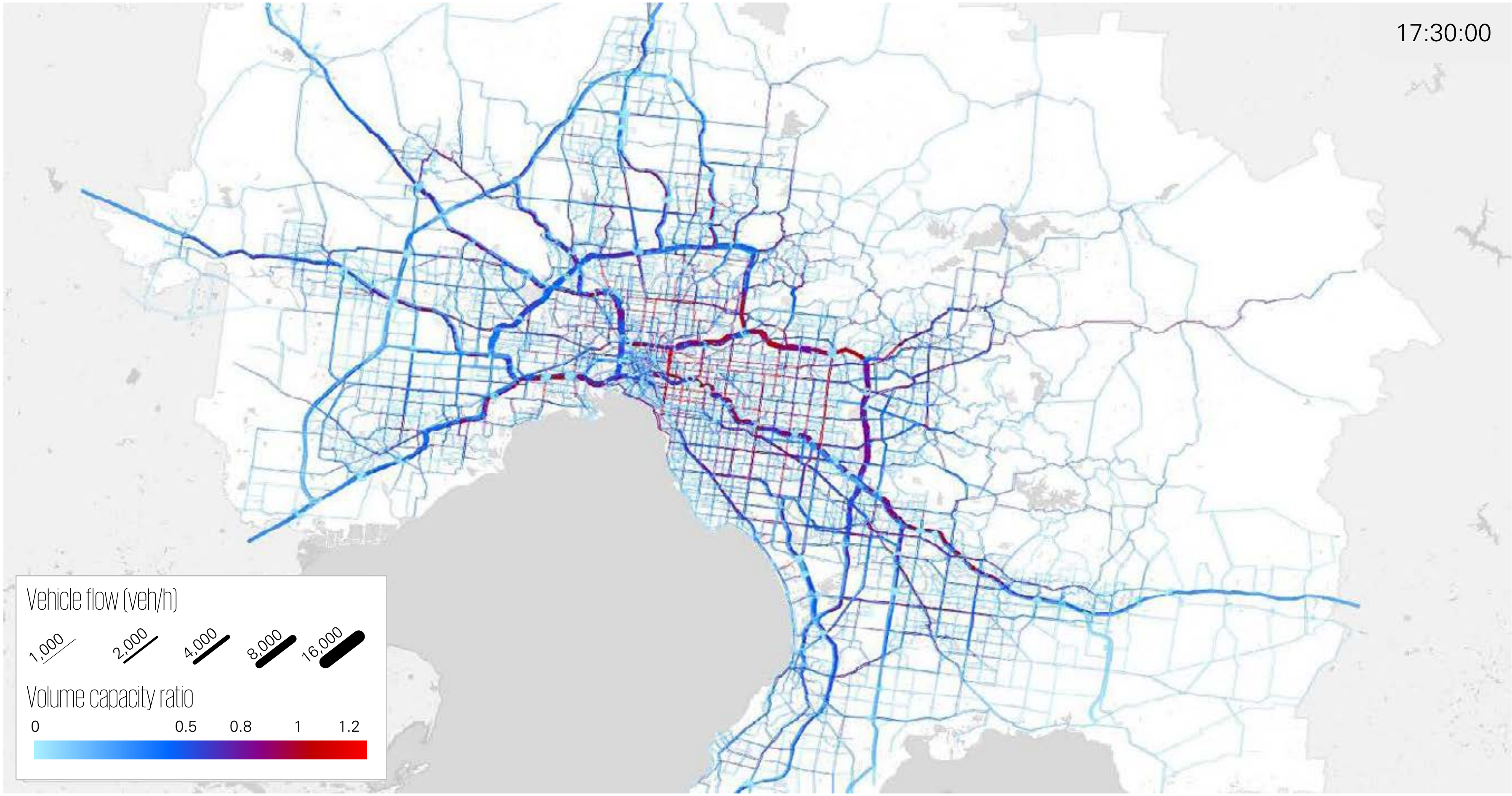
Source: MABM

Volume capacity ratio: Hydrogen highway, afternoon peak



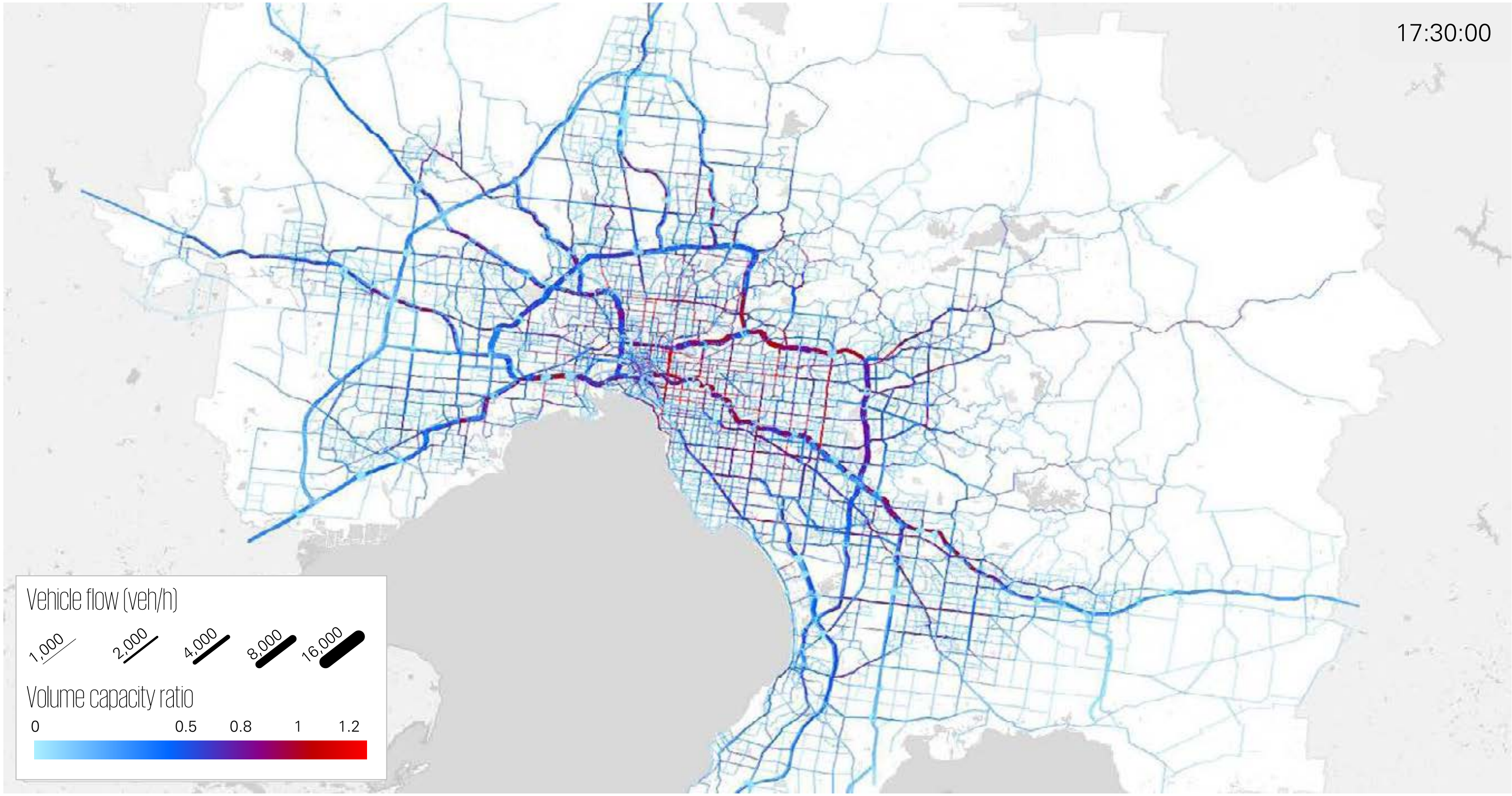
Source: MABM

Volume capacity ratio: Private drive, No empty running, afternoon peak



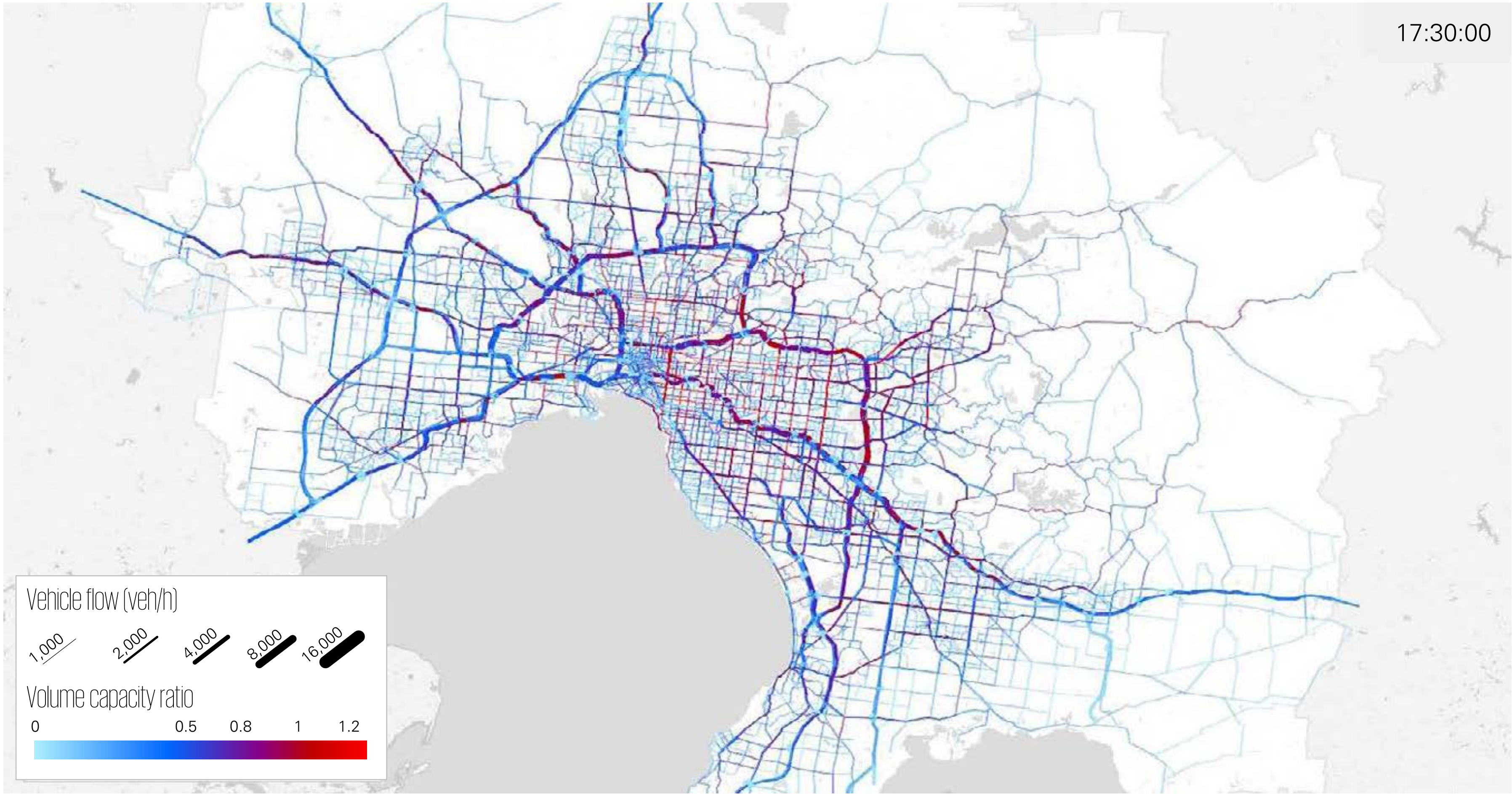
Source: MABM

Volume capacity ratio: Private drive, Low MUTT, afternoon peak



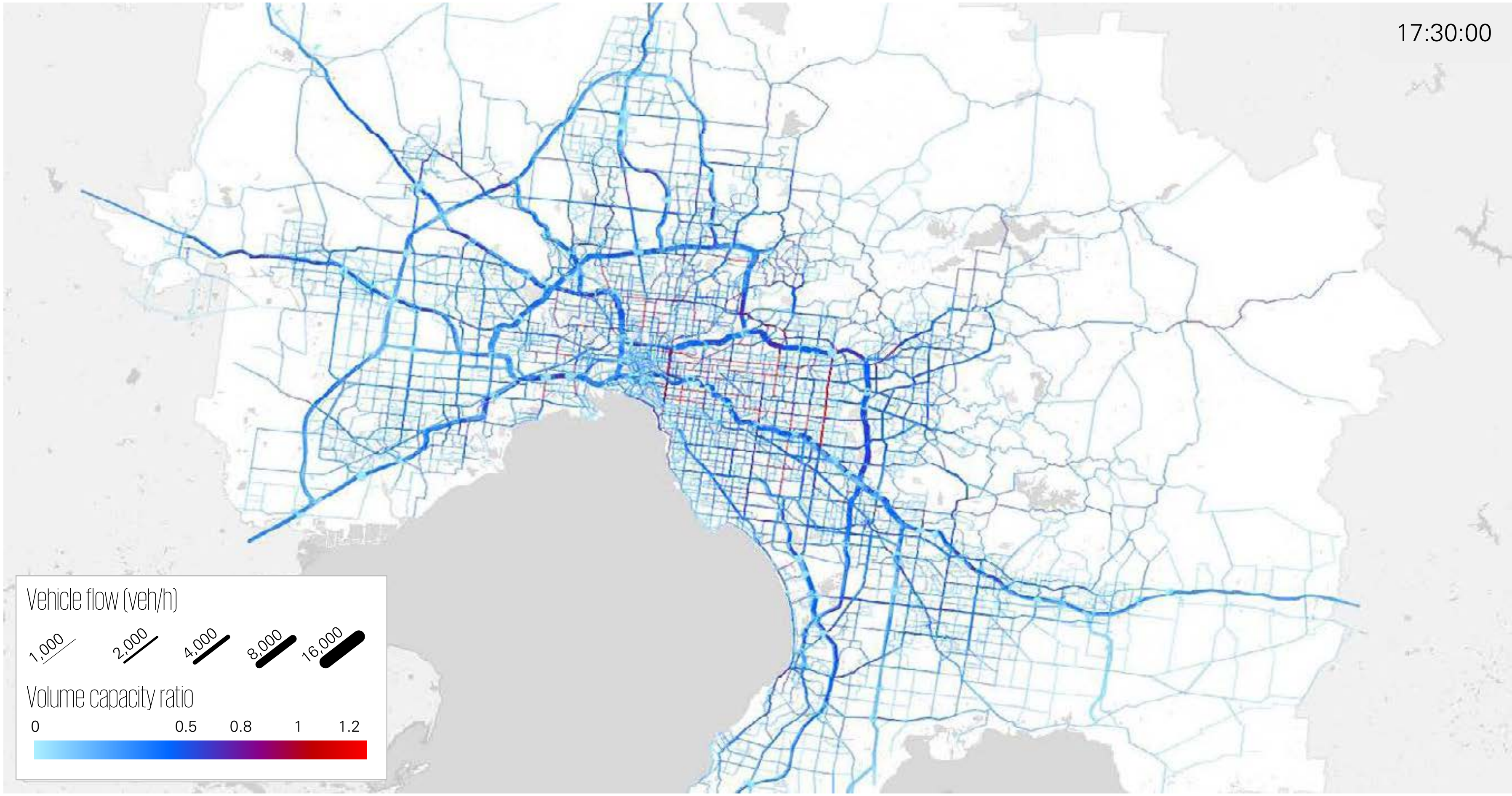
Source: MABM

Volume capacity ratio: Private drive, Low flow, afternoon peak



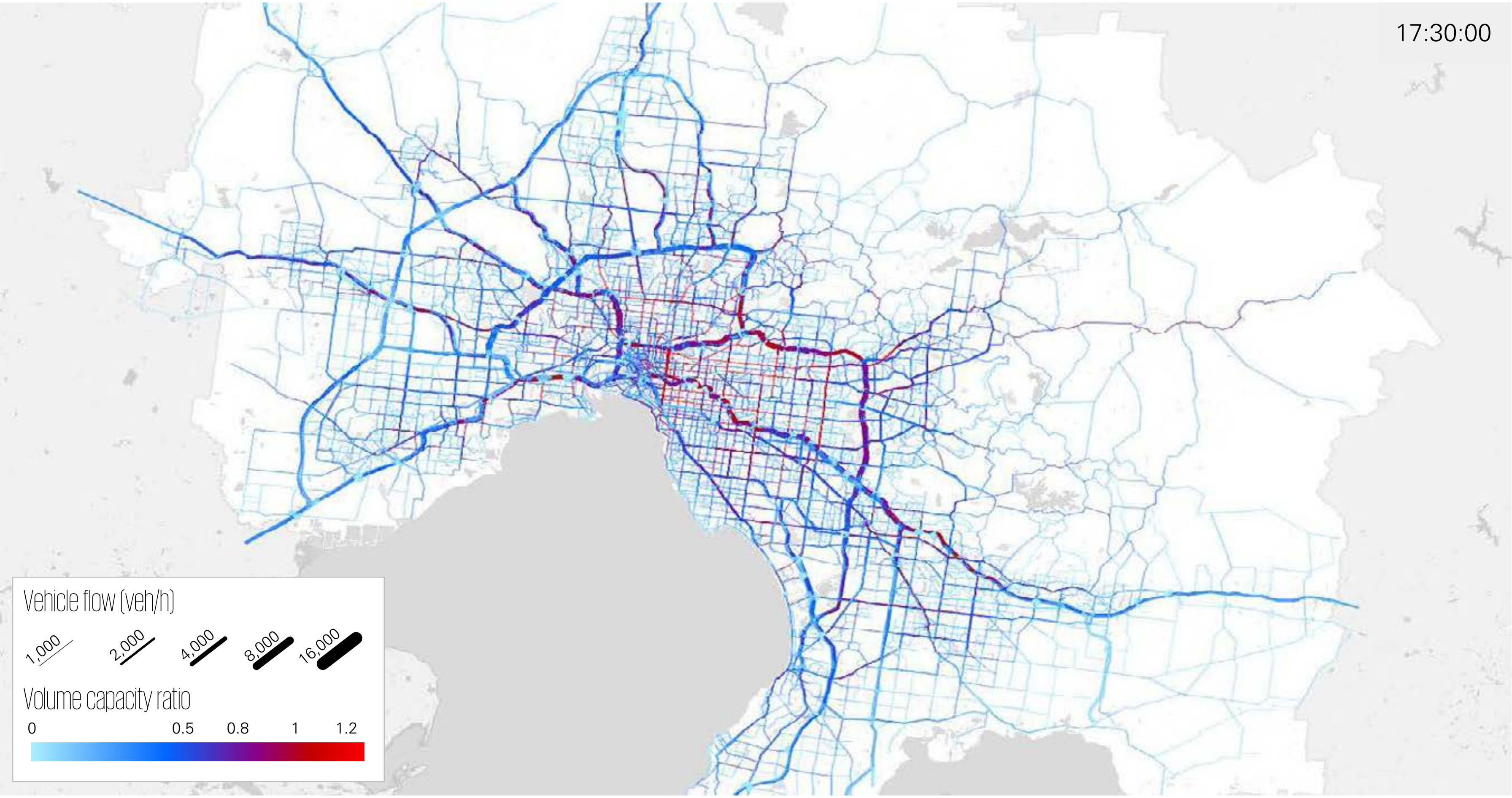
Source: MABM

Volume capacity ratio: Private drive, No mode shift, afternoon peak



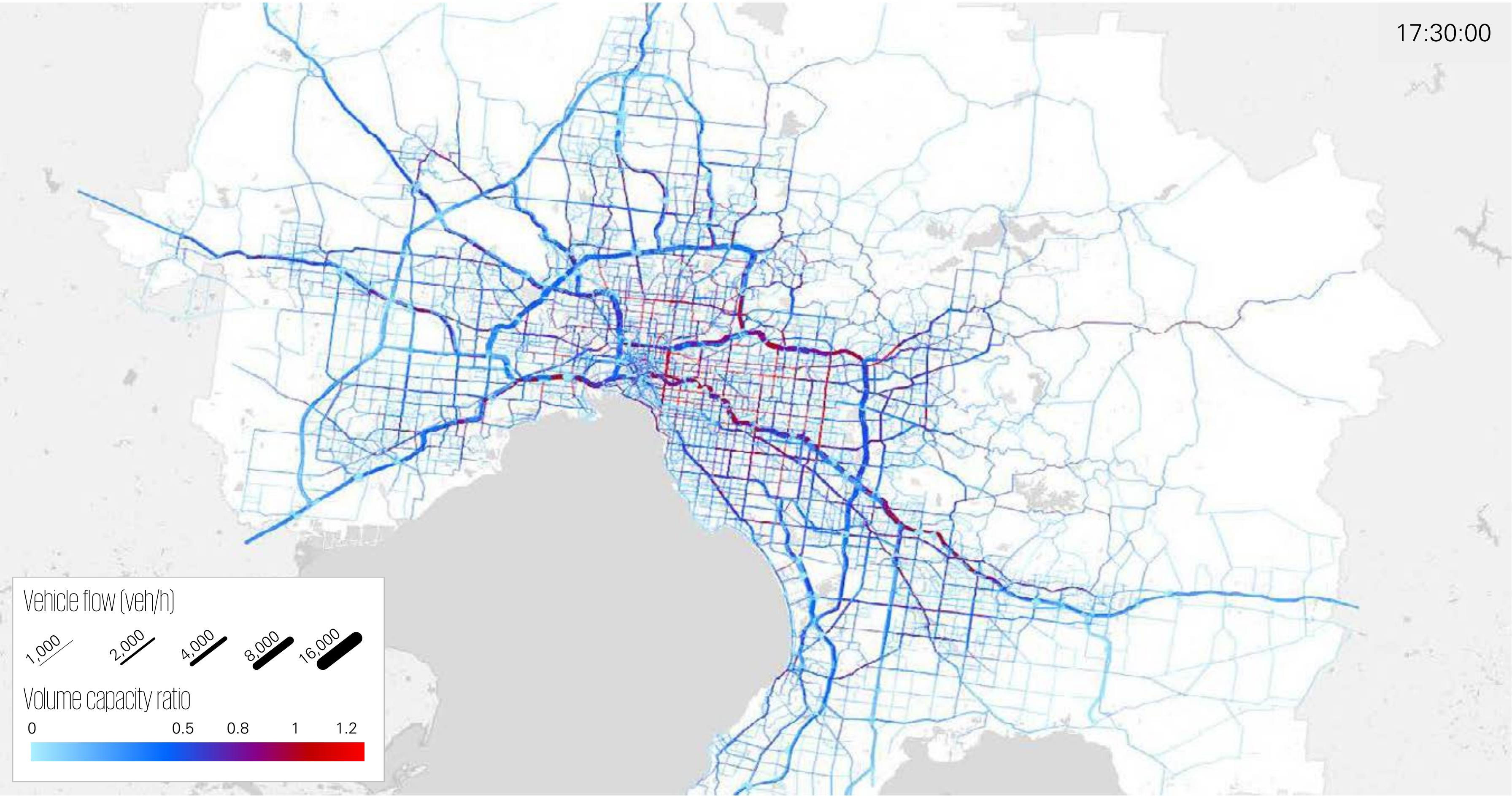
Source: MABM

Volume capacity ratio: Private drive, Area based charge, afternoon peak



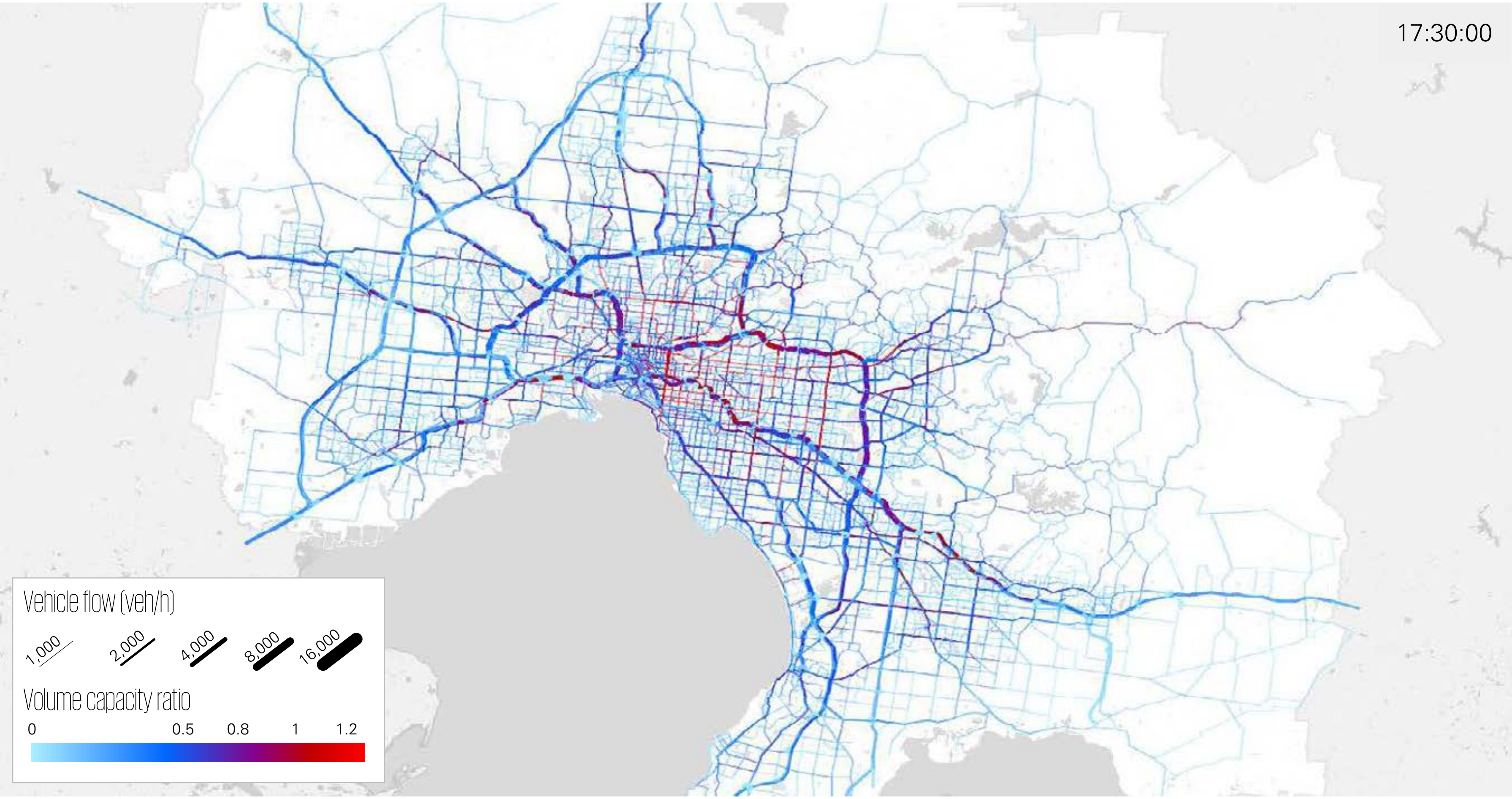
Source: MABM

Volume capacity ratio: Private drive, Distance based charge, afternoon peak



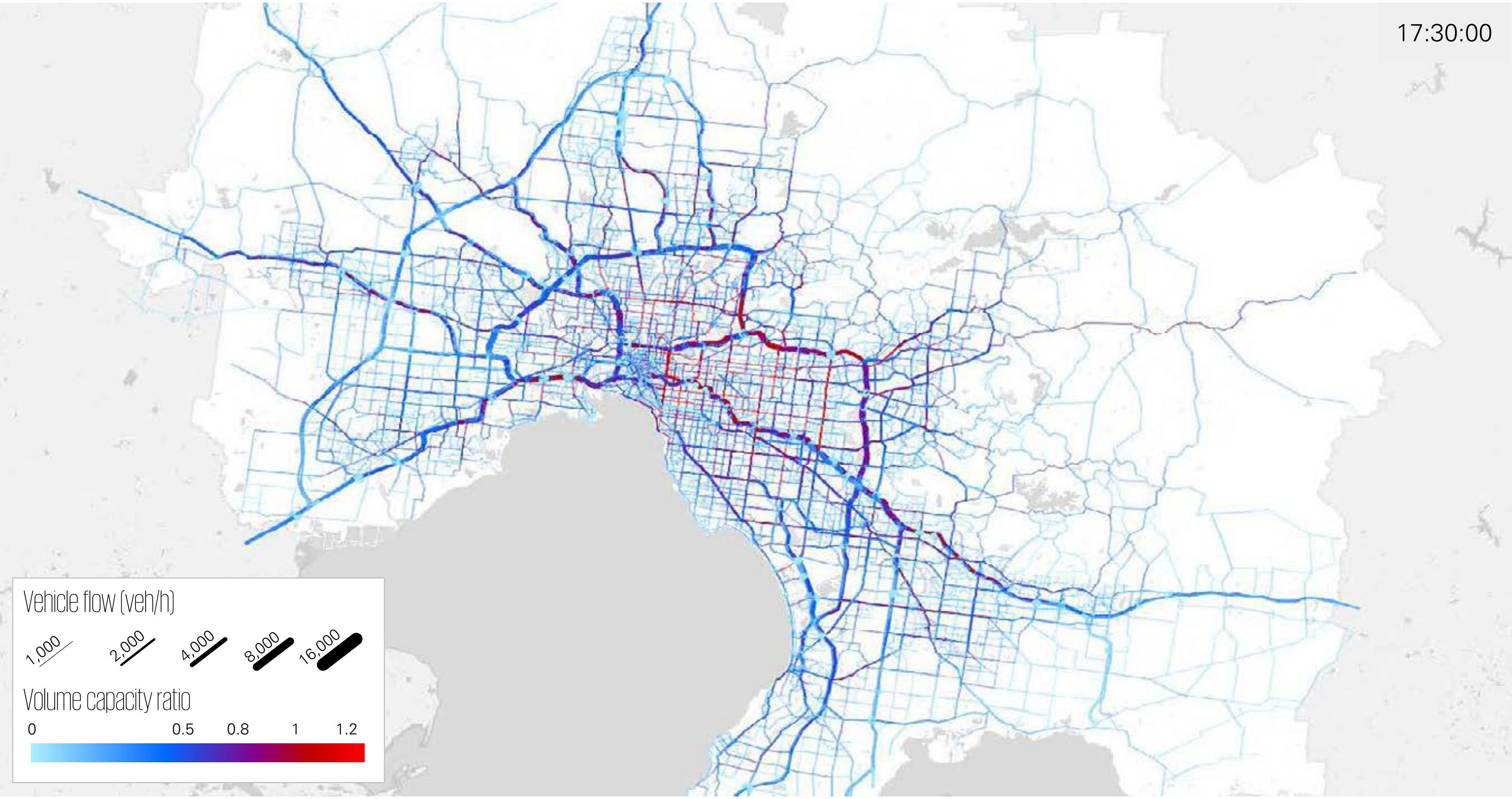
Source: MABM

Volume capacity ratio: Private drive, Freight to night, afternoon peak



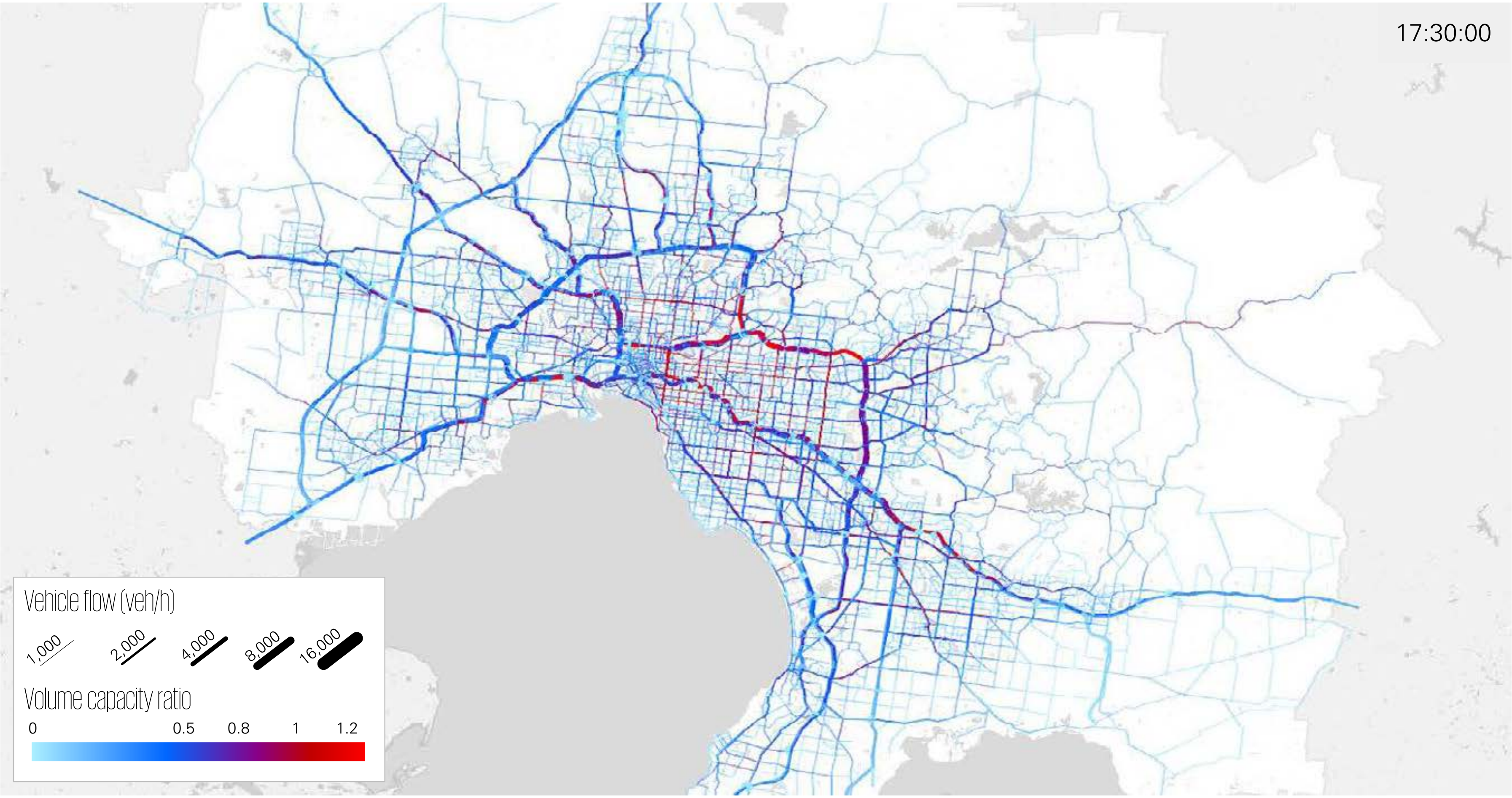
Source: MABM

Volume capacity ratio: Private drive, Expanded markets, afternoon peak



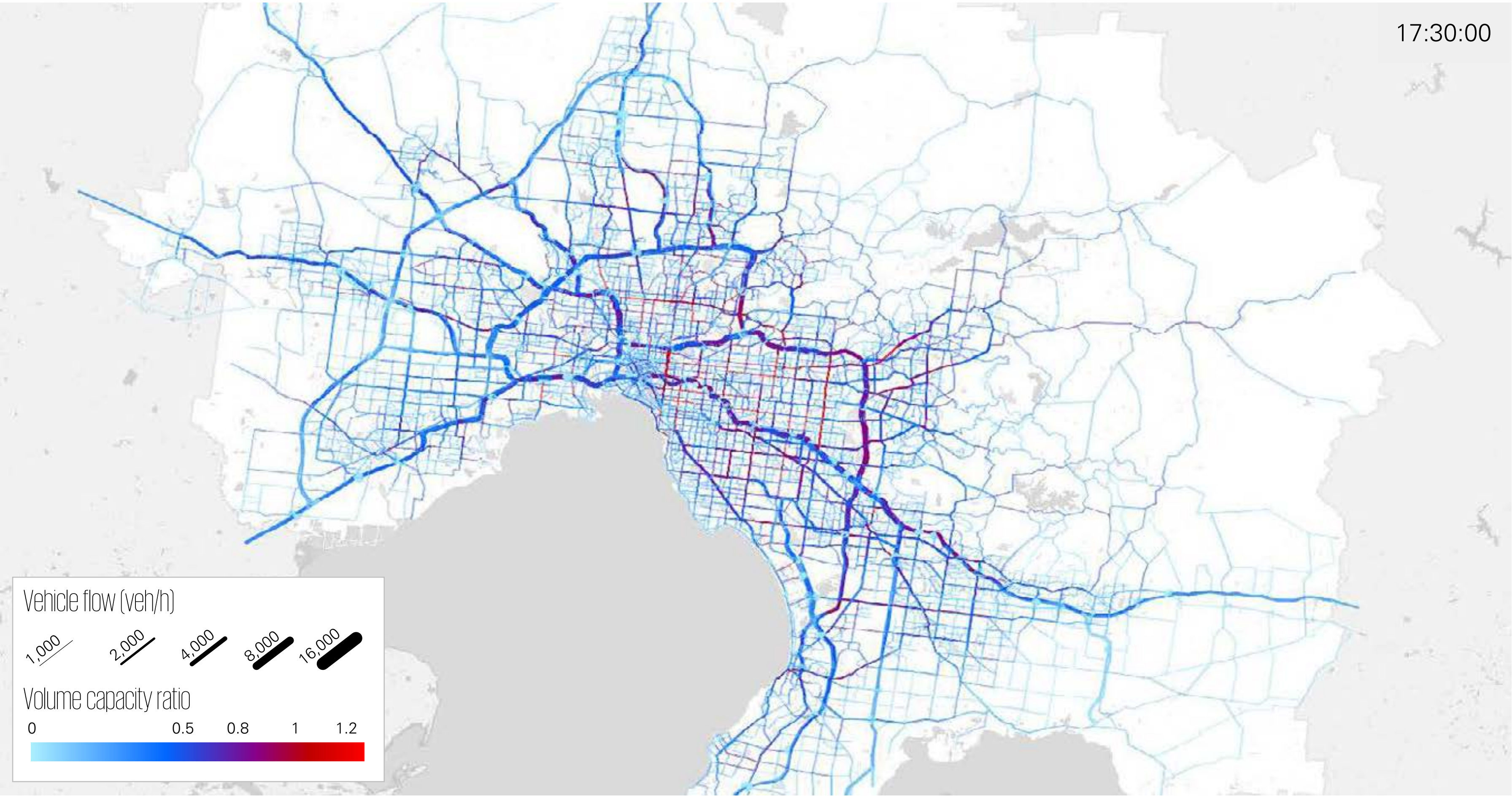
Source: MABM

Volume capacity ratio: Private drive, Station drop-off and pick-up, afternoon peak



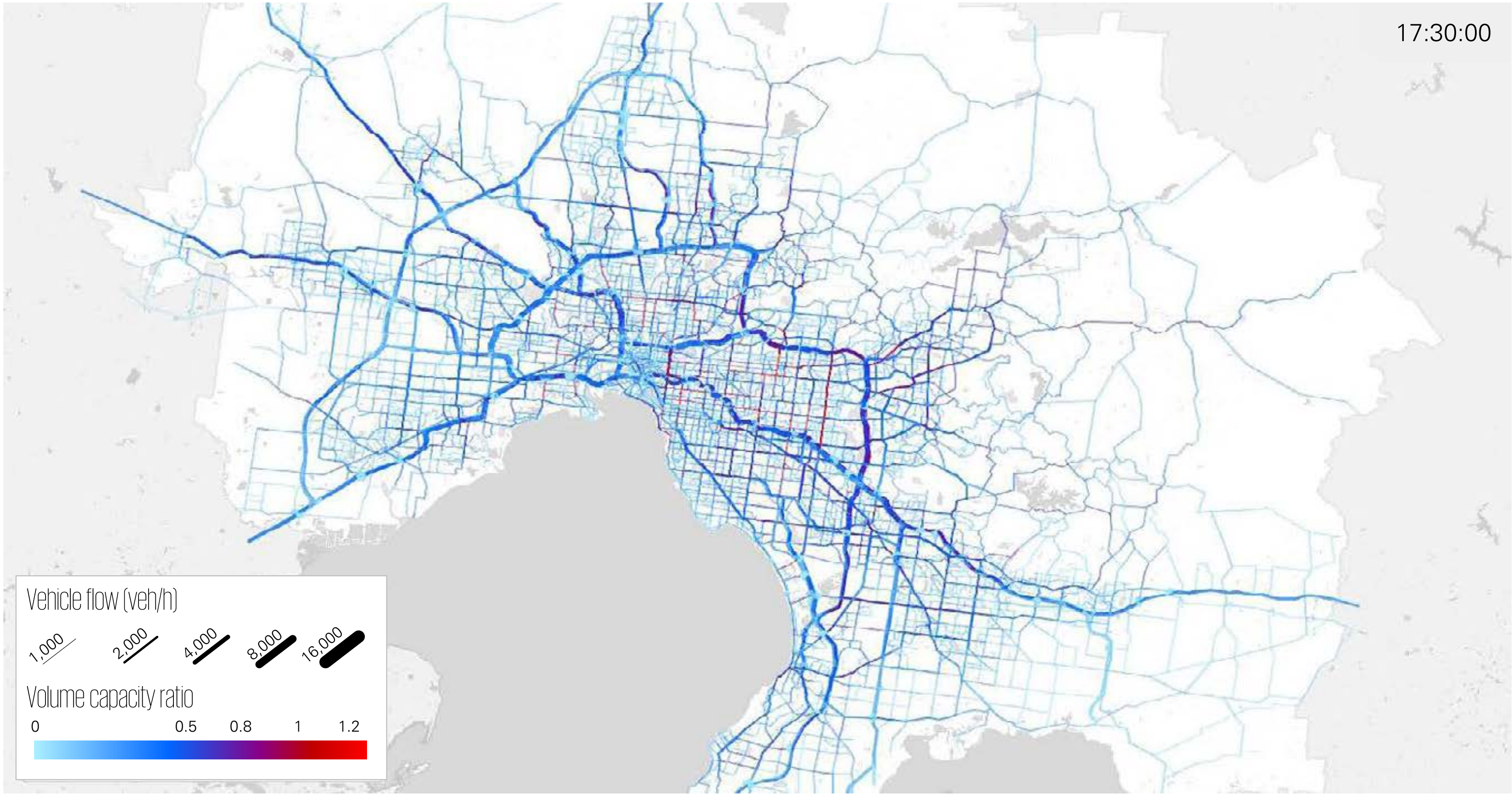
Source: MABM

Volume capacity ratio: Fleet street, Subscription fare, afternoon peak



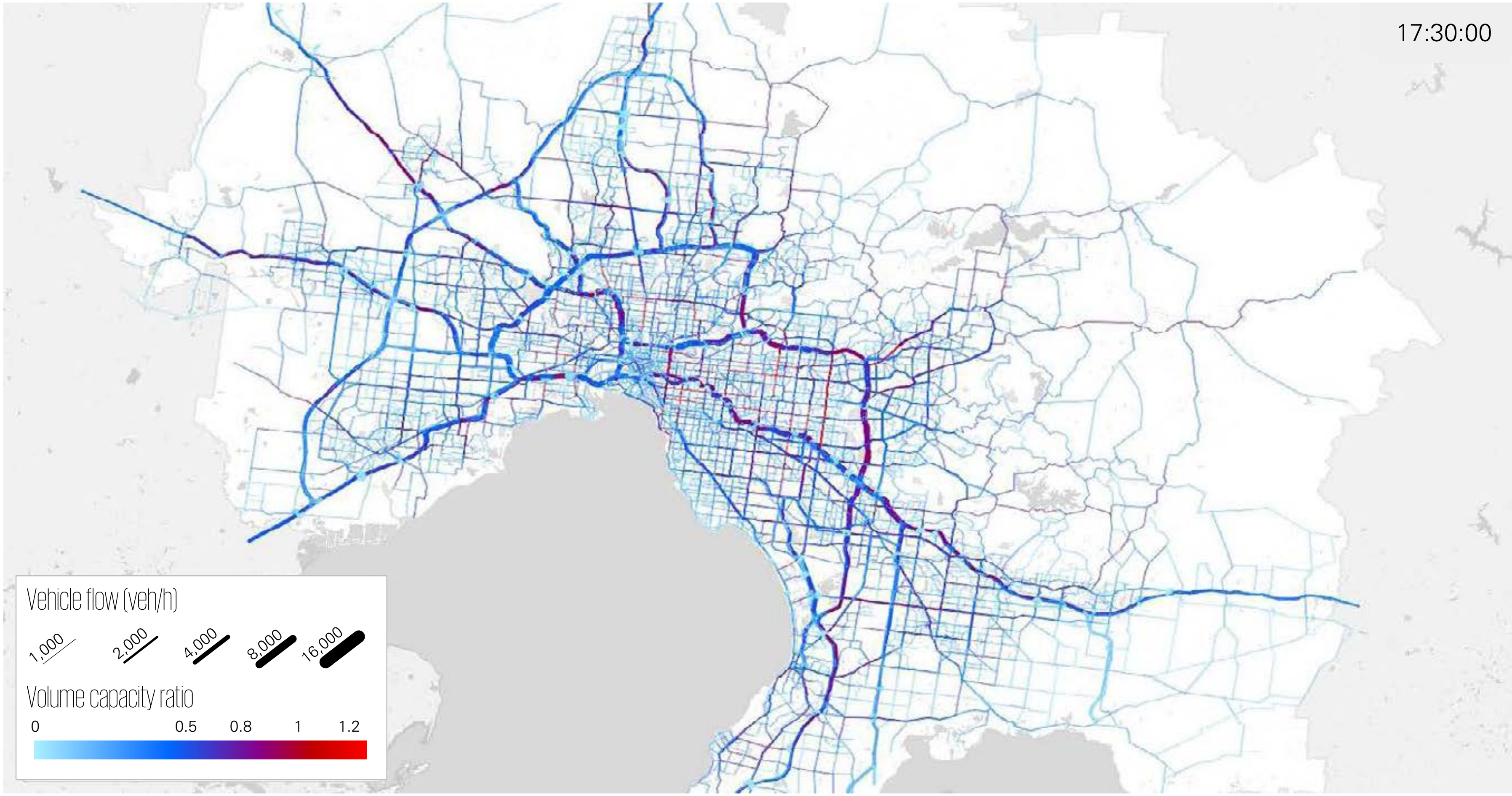
Source: MABM

Volume capacity ratio: Fleet street, Low MUTT, afternoon peak



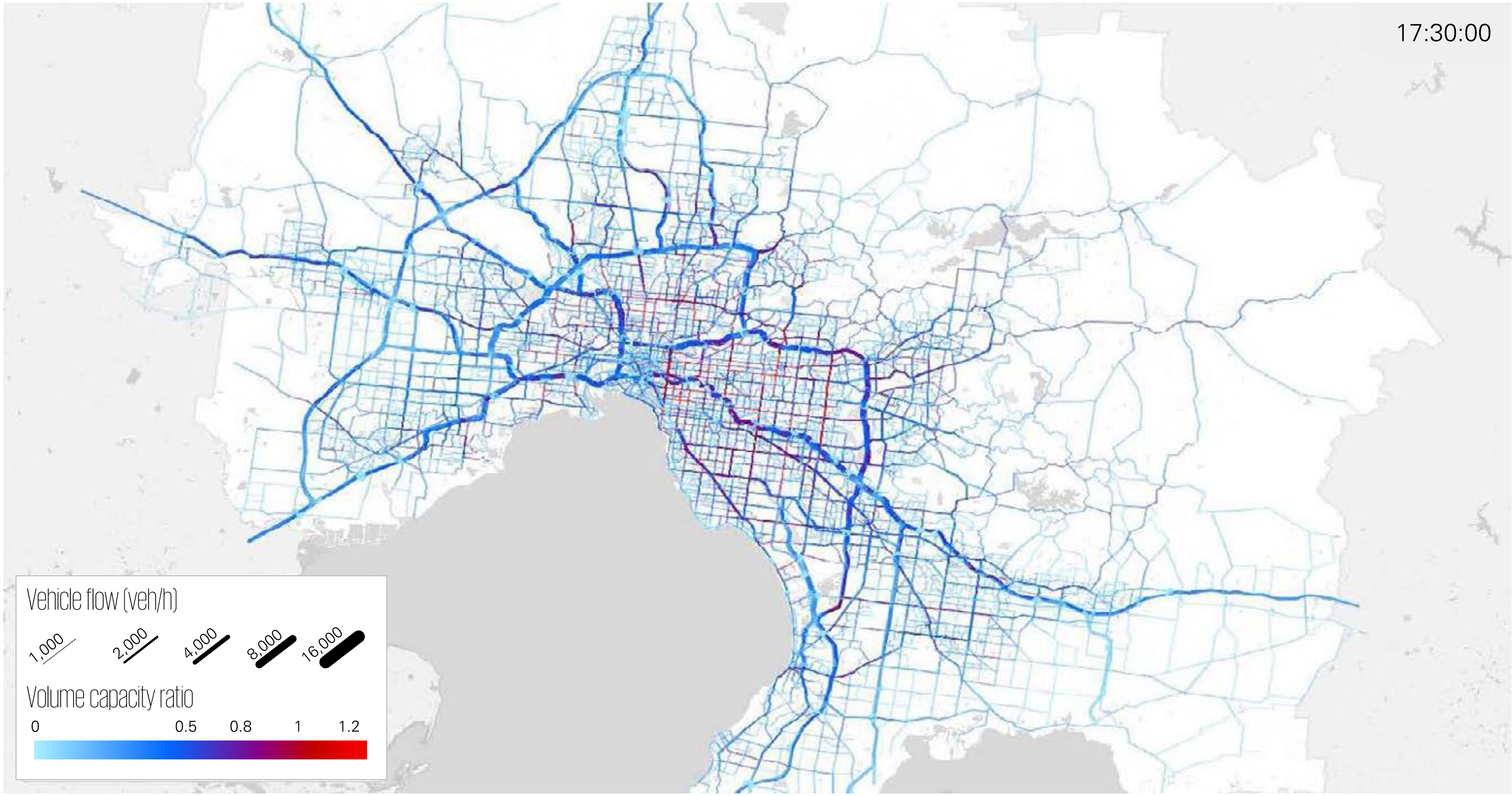
Source: MABM

Volume capacity ratio: Fleet street, Low flow, afternoon peak



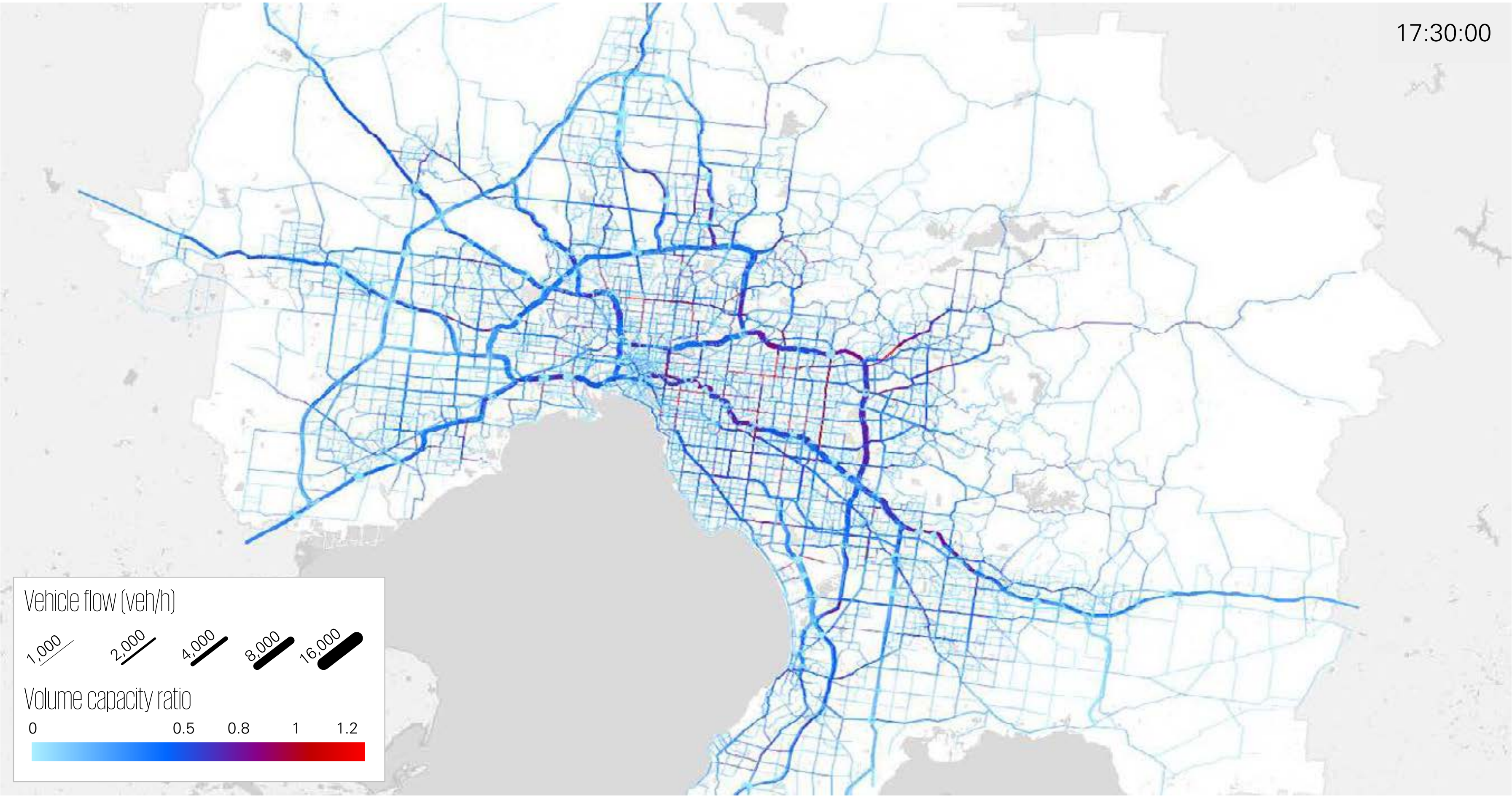
Source: MABM

Volume capacity ratio: Fleet street, No mode shift, afternoon peak



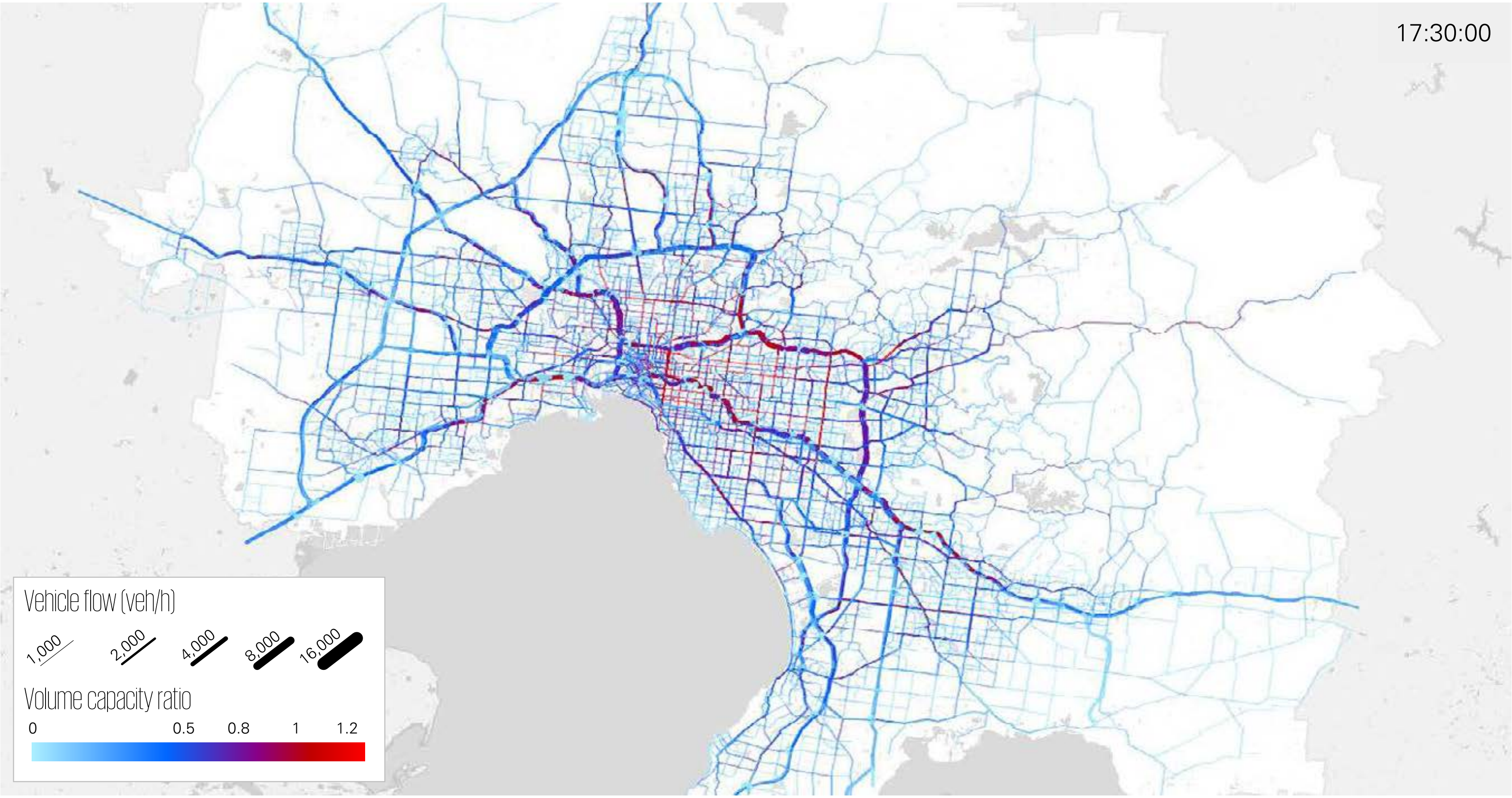
Source: MABM

Volume capacity ratio: Fleet street, Calibrated fleet size, afternoon peak



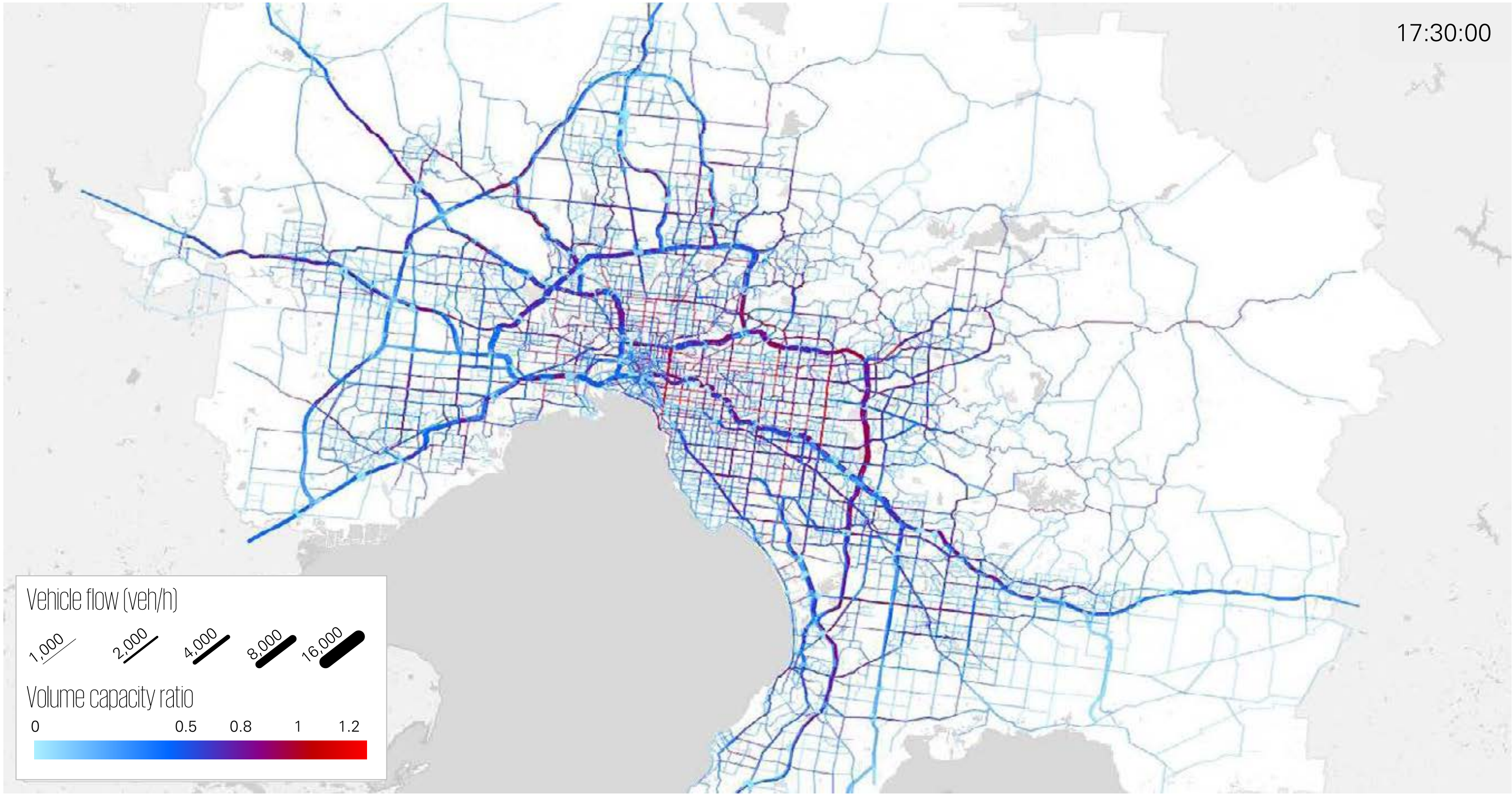
Source: MABM

Volume capacity ratio: Fleet Street, No new (pre-construction) major road projects, afternoon peak



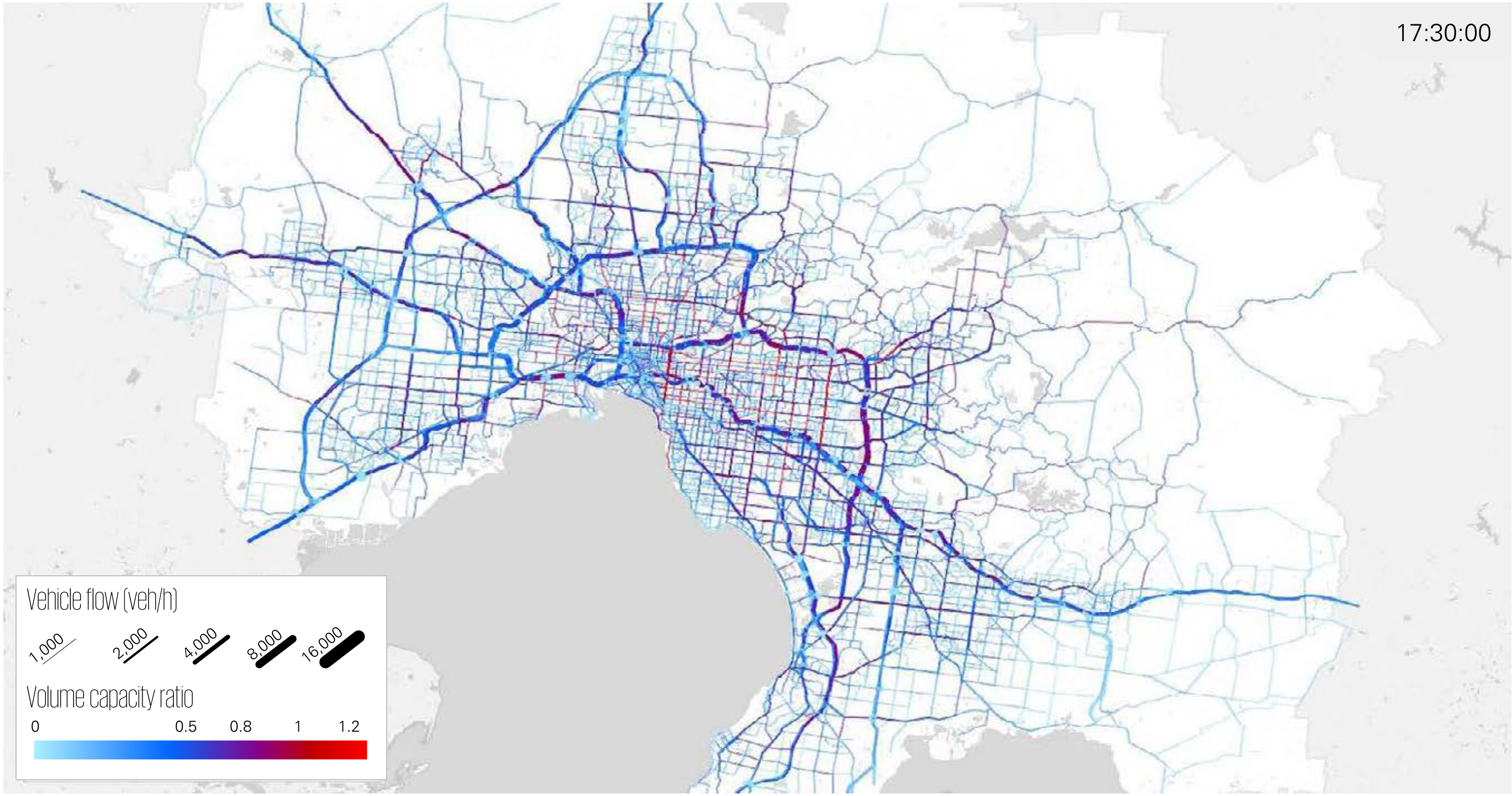
Source: MABM

Volume capacity ratio: Slow lane, Low MUTT, afternoon peak



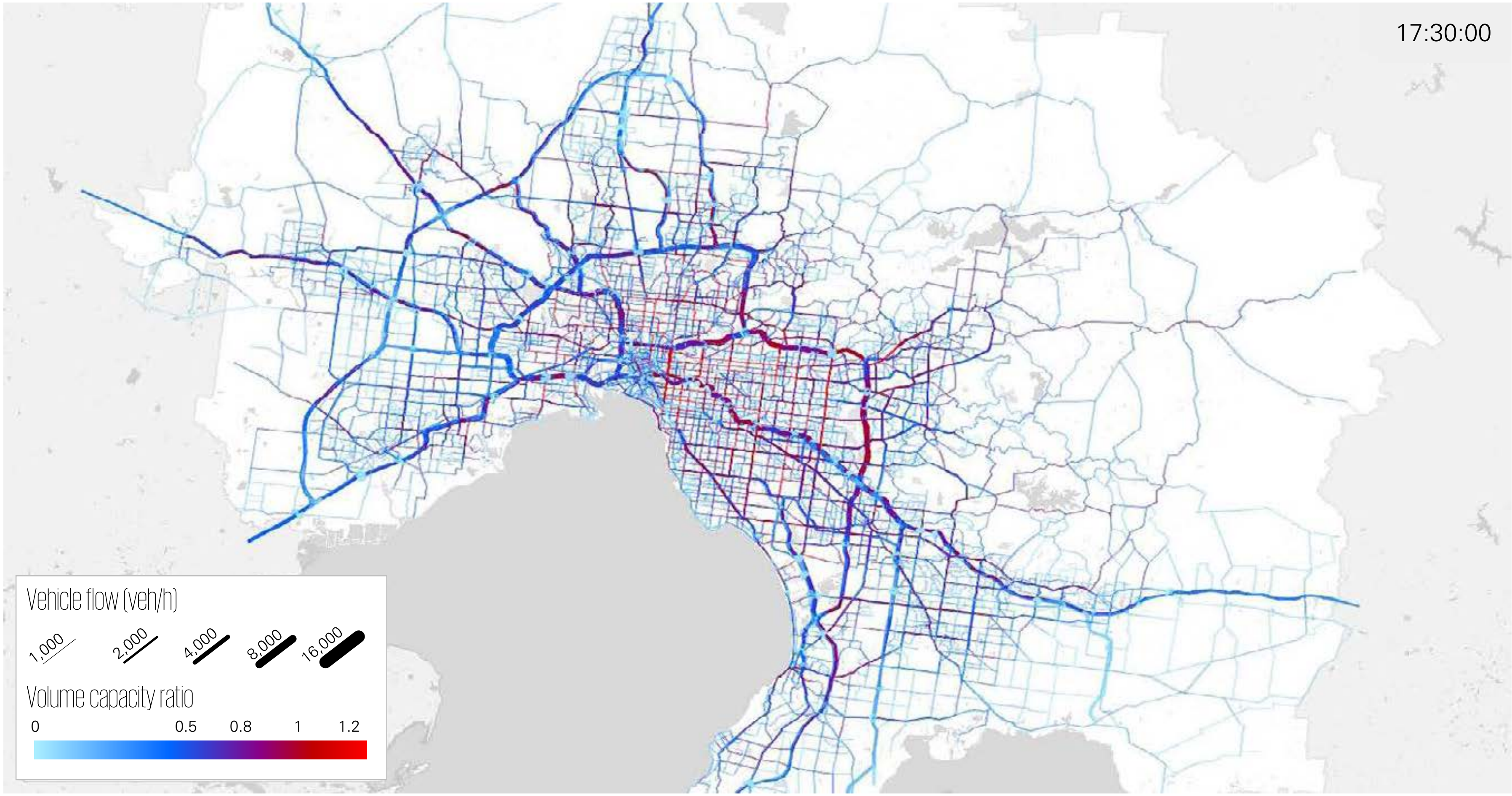
Source: MABM

Volume capacity ratio: Slow lane, Low flow, afternoon peak



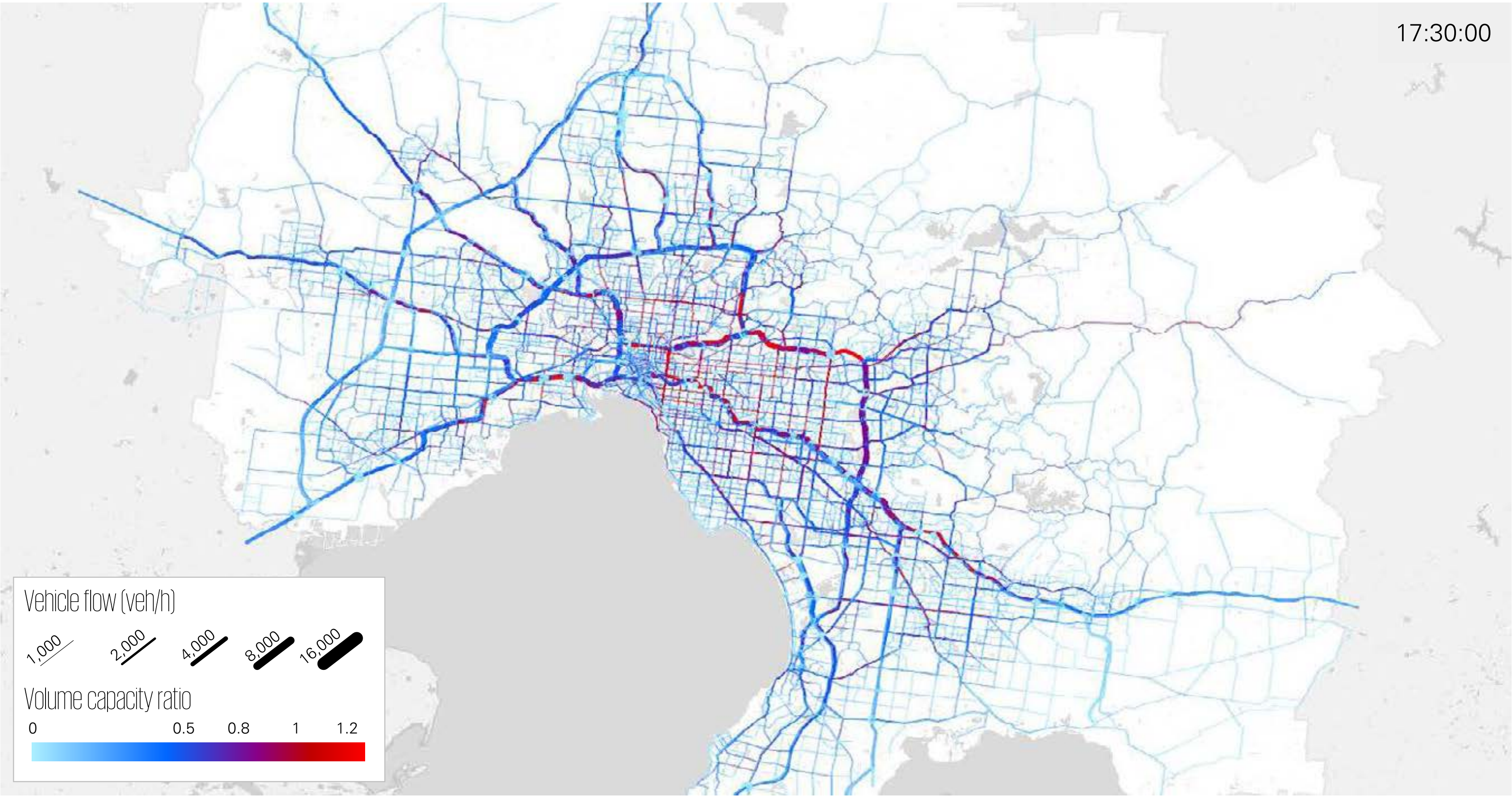
Source: MABM

Volume capacity ratio: Slow lane, No mode shift, afternoon peak



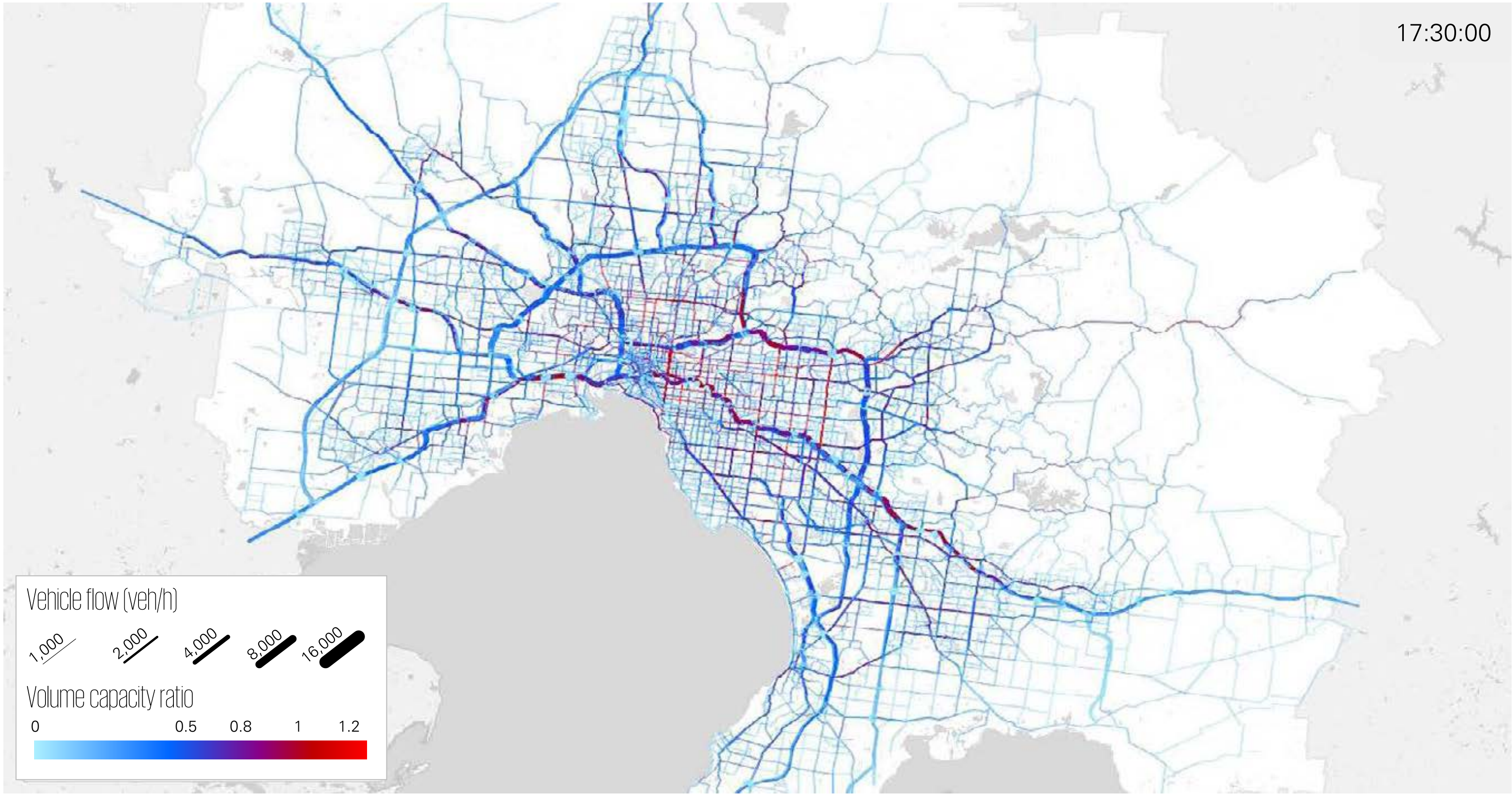
Source: MABM

Volume capacity ratio: Private slow lane, Slow lane, afternoon peak



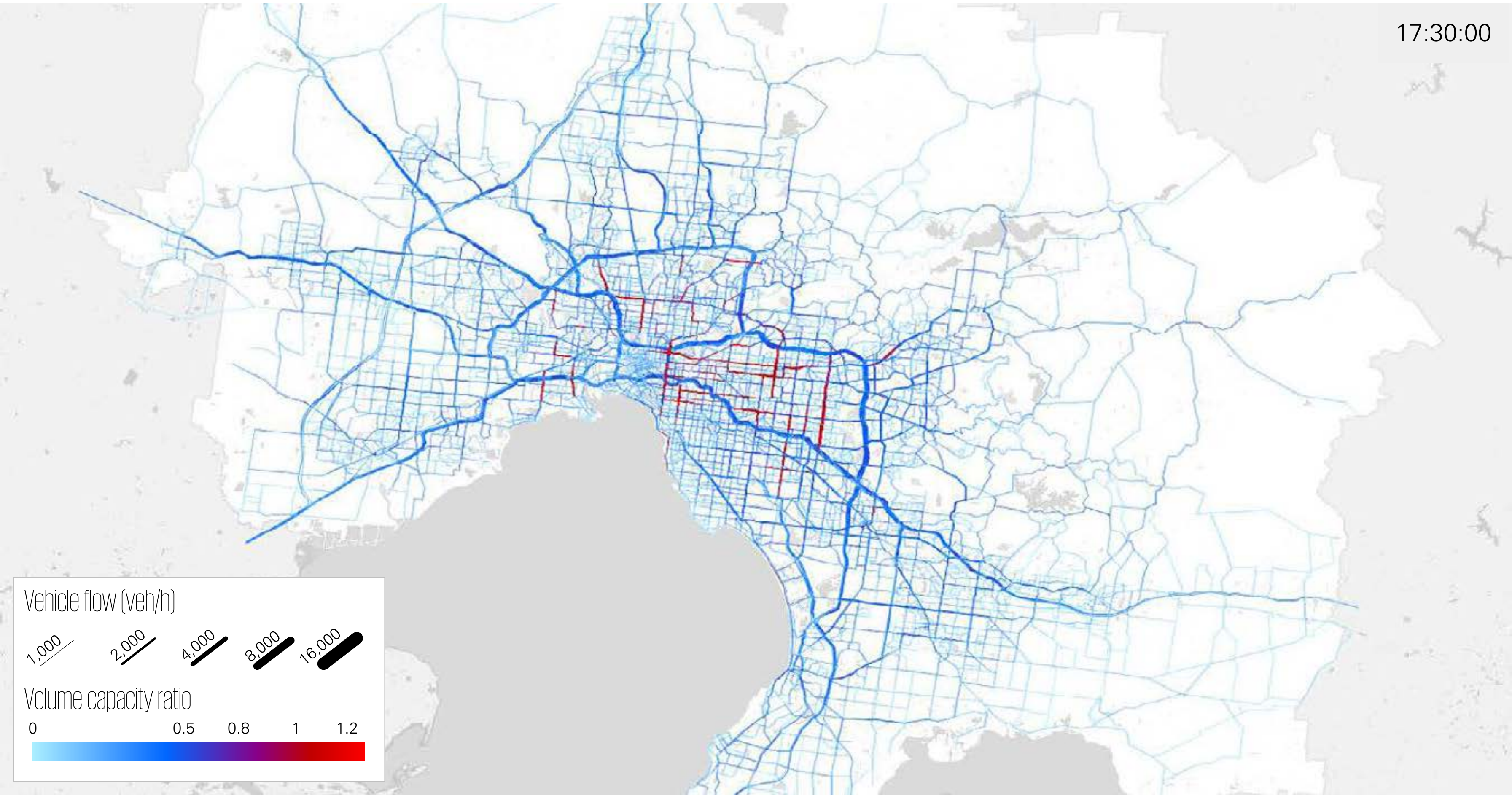
Source: MABM

Volume capacity ratio: Hydrogen highway, No empty running, afternoon peak



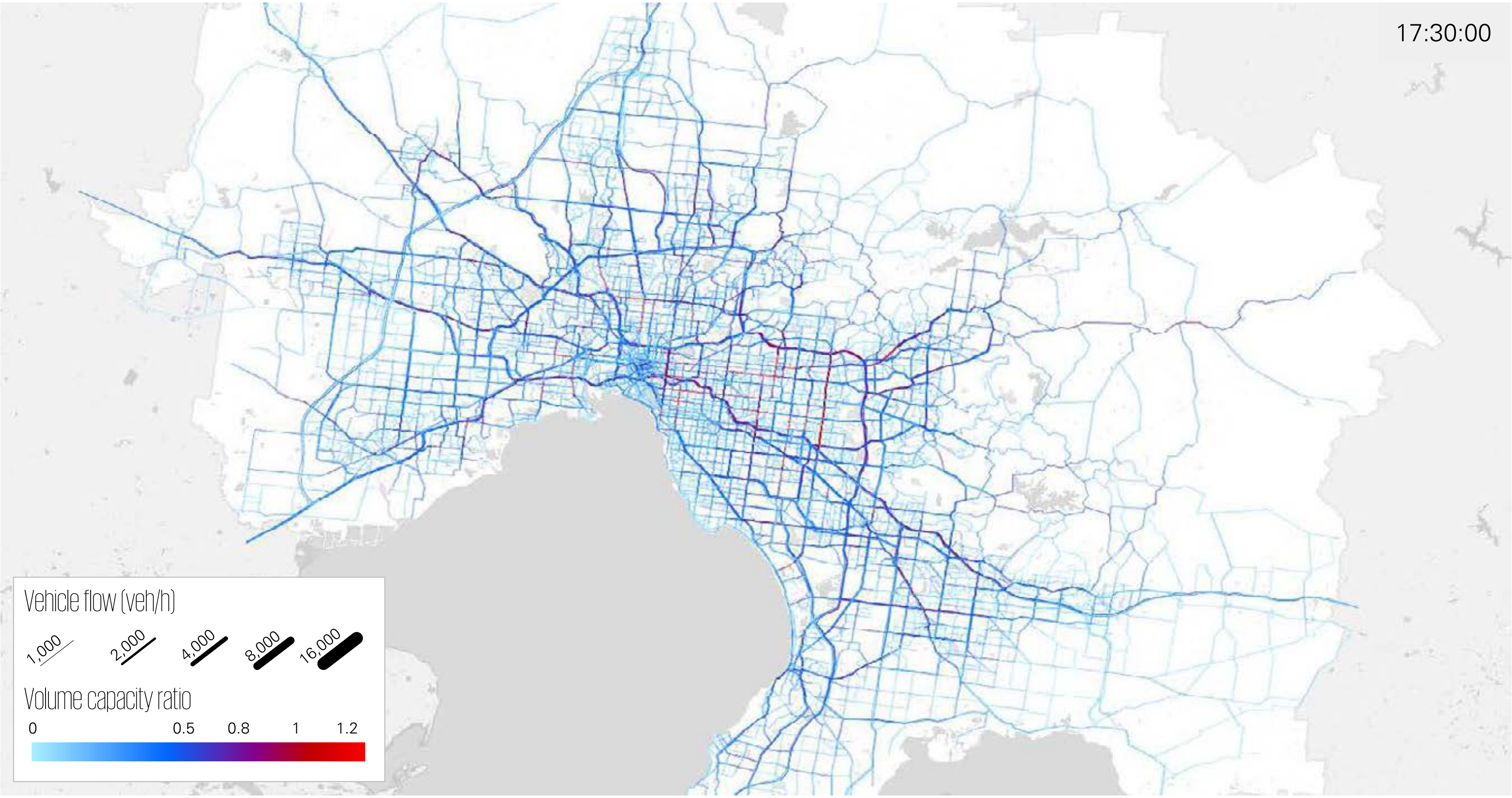
Source: MABM

Volume capacity ratio: Mix of scenarios, afternoon peak



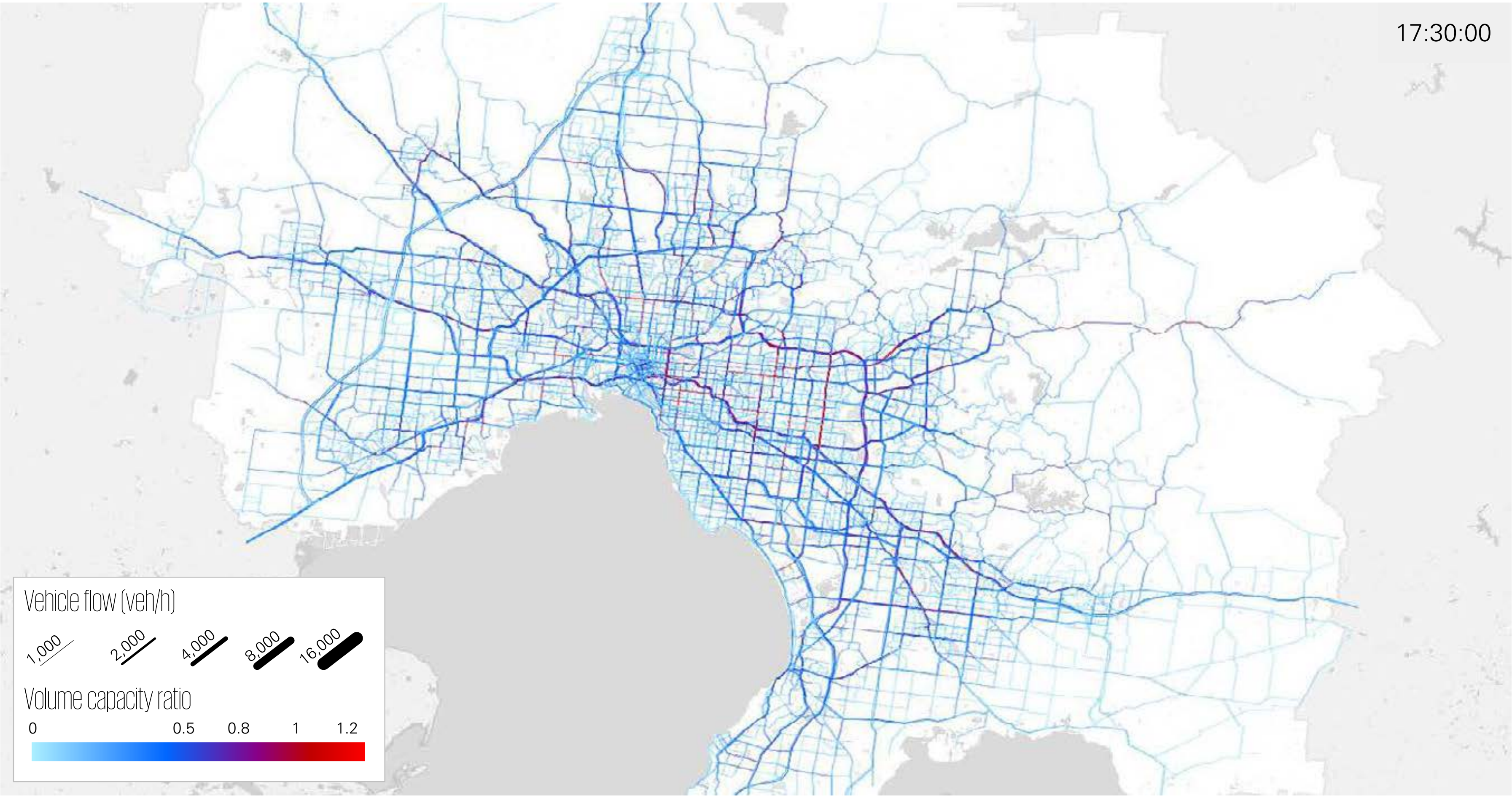
Source: MABM

Volume capacity ratio: Mix of scenarios, Centralised land use, afternoon peak



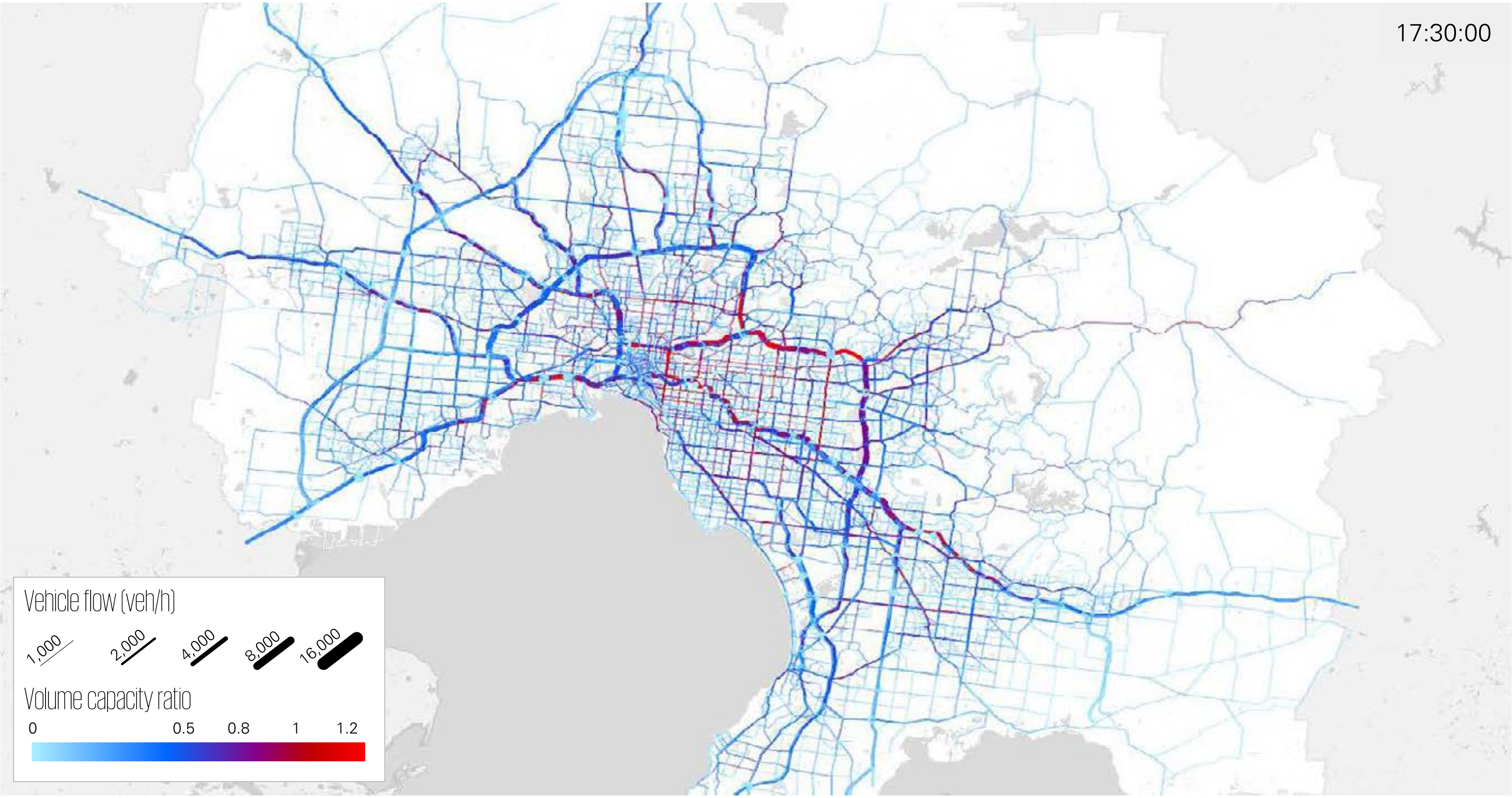
Source: MABM

Volume capacity ratio: Mix of scenarios, Expanded land use, afternoon peak



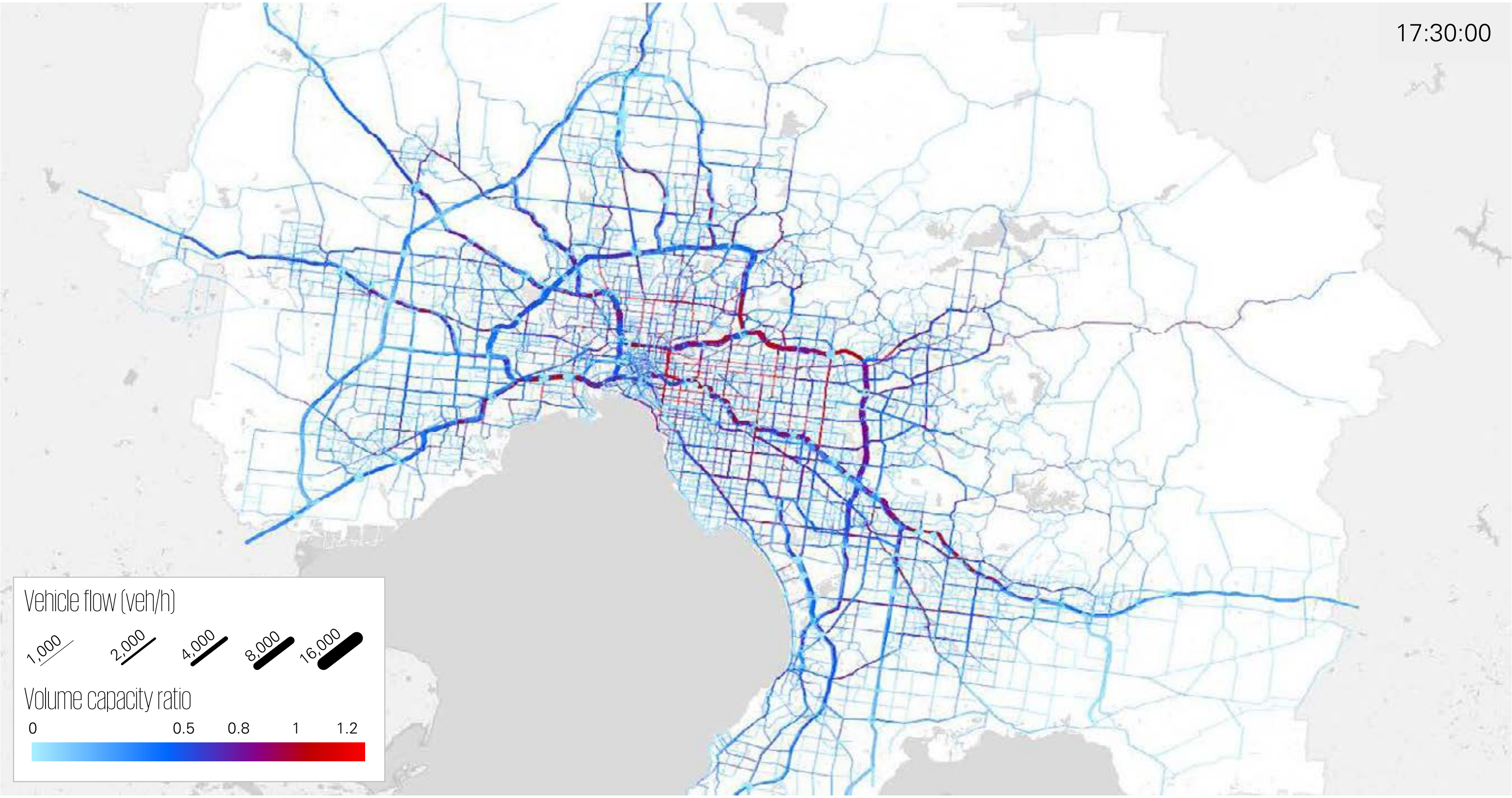
Source: MABM

Volume capacity ratio: Private drive, Centralised land use, afternoon peak



Source: MABM

Volume capacity ratio: Private drive, Expanded land use, afternoon peak

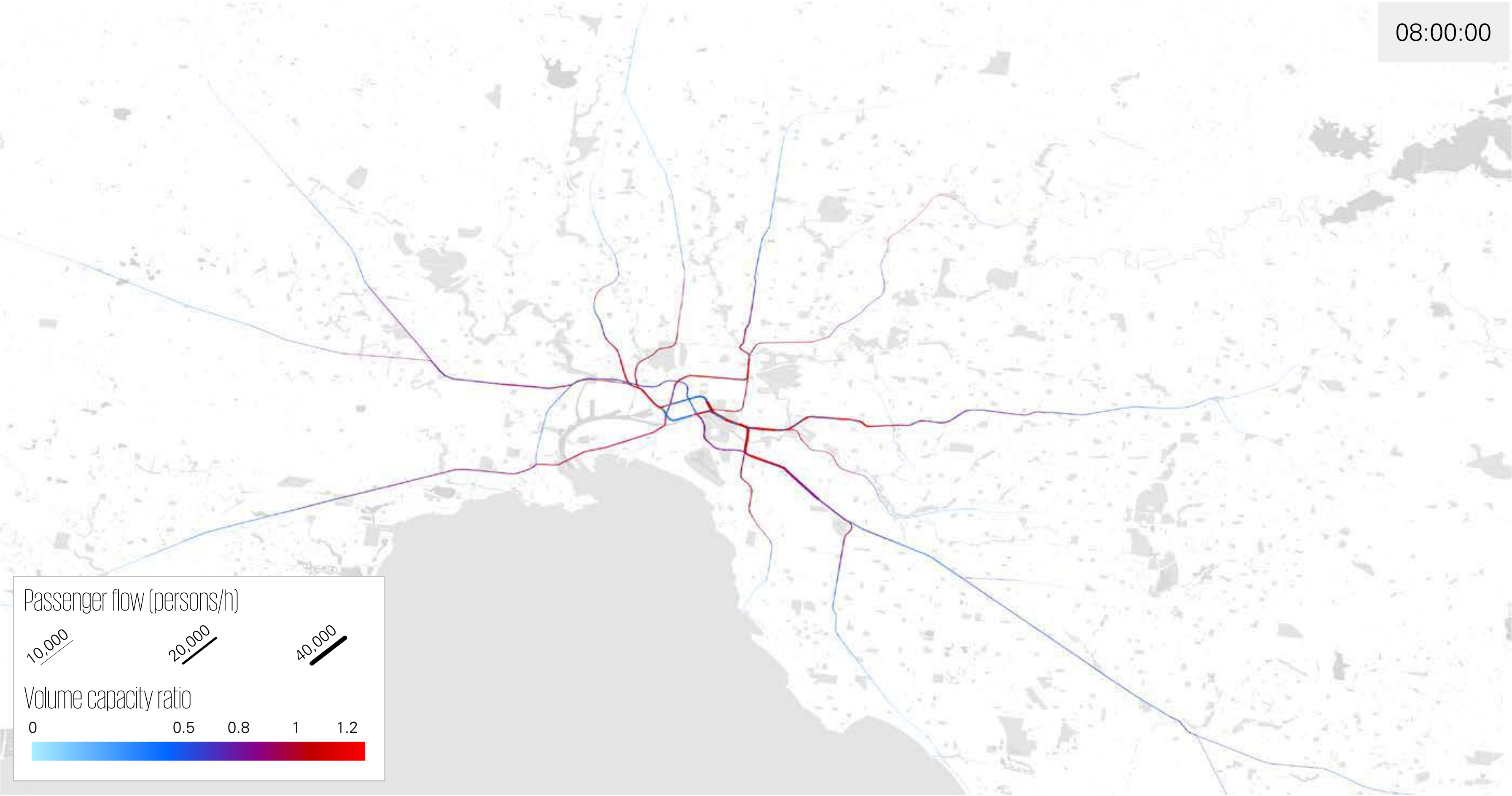


Source: MABM

Volume capacity ratio, rail: Dead end, morning peak

Source: MABM

Volume capacity ratio, rail: Private drive, morning peak



Source: MABM

Volume capacity ratio, rail: Fleet street, morning peak

Source: MABM

Volume capacity ratio, rail: Slow lane, morning peak

Source: MABM

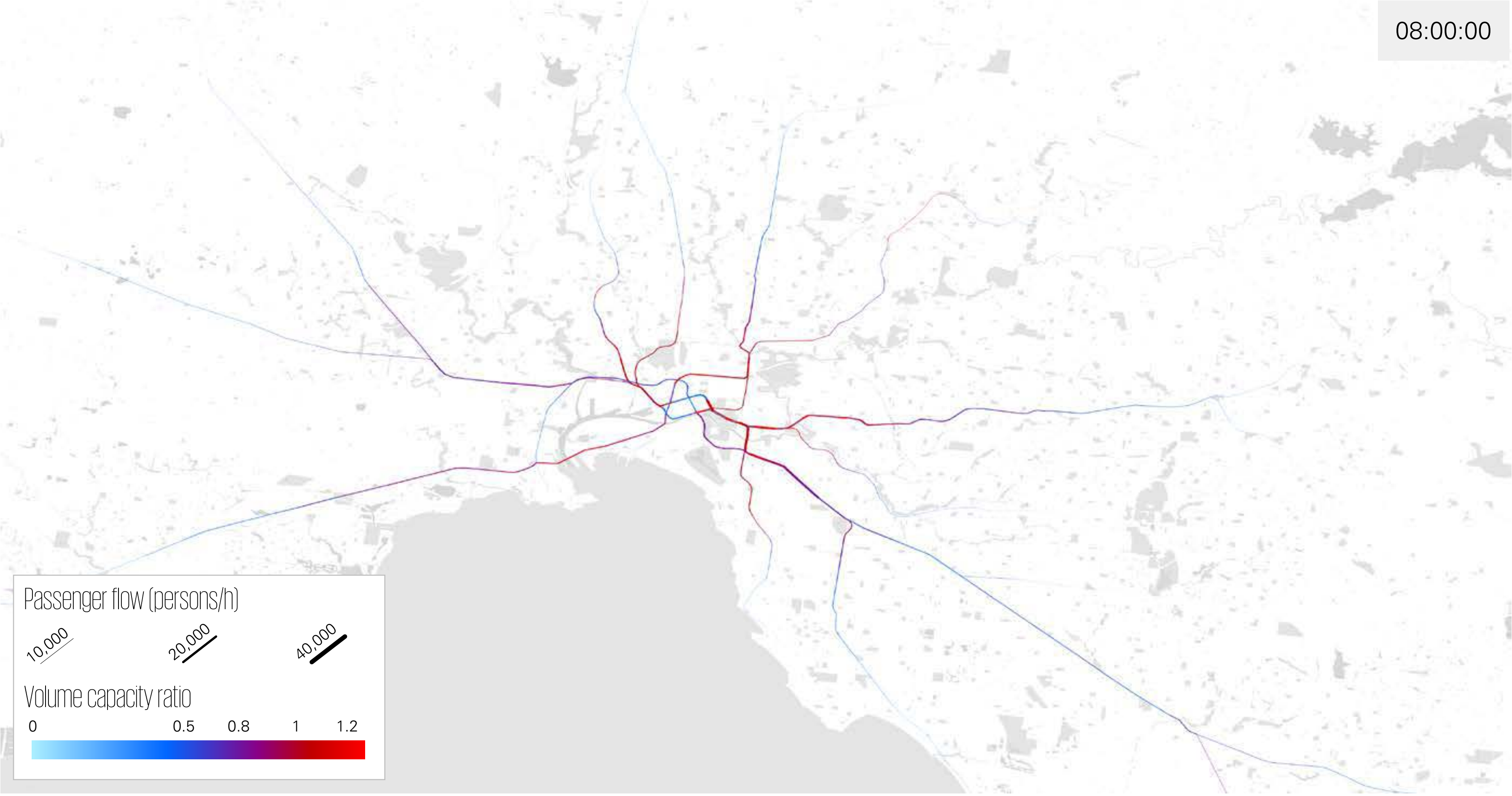
Volume capacity ratio, rail: Electric avenue, morning peak

Source: MABM

Volume capacity ratio, rail: Hydrogen highway, morning peak

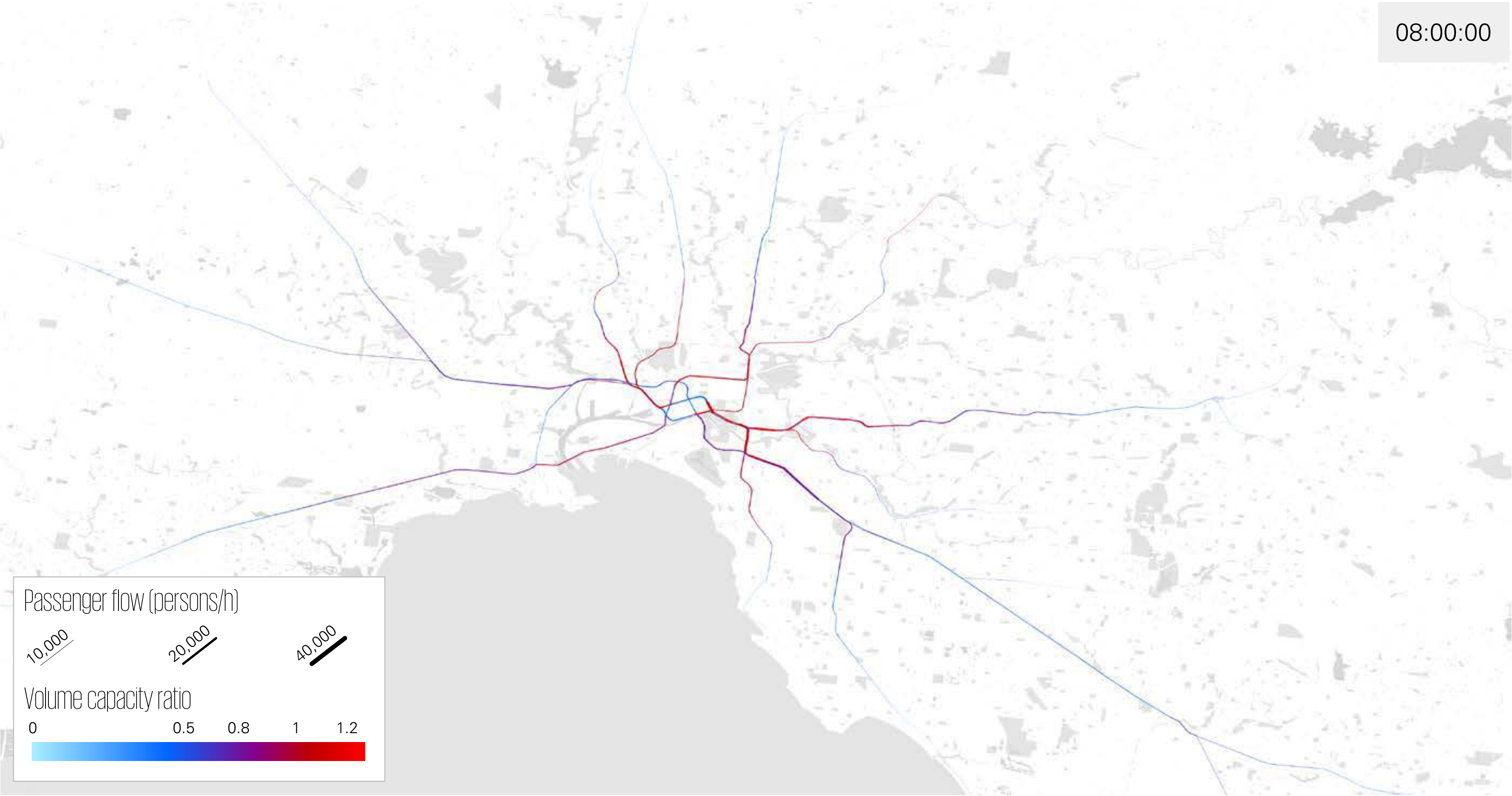
Source: MABM

Volume capacity ratio, rail: Private drive, No empty running, morning peak



Source: MABM

Volume capacity ratio, rail: Private drive, Low MUTT, morning peak



Source: MABM

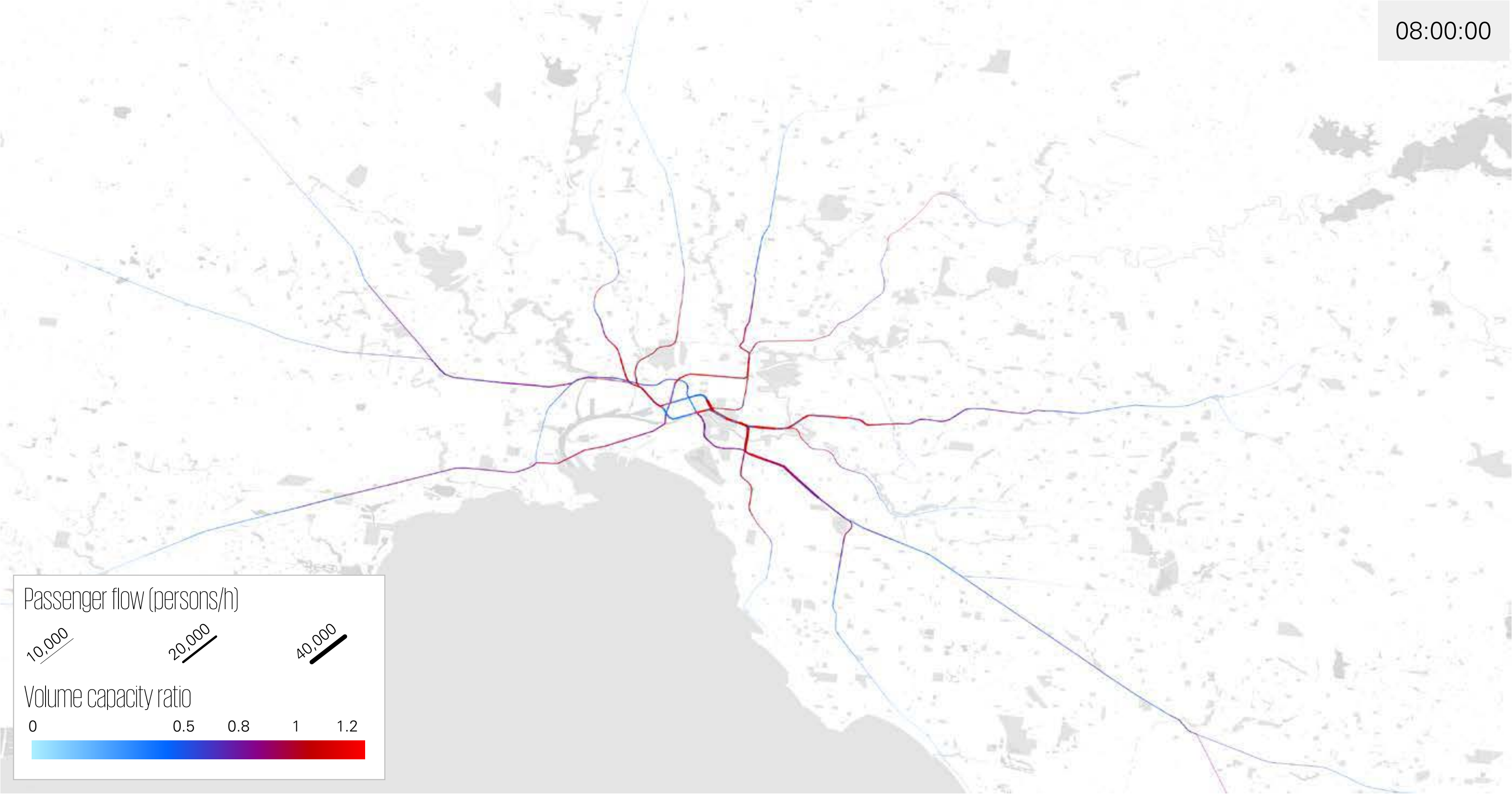
Volume capacity ratio, rail: Private drive, Low flow, morning peak

Source: MABM

Volume capacity ratio, rail: Private drive, No mode shift, morning peak

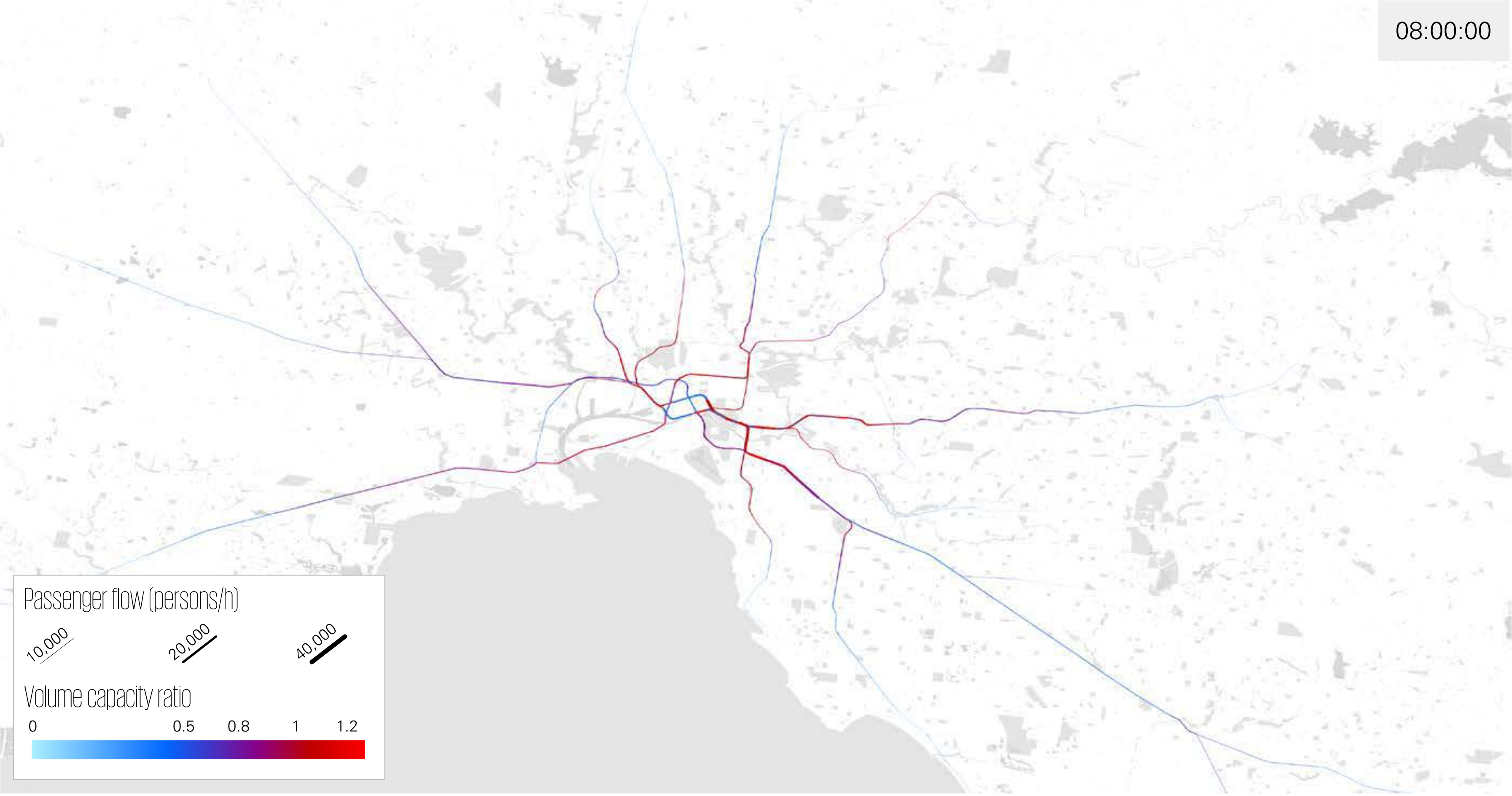
Source: MABM

Volume capacity ratio, rail: Private drive, Area based charge, morning peak



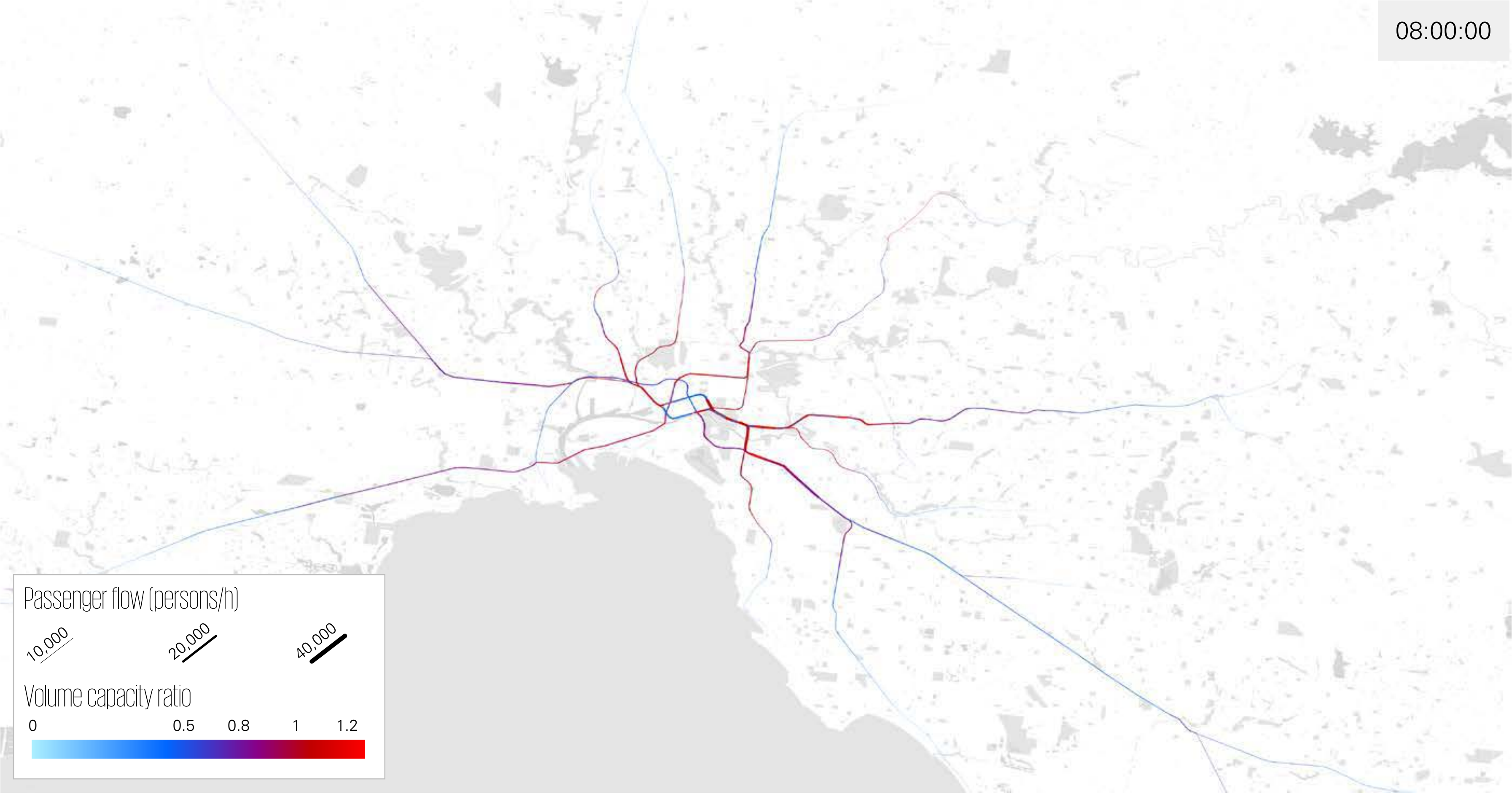
Source: MABM

Volume capacity ratio, rail: Private drive, Distance based charge, morning peak



Source: MABM

Volume capacity ratio, rail: Private drive, Freight to night, morning peak

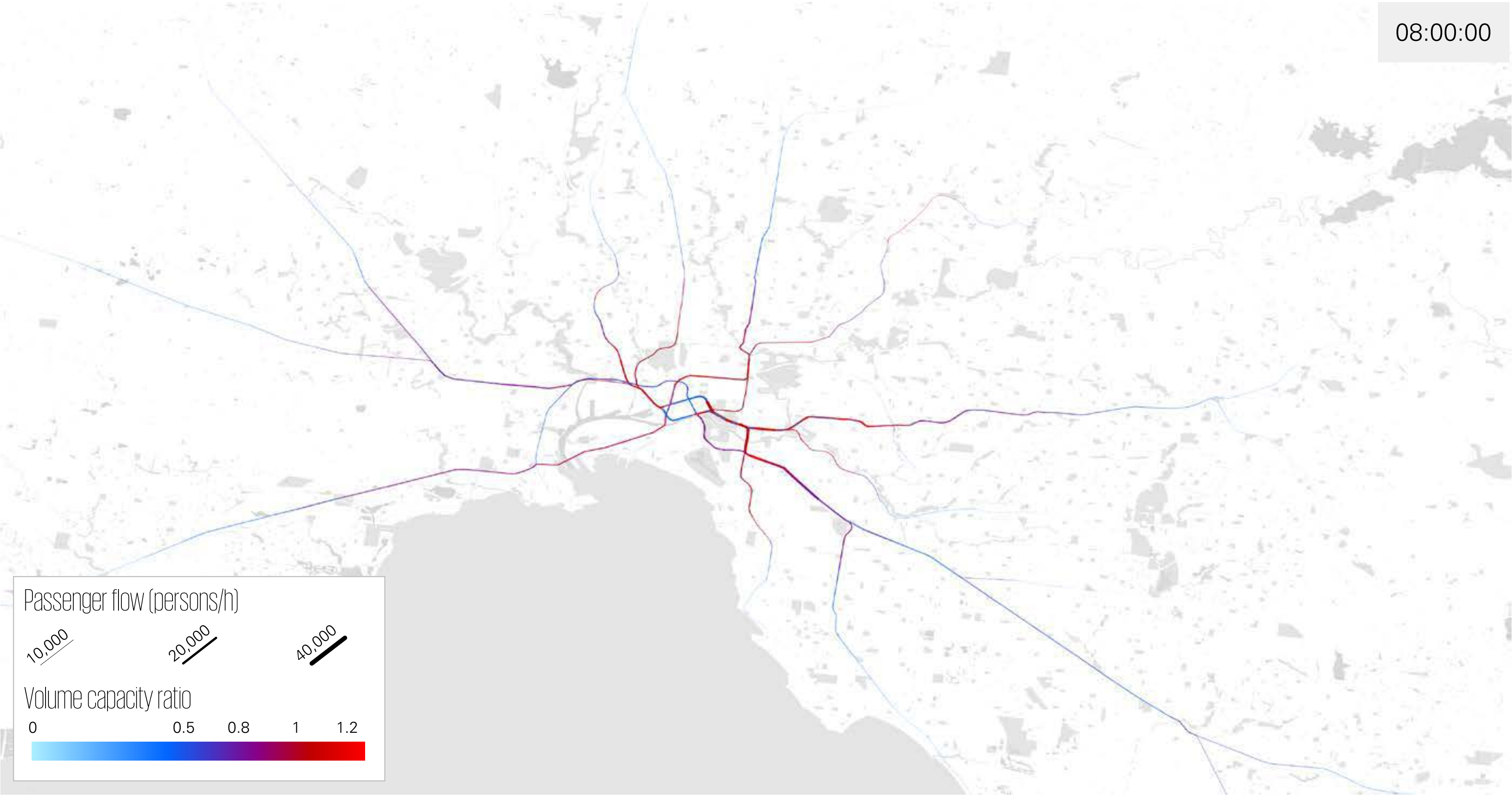


Source: MABM

Volume capacity ratio, rail: Private drive, Expanded markets, morning peak

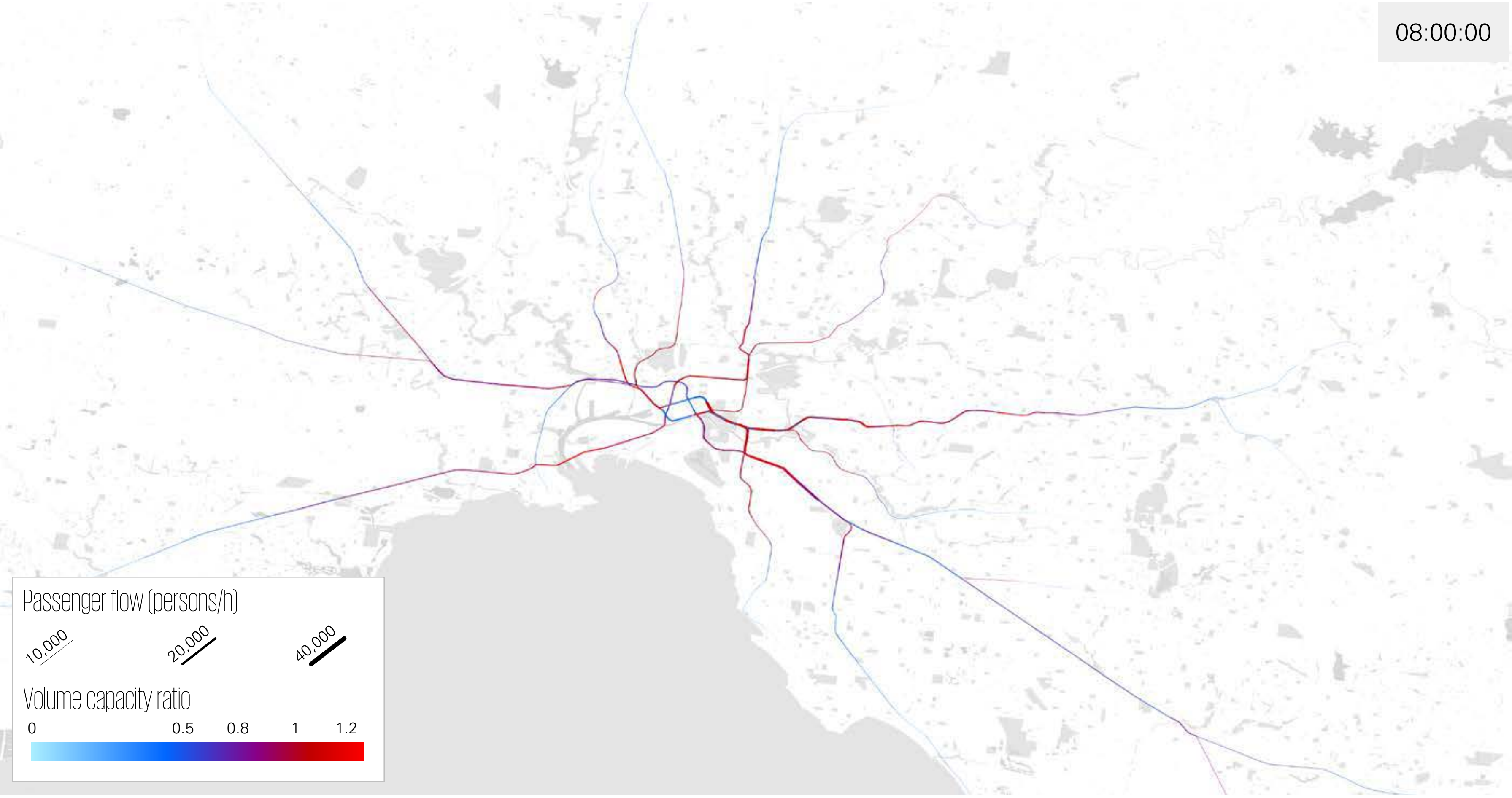
Source: MABM

Volume capacity ratio, rail: Private drive, Station drop-off and pick-up, morning peak



Source: MABM

Volume capacity ratio, rail: Fleet street, Subscription fare, morning peak



Source: MABM

Volume capacity ratio, rail: Fleet street, Calibrated fleet size, morning peak

Source: MABM

Volume capacity ratio, rail: Fleet Street, No new (pre-construction) major road projects, morning peak

Source: MABM

Volume capacity ratio, rail: Fleet street, Low MUTT, morning peak

Source: MABM

Volume capacity ratio, rail: Fleet street, Low flow, morning peak

Source: MABM

Volume capacity ratio, rail: Fleet street, No mode shift, morning peak

Source: MABM

Volume capacity ratio, rail: Slow lane, Low MUTT, morning peak

Source: MABM

Volume capacity ratio, rail: Slow lane, Low flow, morning peak

Source: MABM

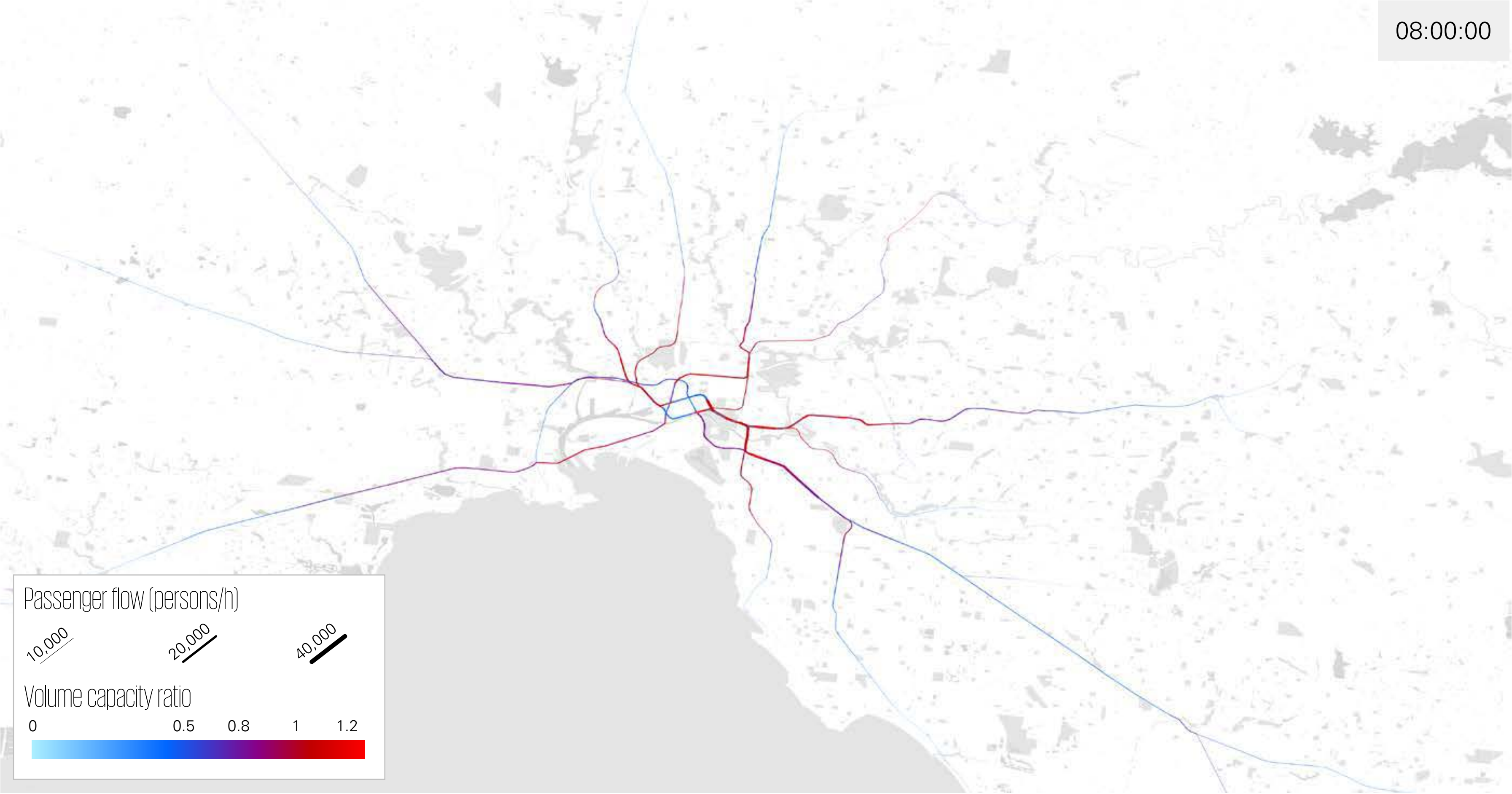
Volume capacity ratio, rail: Slow lane, No mode shift, morning peak

Source: MABM

Volume capacity ratio, rail: Private slow lane, Slow lane, morning peak

Source: MABM

Volume capacity ratio, rail: Hydrogen highway, No empty running, morning peak



Source: MABM

Volume capacity ratio, rail: Mix of scenarios, morning peak

Source: MABM

Volume capacity ratio, rail: Mix of scenarios, Centralised land use, morning peak

Source: MABM

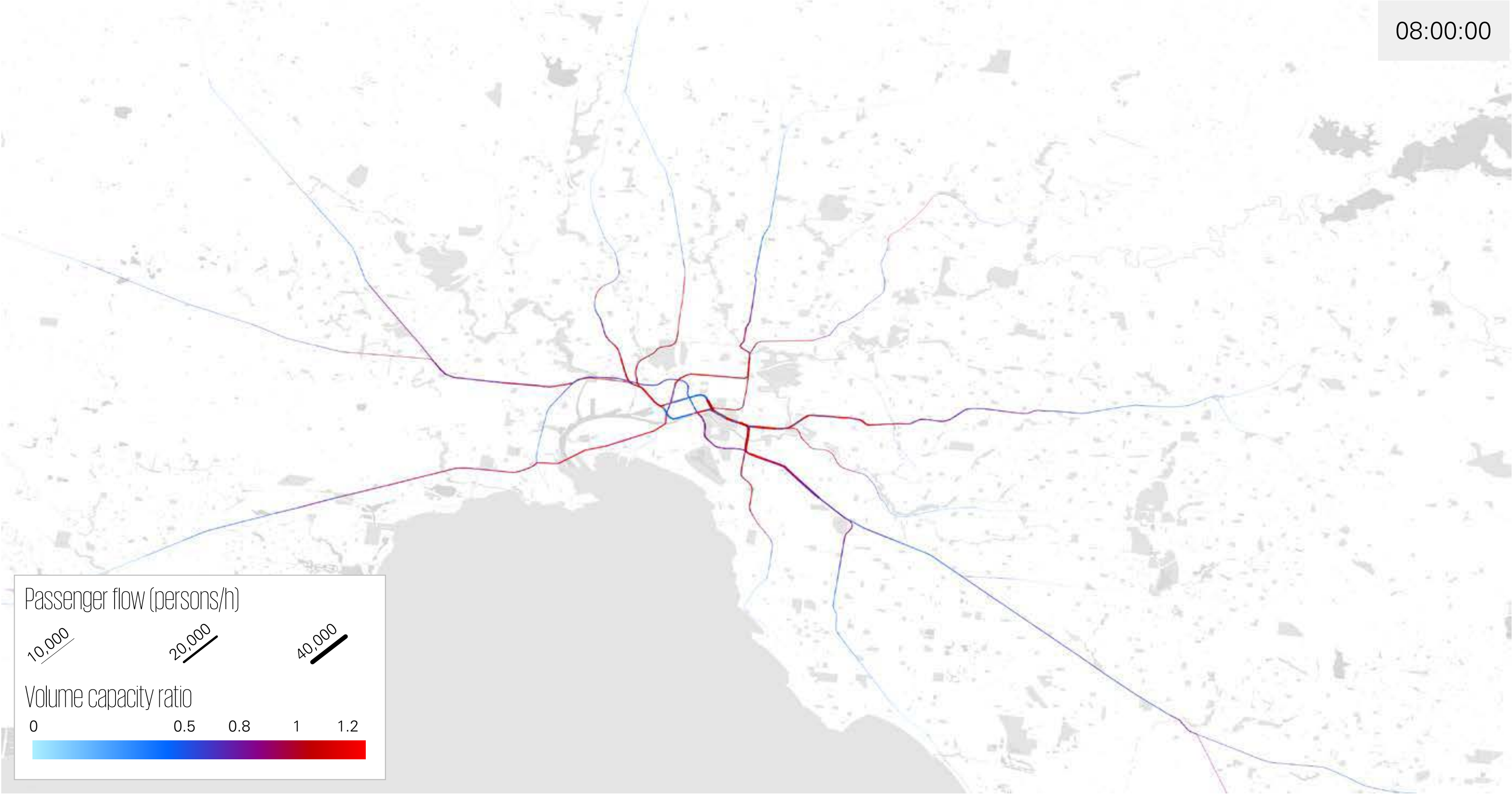
Volume capacity ratio, rail: Mix of scenarios, Expanded land use, morning peak

Source: MABM

Volume capacity ratio, rail: Private drive, Centralised land use, morning peak

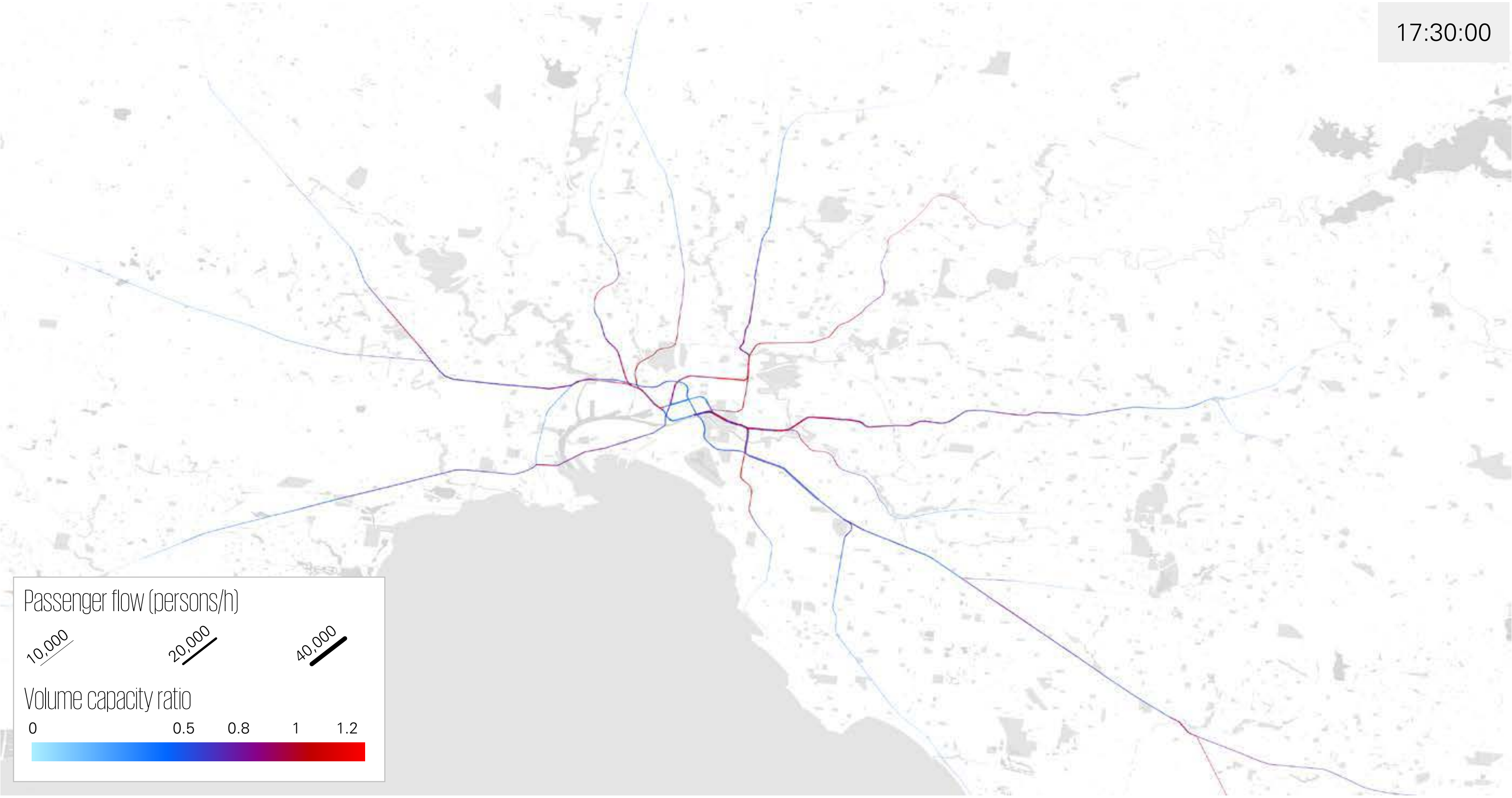
Source: MABM

Volume capacity ratio, rail: Private drive, Expanded land use, morning peak



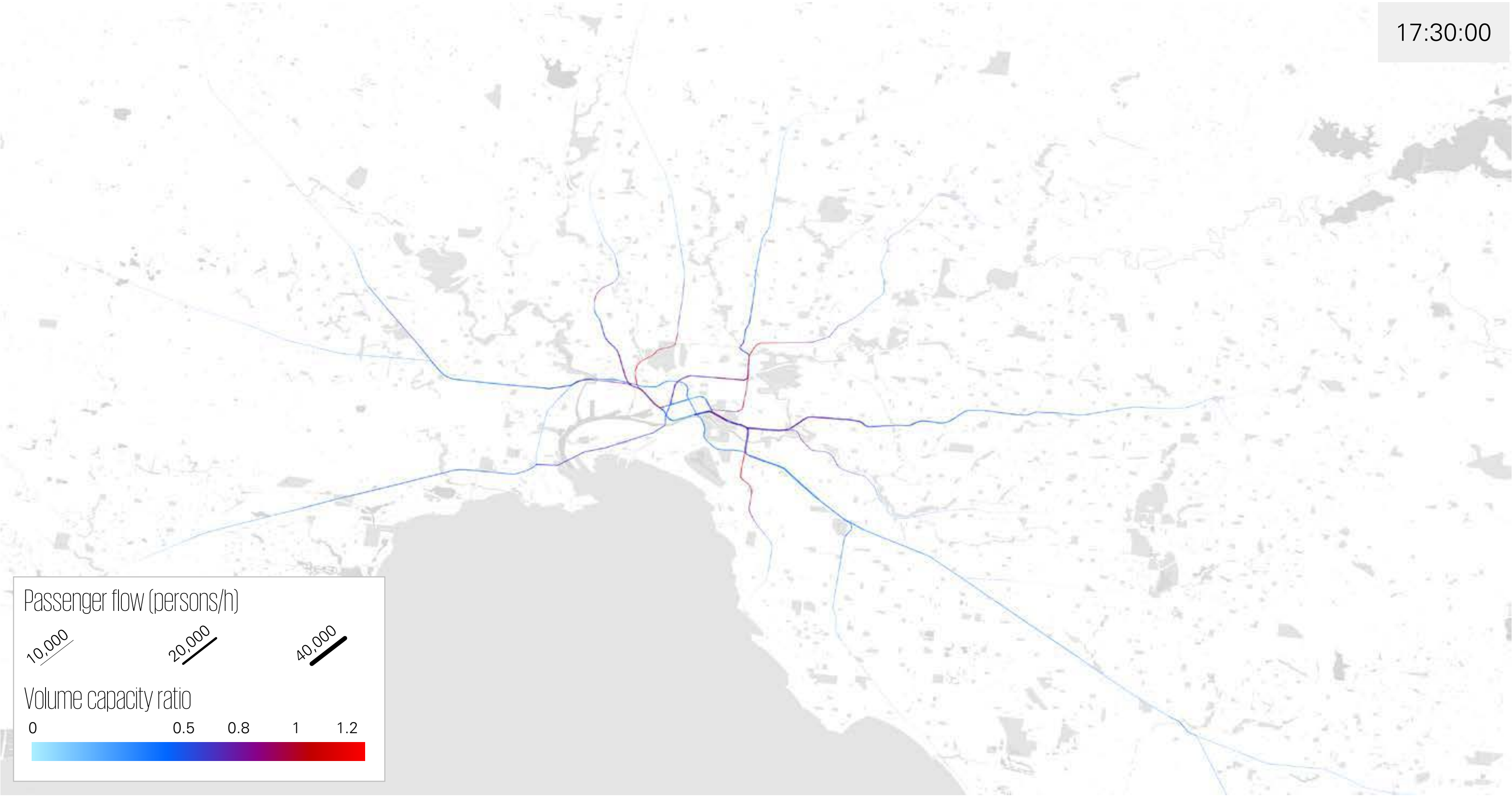
Source: MABM

Volume capacity ratio, rail: Dead end, afternoon peak



Source: MABM

Volume capacity ratio, rail: Private drive, afternoon peak

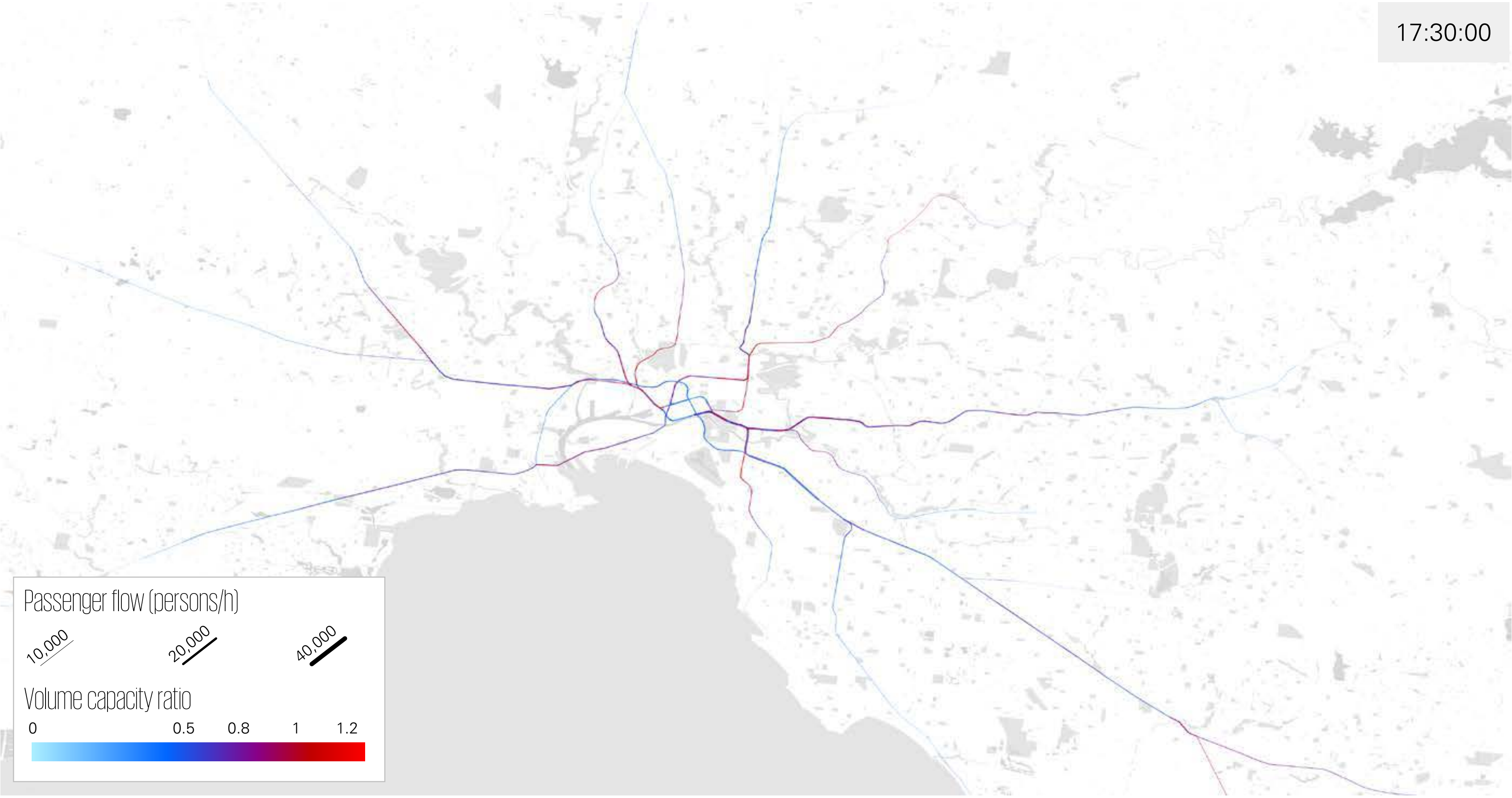


Source: MABM

Volume capacity ratio, rail: Fleet street, afternoon peak

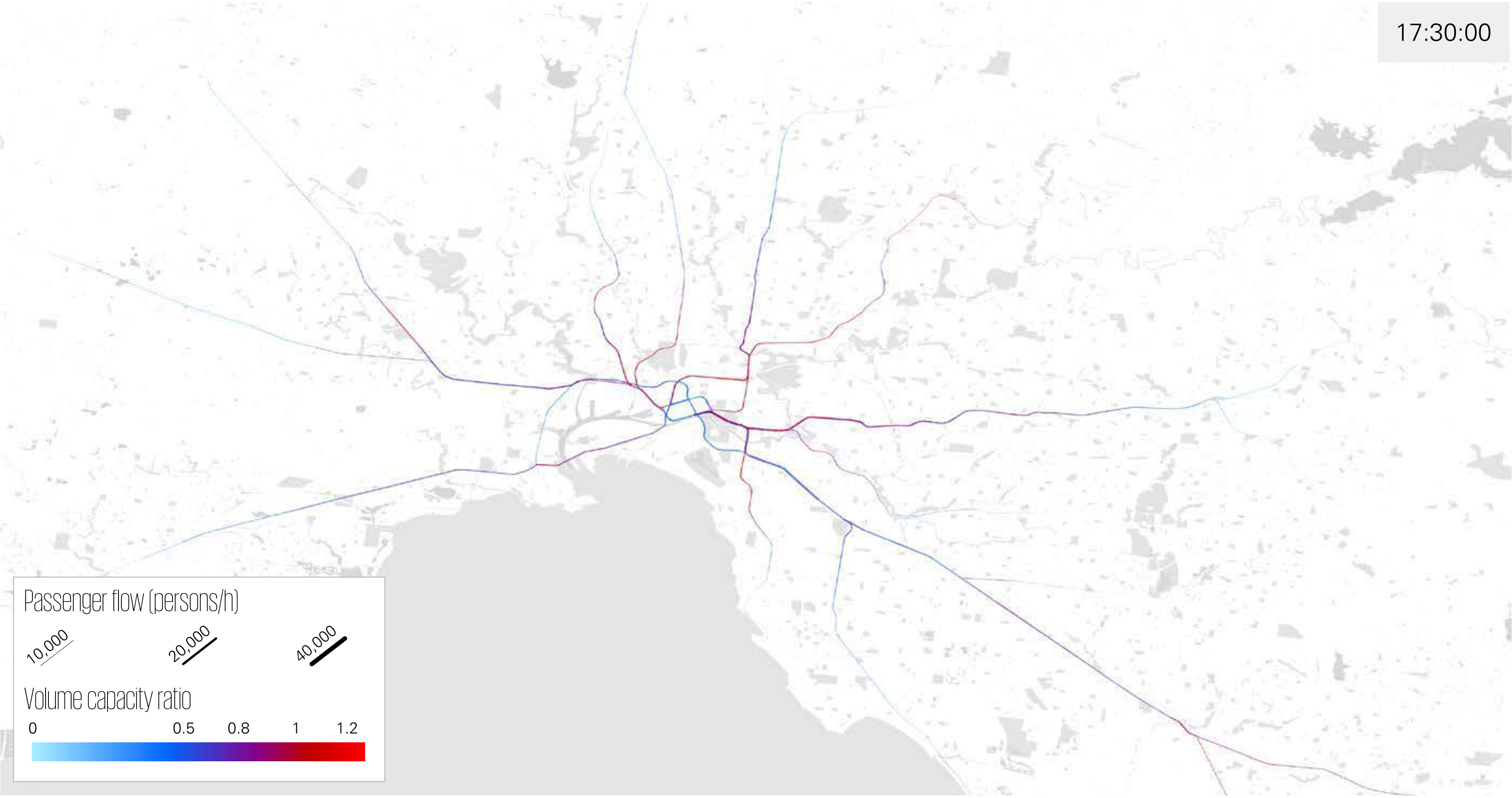
Source: MABM

Volume capacity ratio, rail: Slow lane, afternoon peak



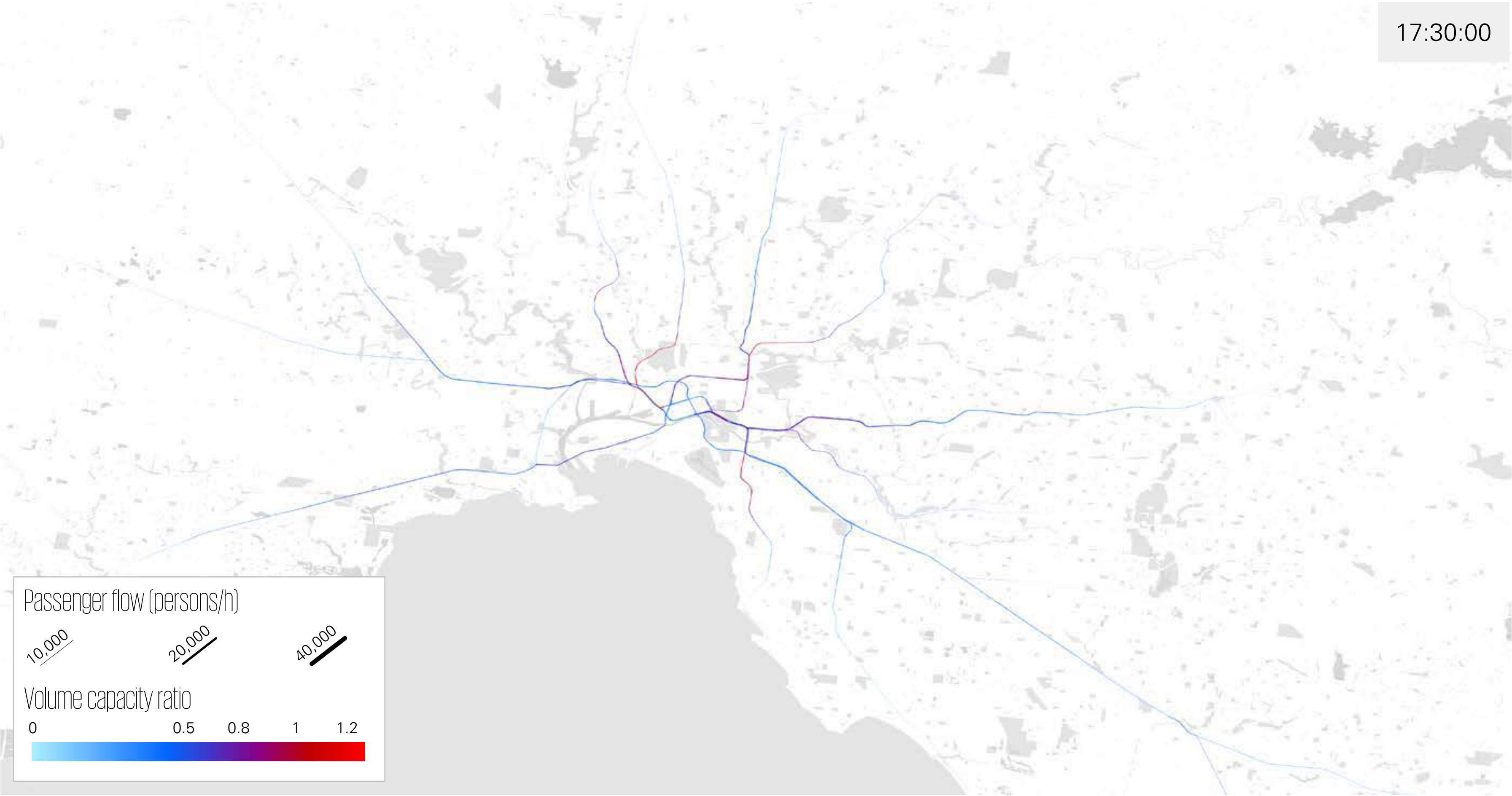
Source: MABM

Volume capacity ratio, rail: Electric avenue, afternoon peak



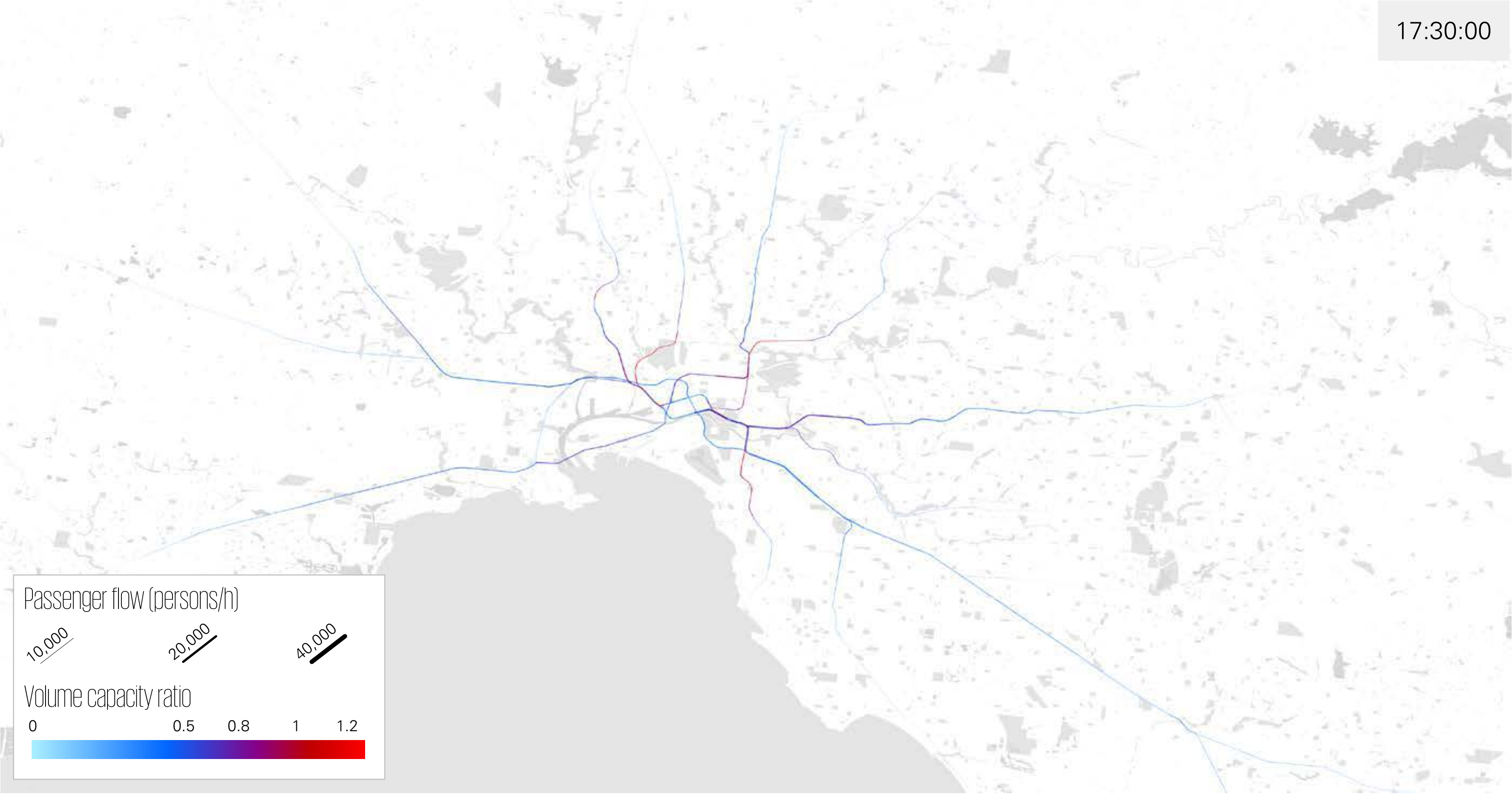
Source: MABM

Volume capacity ratio, rail: Hydrogen highway, afternoon peak



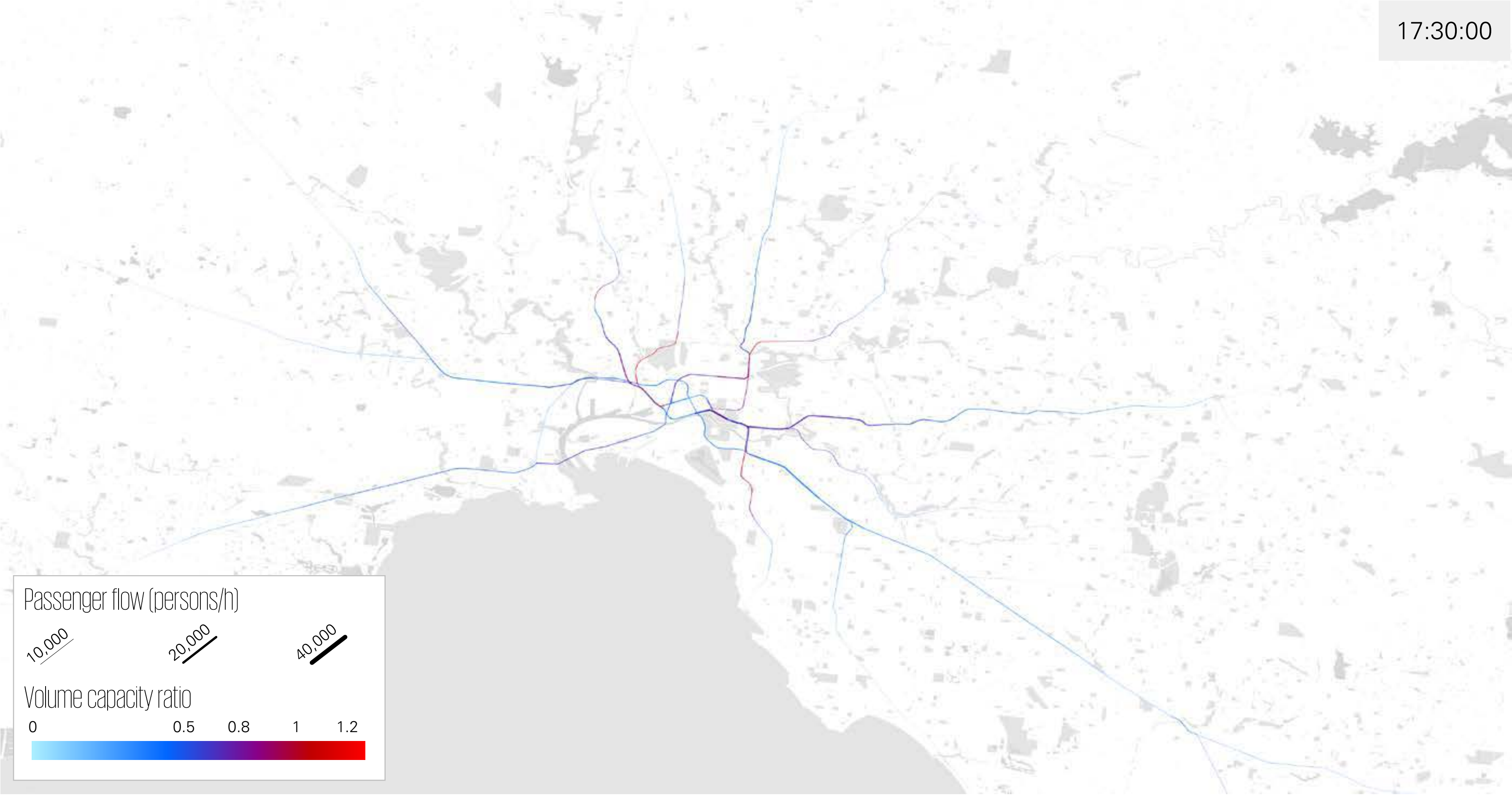
Source: MABM

Volume capacity ratio, rail: Private drive, No empty running, afternoon peak



Source: MABM

Volume capacity ratio, rail: Private drive, Low MUTT, afternoon peak

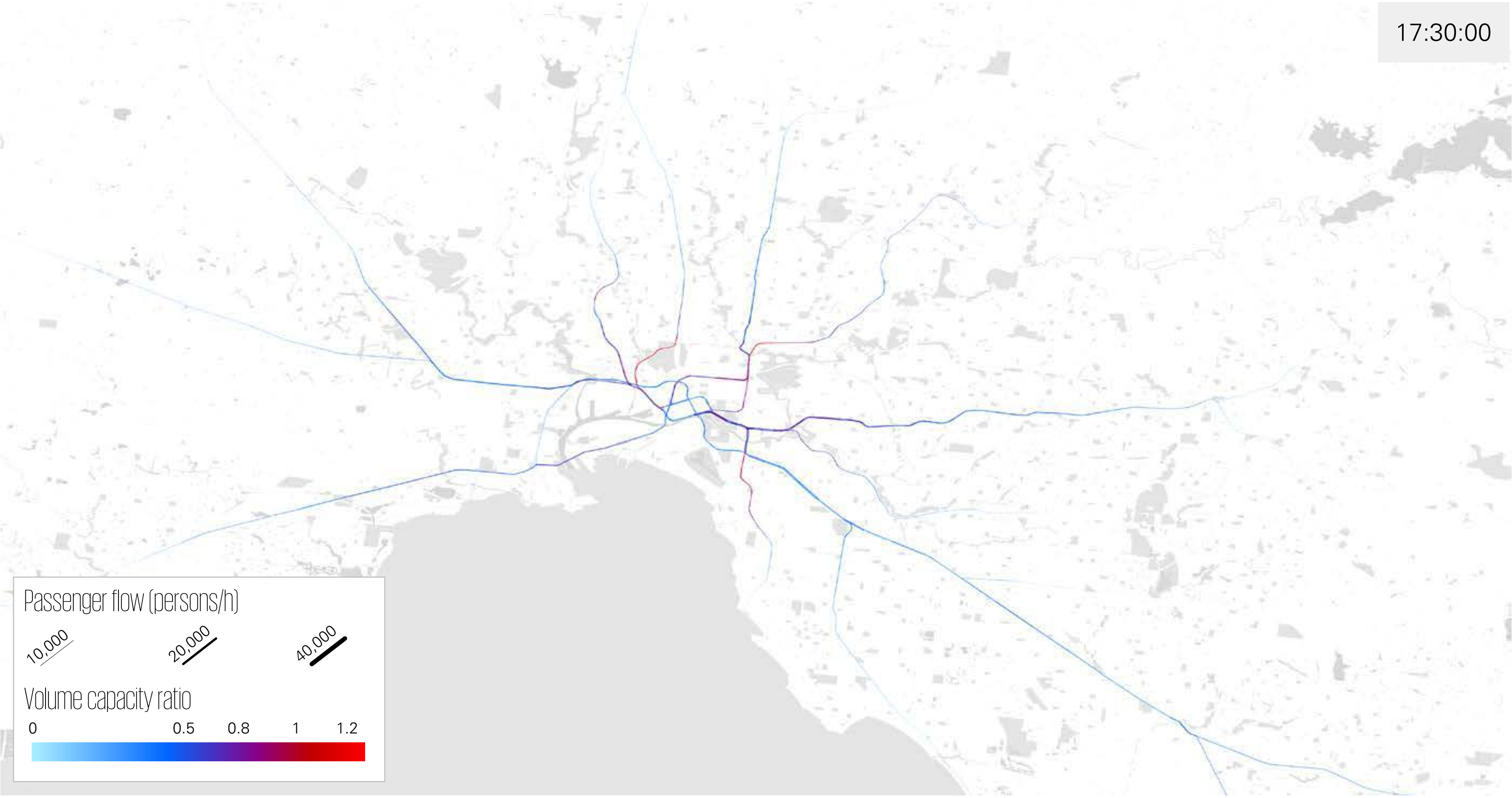


Source: MABM

Volume capacity ratio, rail: Private drive, Low flow, afternoon peak

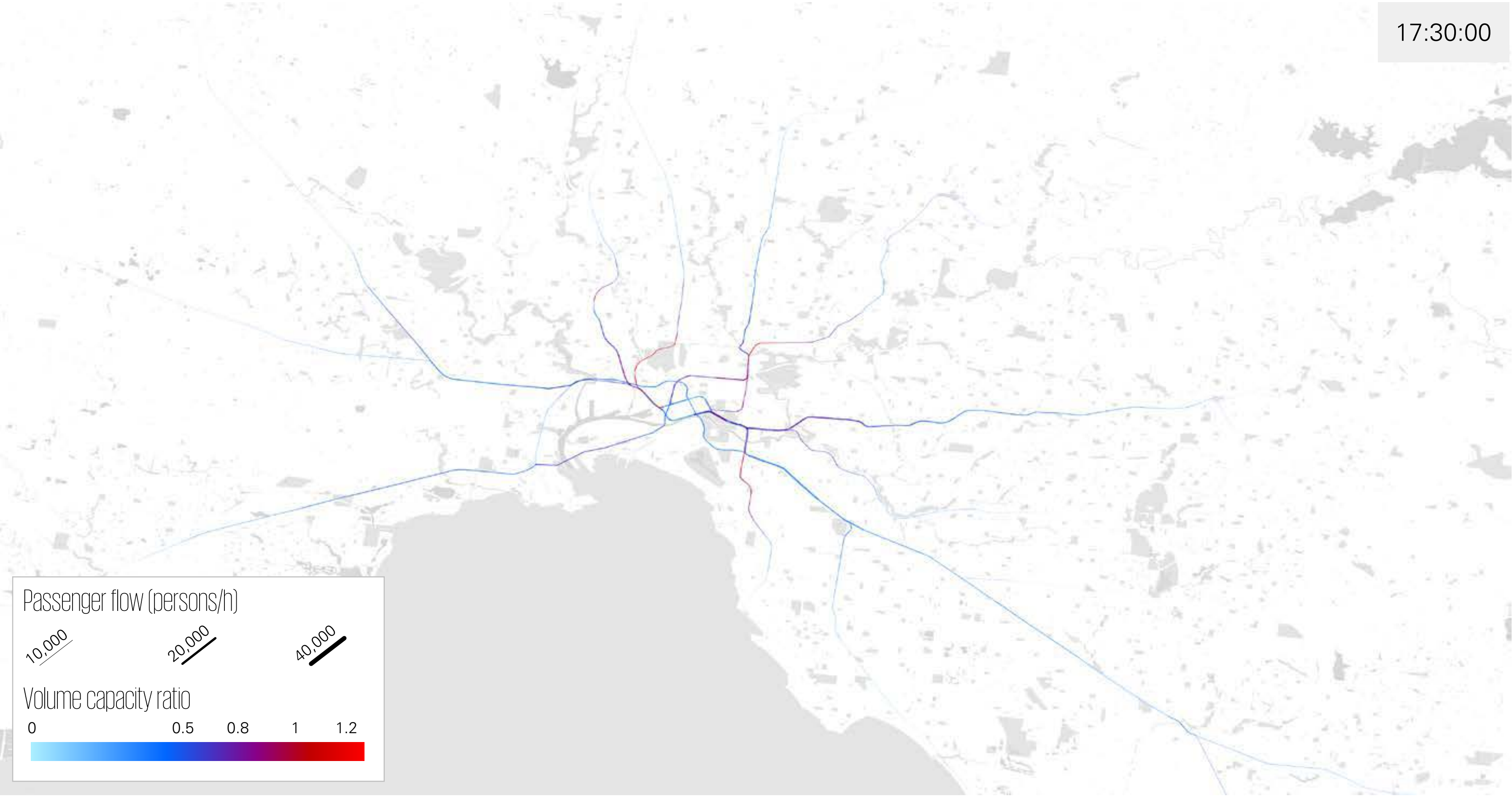
Source: MABM

Volume capacity ratio, rail: Private drive, No mode shift, afternoon peak



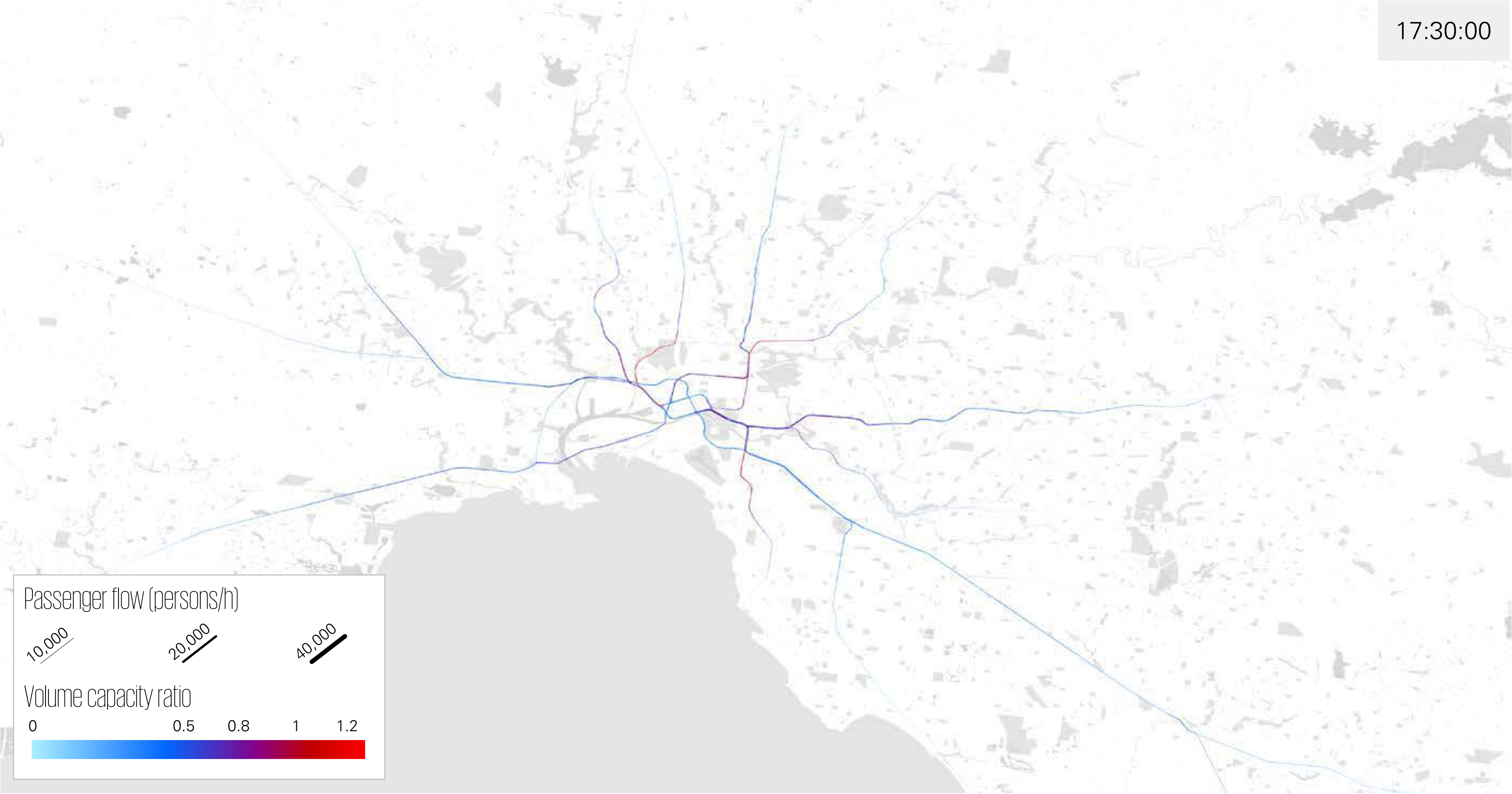
Source: MABM

Volume capacity ratio, rail: Private drive, Area based charge, afternoon peak



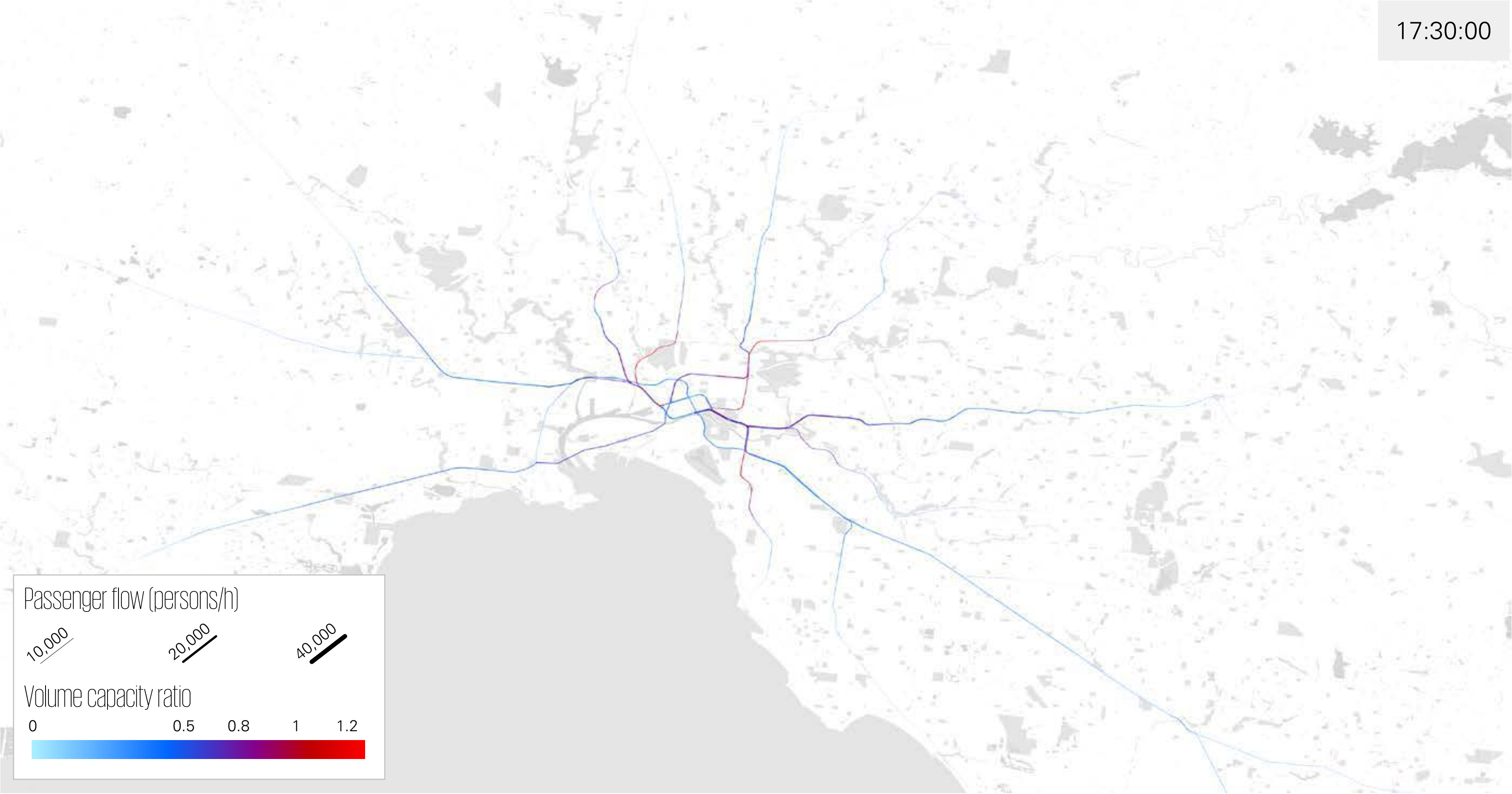
Source: MABM

Volume capacity ratio, rail: Private drive, Distance based charge, afternoon peak



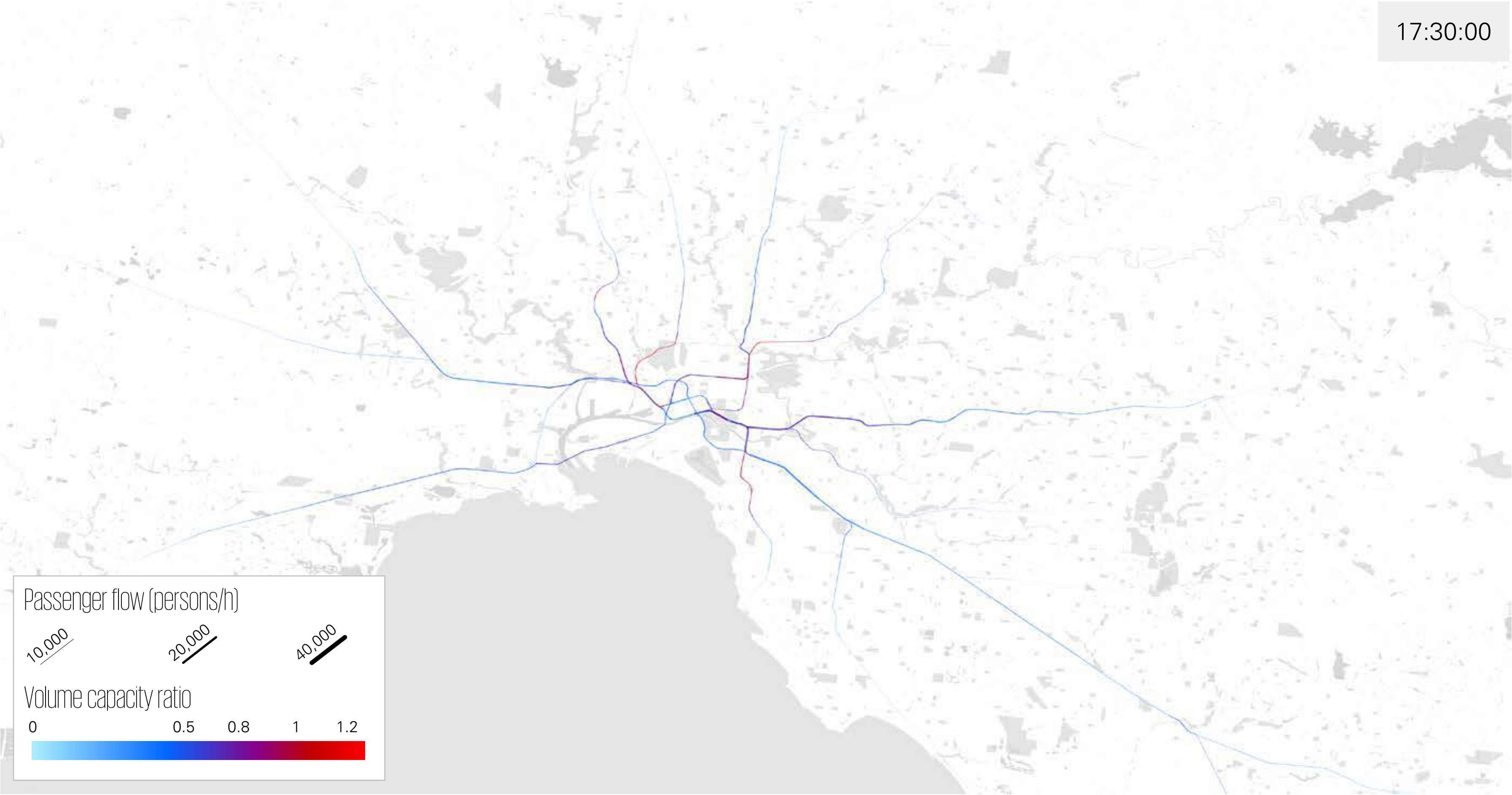
Source: MABM

Volume capacity ratio, rail: Private drive, Freight to night, afternoon peak



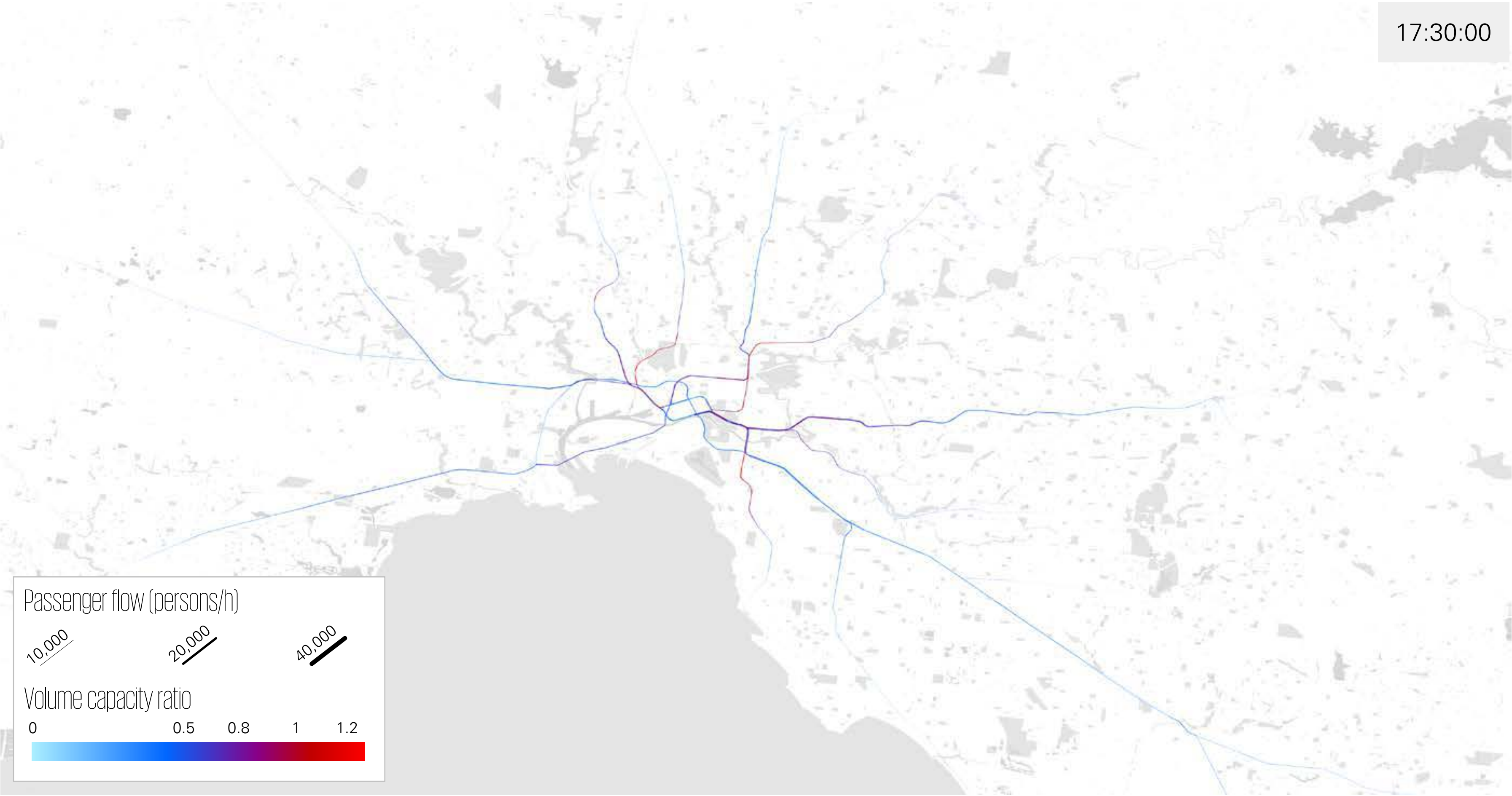
Source: MABM

Volume capacity ratio, rail: Private drive, Expanded markets, afternoon peak



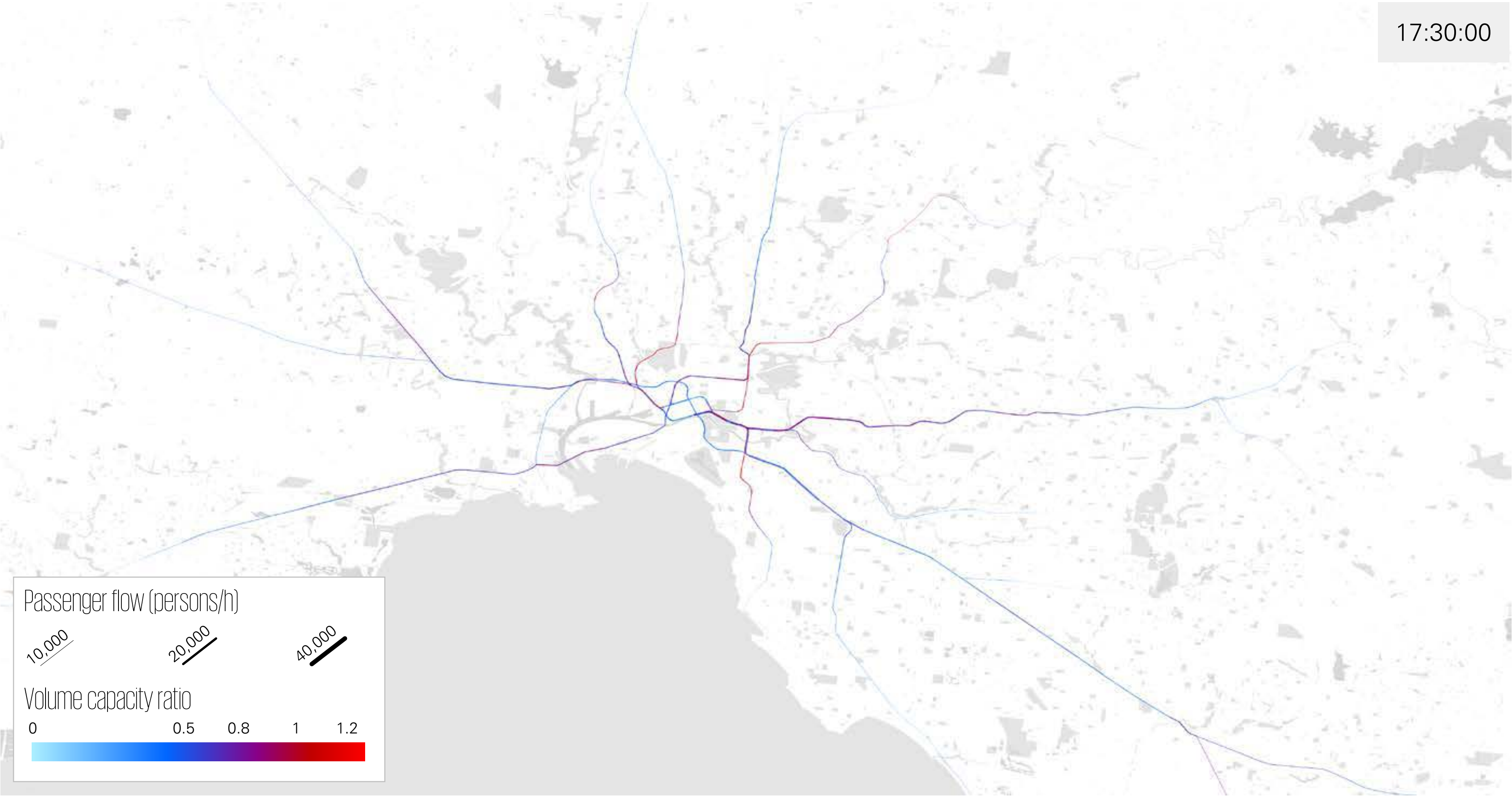
Source: MABM

Volume capacity ratio, rail: Private drive, Station drop-off and pick-up, afternoon peak



Source: MABM

Volume capacity ratio, rail: Fleet street, Subscription fare, afternoon peak



Source: MABM

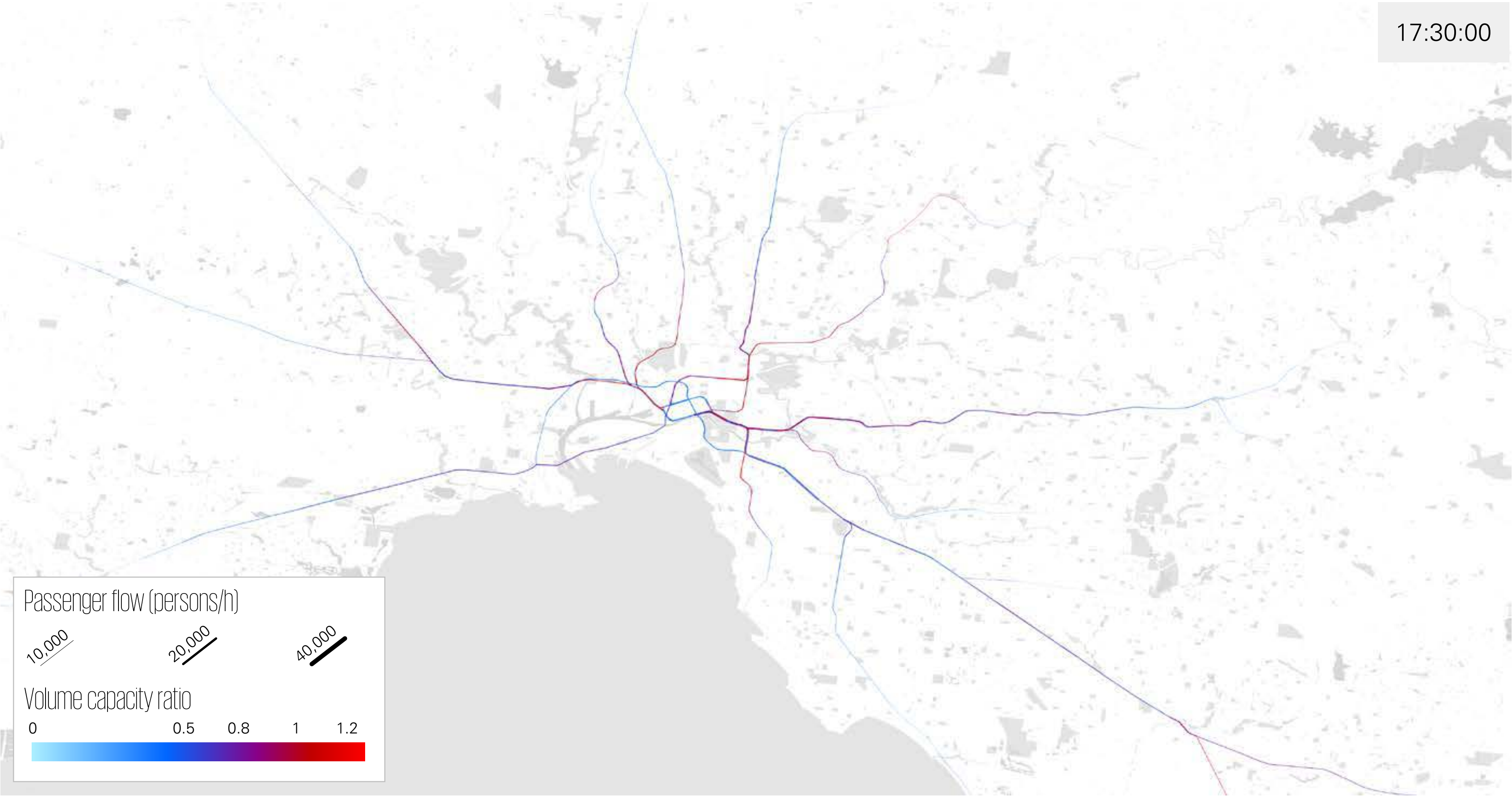
Volume capacity ratio, rail: Fleet street, Low MUTT, afternoon peak

Source: MABM

Volume capacity ratio, rail: Fleet street, Low flow, afternoon peak

Source: MABM

Volume capacity ratio, rail: Fleet street, No mode shift, afternoon peak



Source: MABM

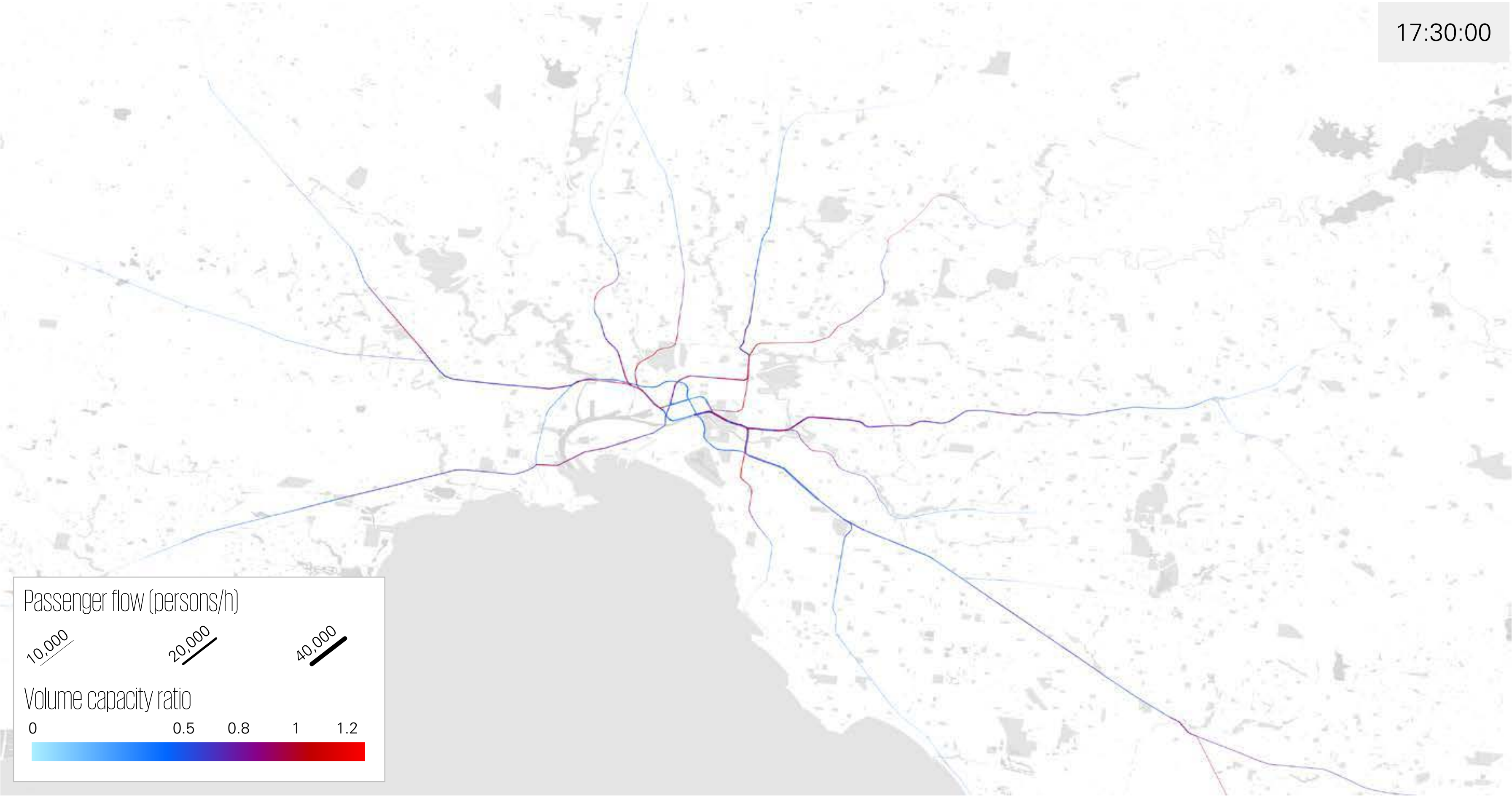
Volume capacity ratio, rail: Fleet street, Calibrated fleet size, afternoon peak

Source: MABM

Volume capacity ratio, rail: Fleet Street, No new (pre-construction) major road projects, afternoon peak

Source: MABM

Volume capacity ratio, rail: Slow lane, Low MUTT, afternoon peak



Source: MABM

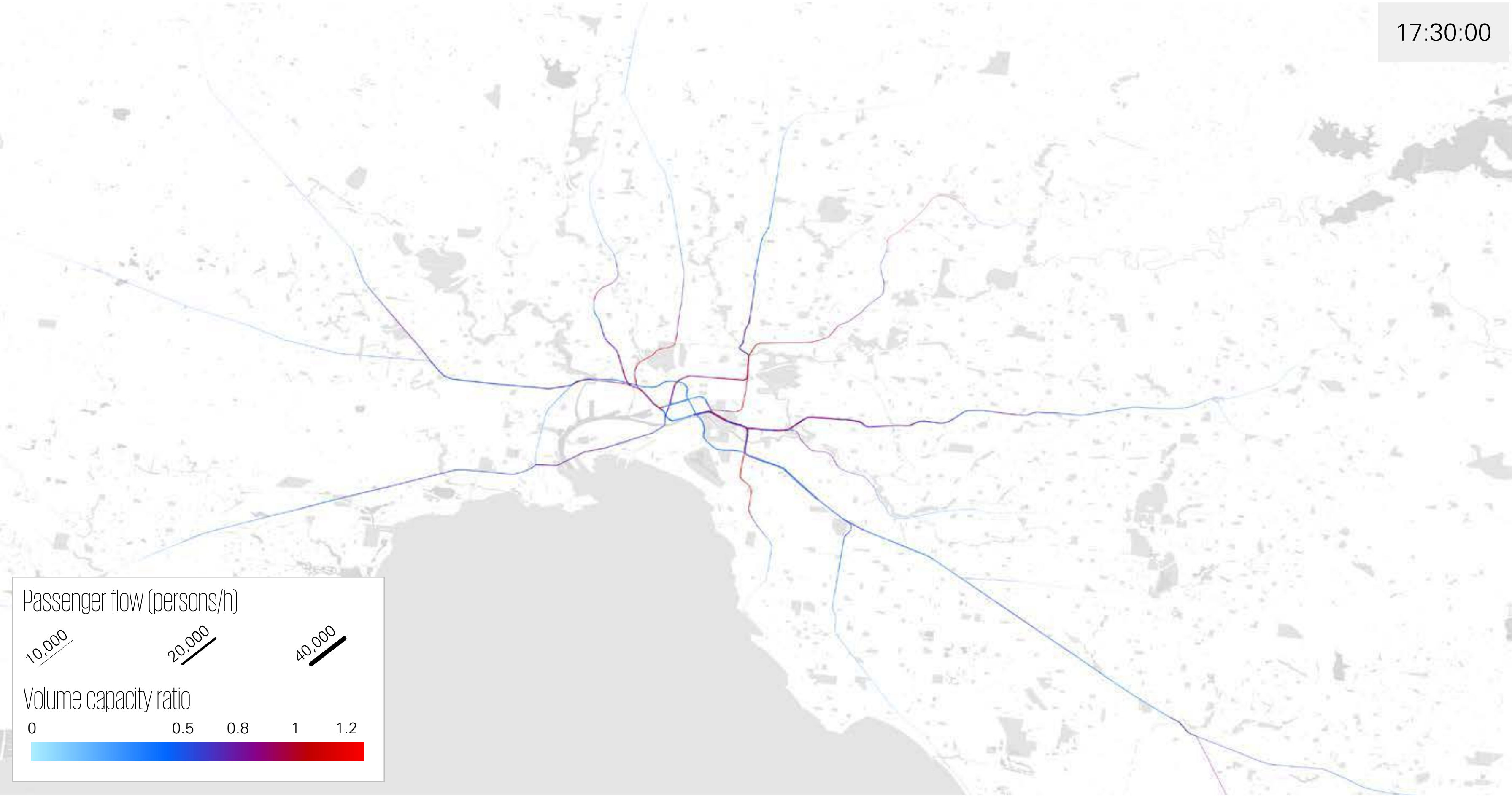
Volume capacity ratio, rail: Slow lane, Low flow, afternoon peak

Source: MABM

Volume capacity ratio, rail: Slow lane, No mode shift, afternoon peak

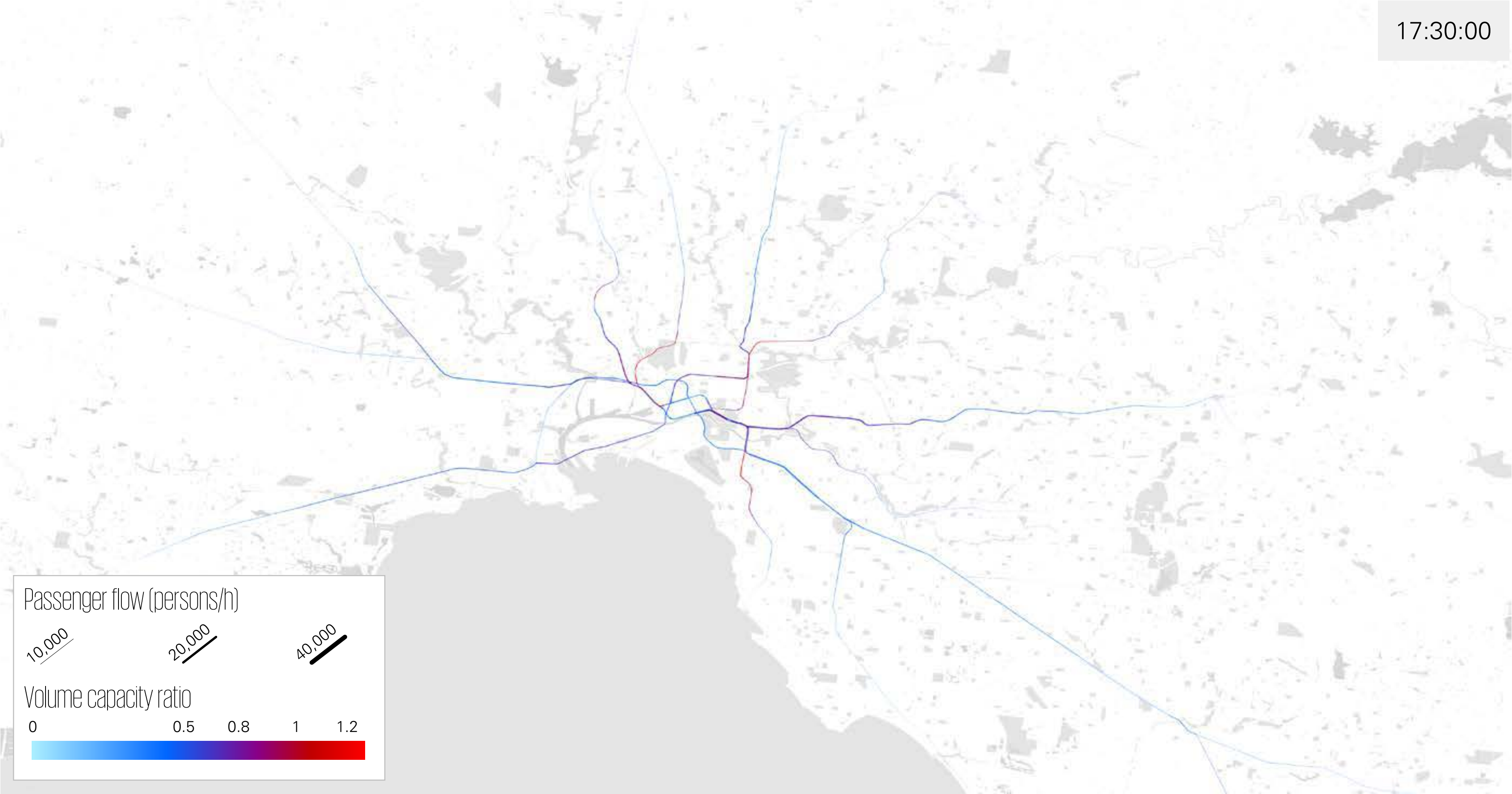
Source: MABM

Volume capacity ratio, rail: Private slow lane, Slow lane, afternoon peak



Source: MABM

Volume capacity ratio, rail: Hydrogen highway, No empty running, afternoon peak

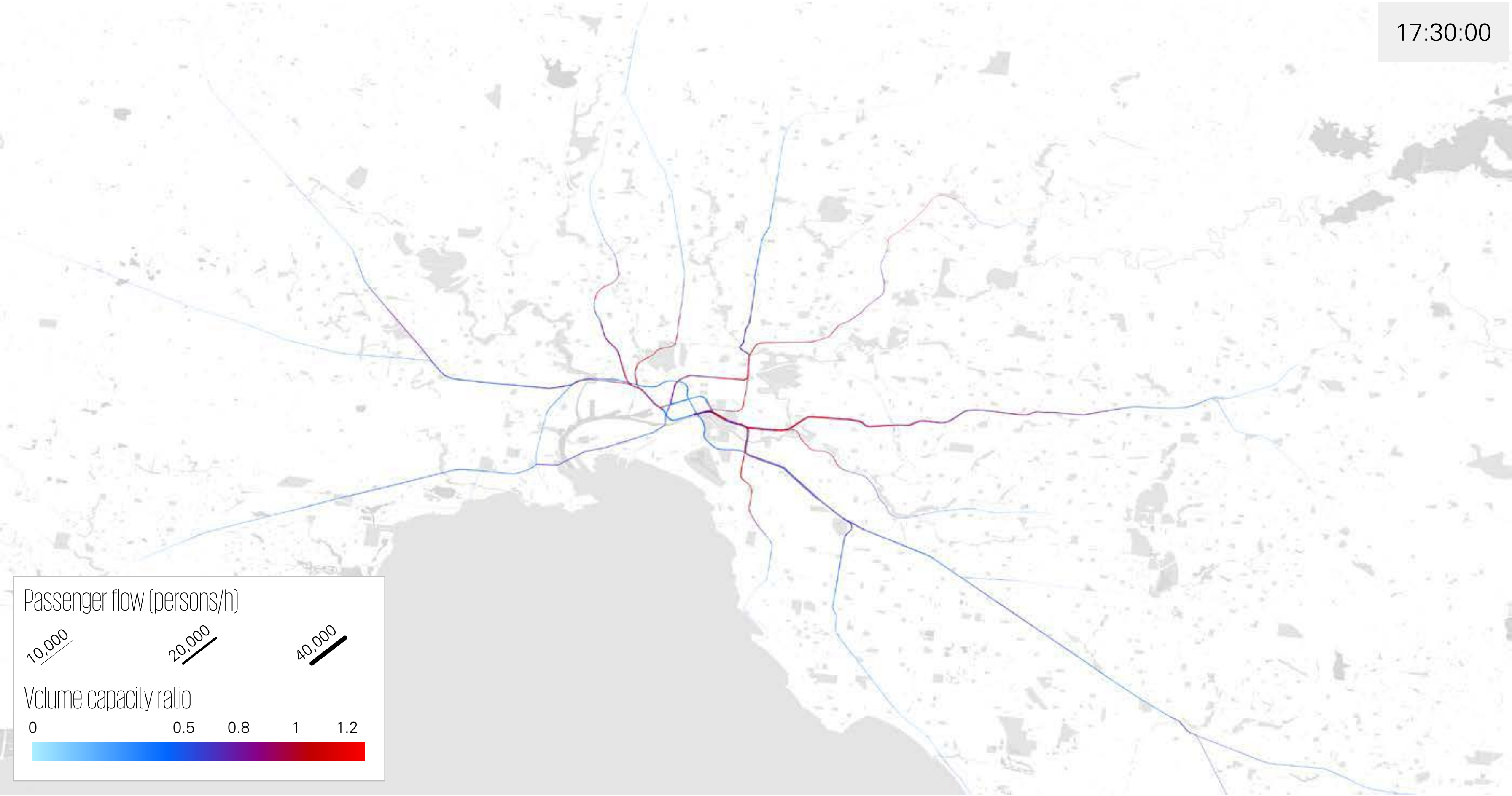


Source: MABM

Volume capacity ratio, rail: Mix of scenarios, afternoon peak

Source: MABM

Volume capacity ratio, rail: Mix of scenarios, Centralised land use, afternoon peak

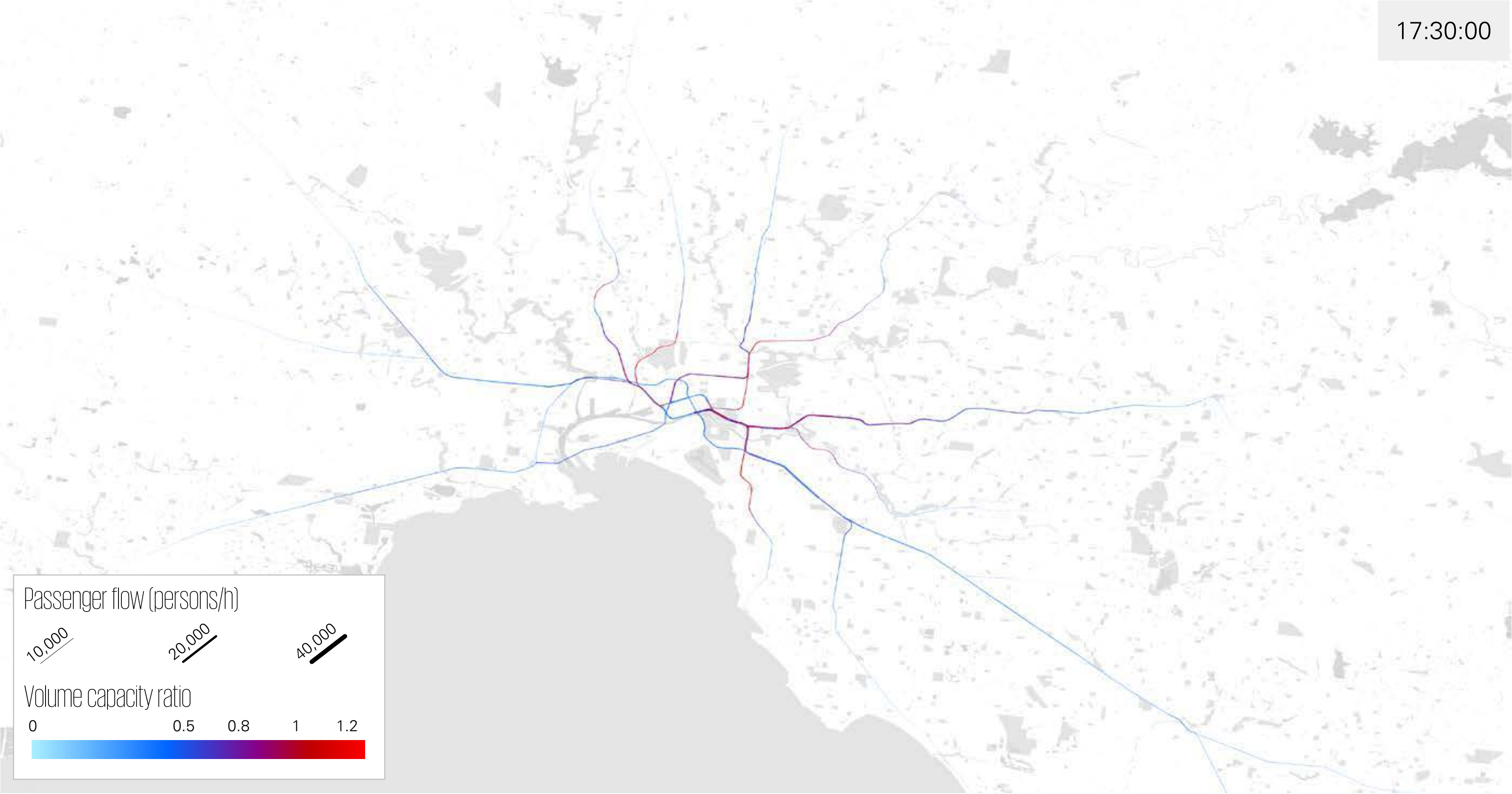


Source: MABM

Volume capacity ratio, rail: Mix of scenarios, Expanded land use, afternoon peak

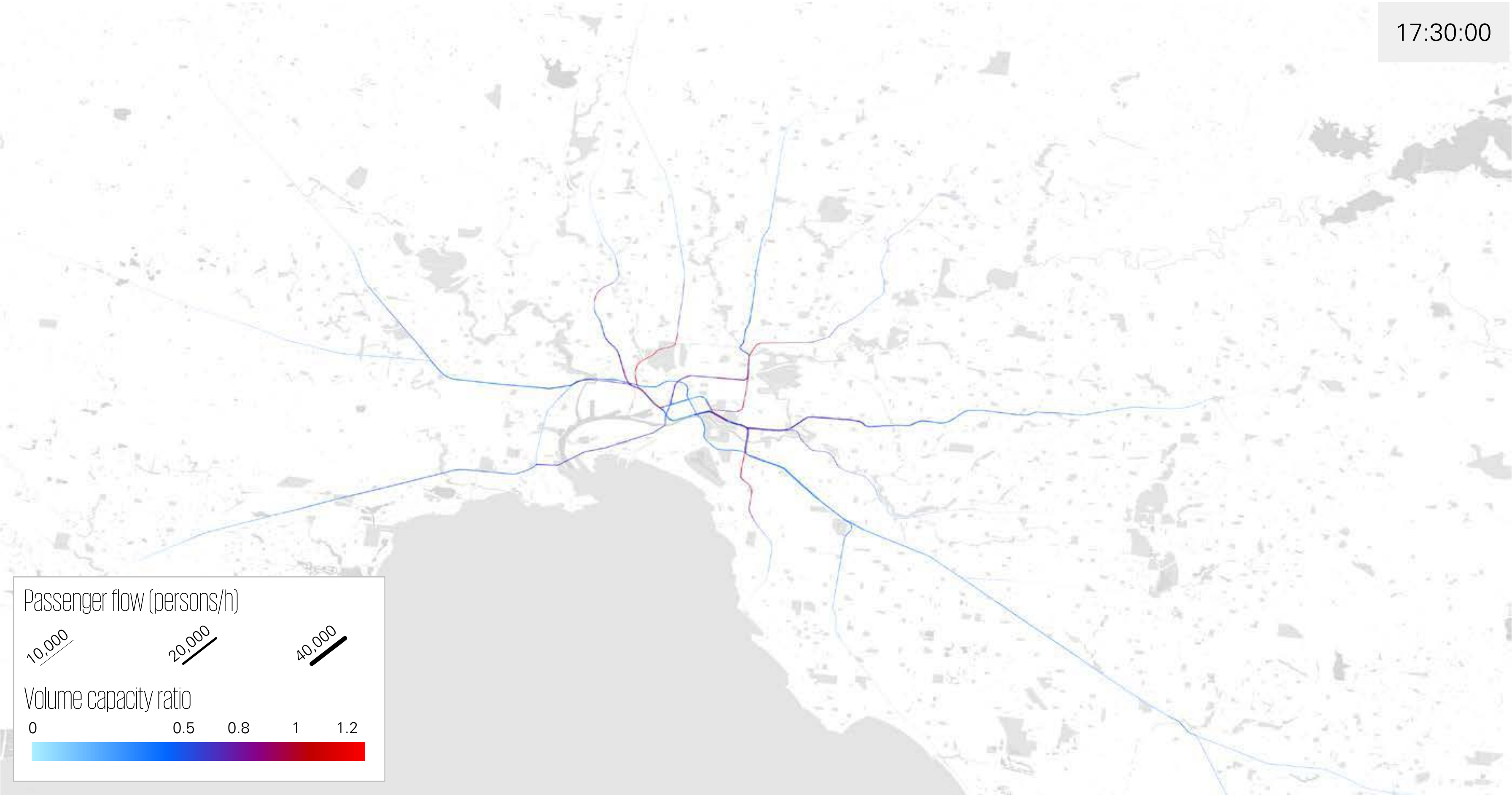
Source: MABM

Volume capacity ratio, rail: Private drive, Centralised land use, afternoon peak



Source: MABM

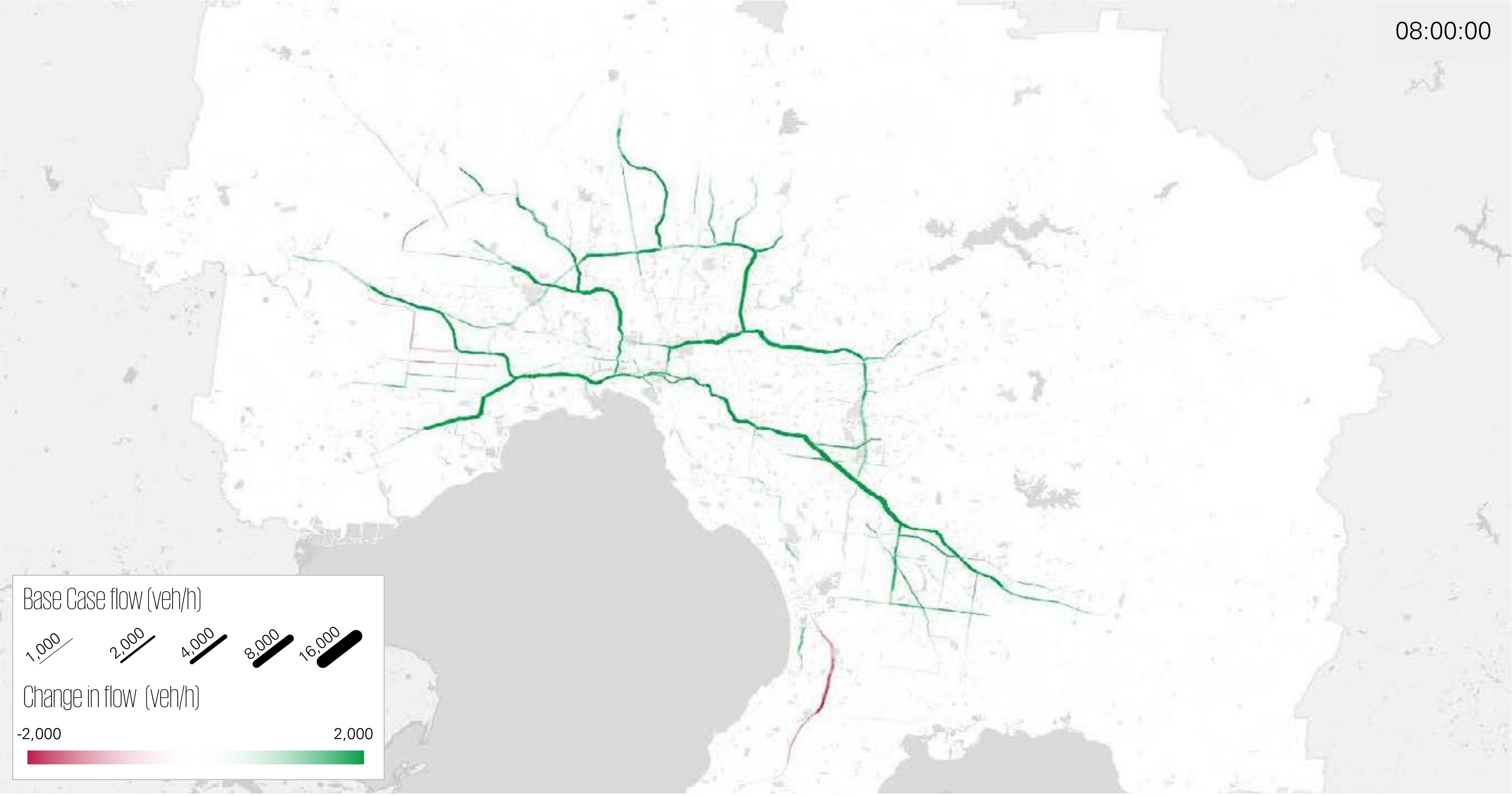
Volume capacity ratio, rail: Private drive, Expanded land use, afternoon peak



Source: MABM

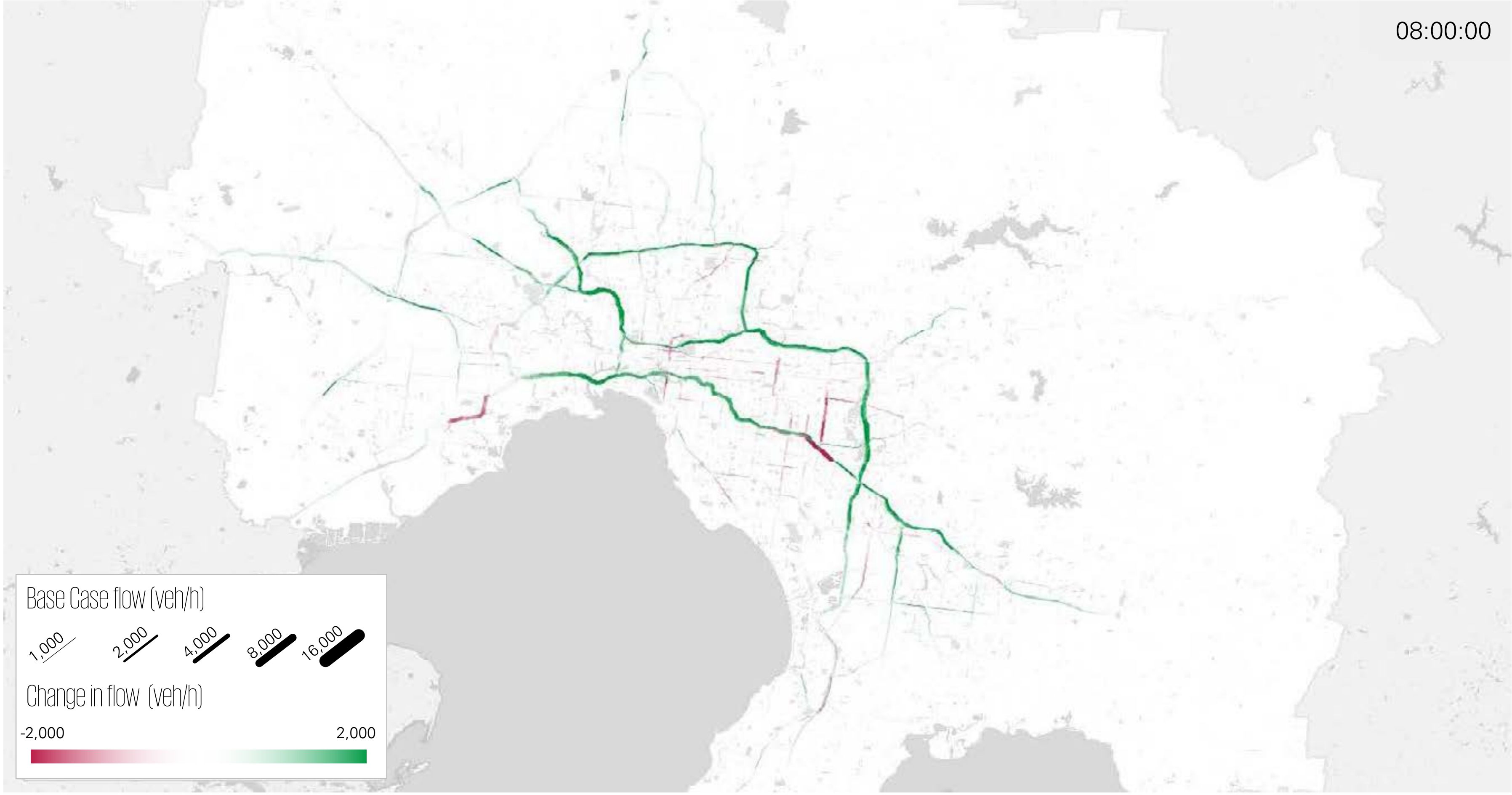
Appendix E: Vehicle flow plots

Change in flow: Private drive vs Dead end, morning peak



Source: MABM

Change in flow: Fleet street vs Dead end, morning peak



Source: MABM

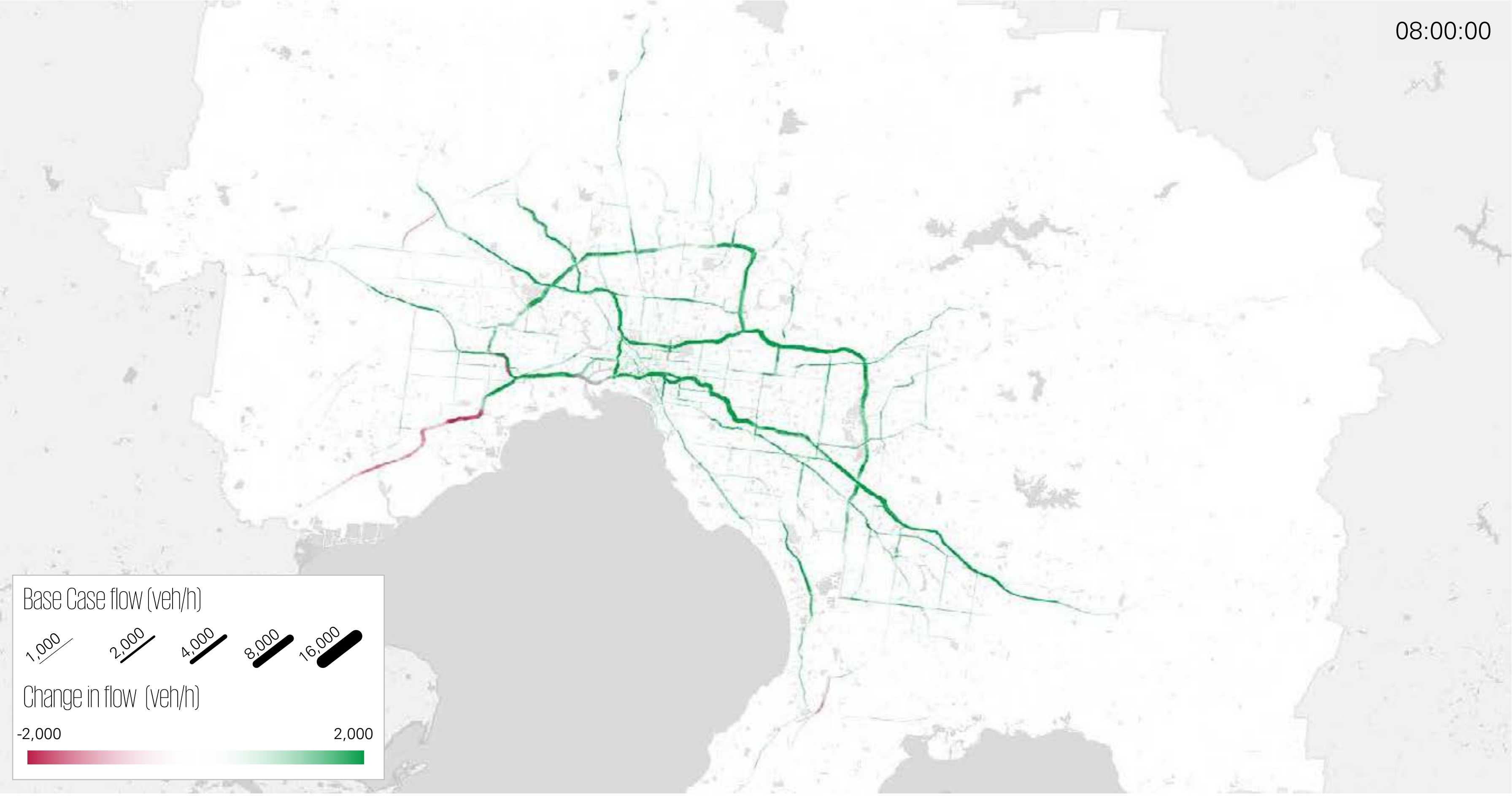
Change in flow: Slow lane vs Dead end, morning peak

Source: MABM

Change in flow: Electric avenue vs Dead end, morning peak

Source: MABM

Change in flow: Hydrogen highway vs Dead end, morning peak



Source: MABM

Change in flow: Private drive, No empty running vs Private drive, morning peak

Source: MABM

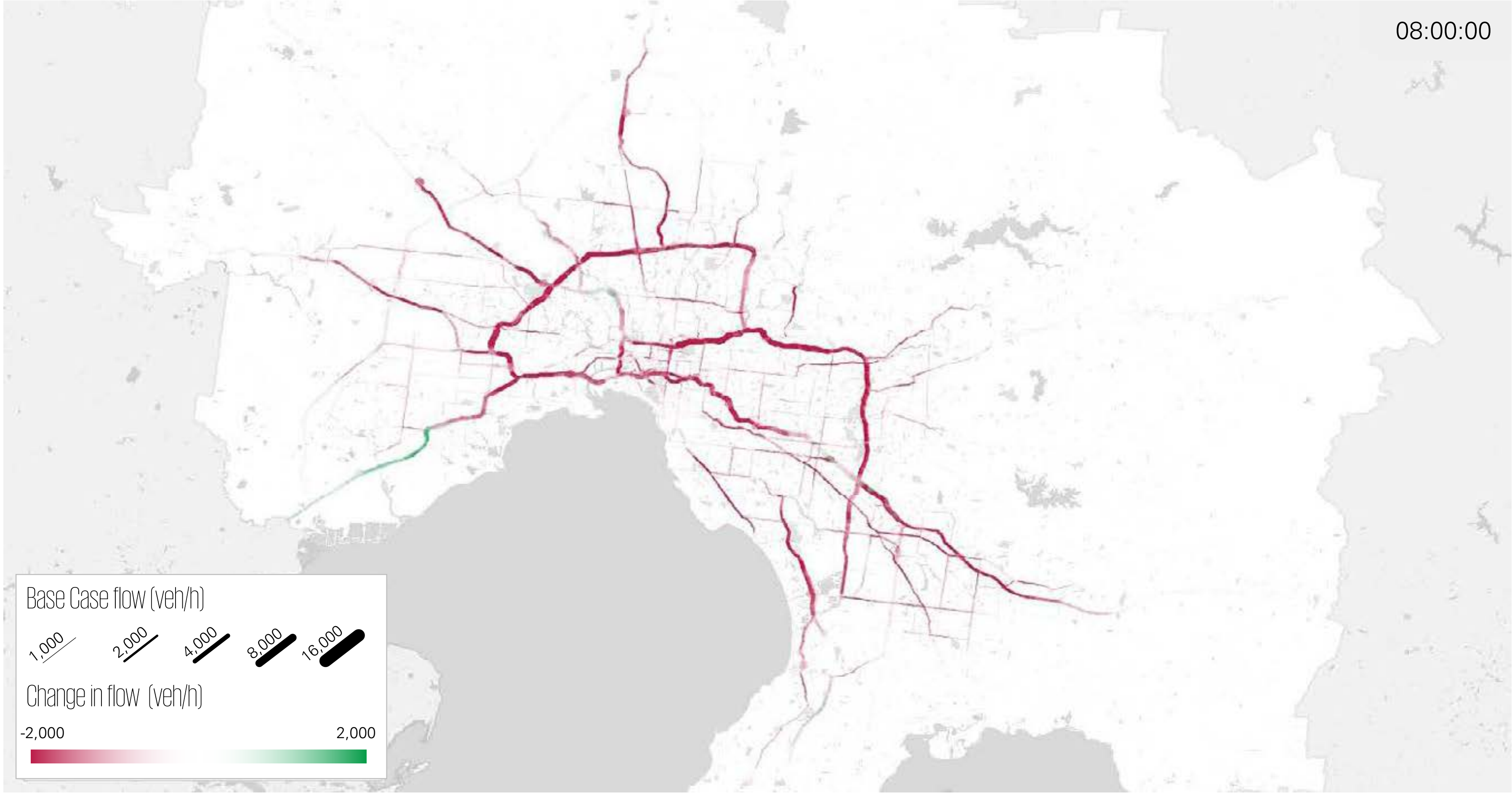
Change in flow: Private drive, Low MUTT vs Private drive, No empty running morning peak

Source: MABM

Change in flow: Private drive, Low flow vs Private drive, No empty running, morning peak

Source: MABM

Change in flow: Private drive, No mode shift vs Private drive, No empty running, morning peak

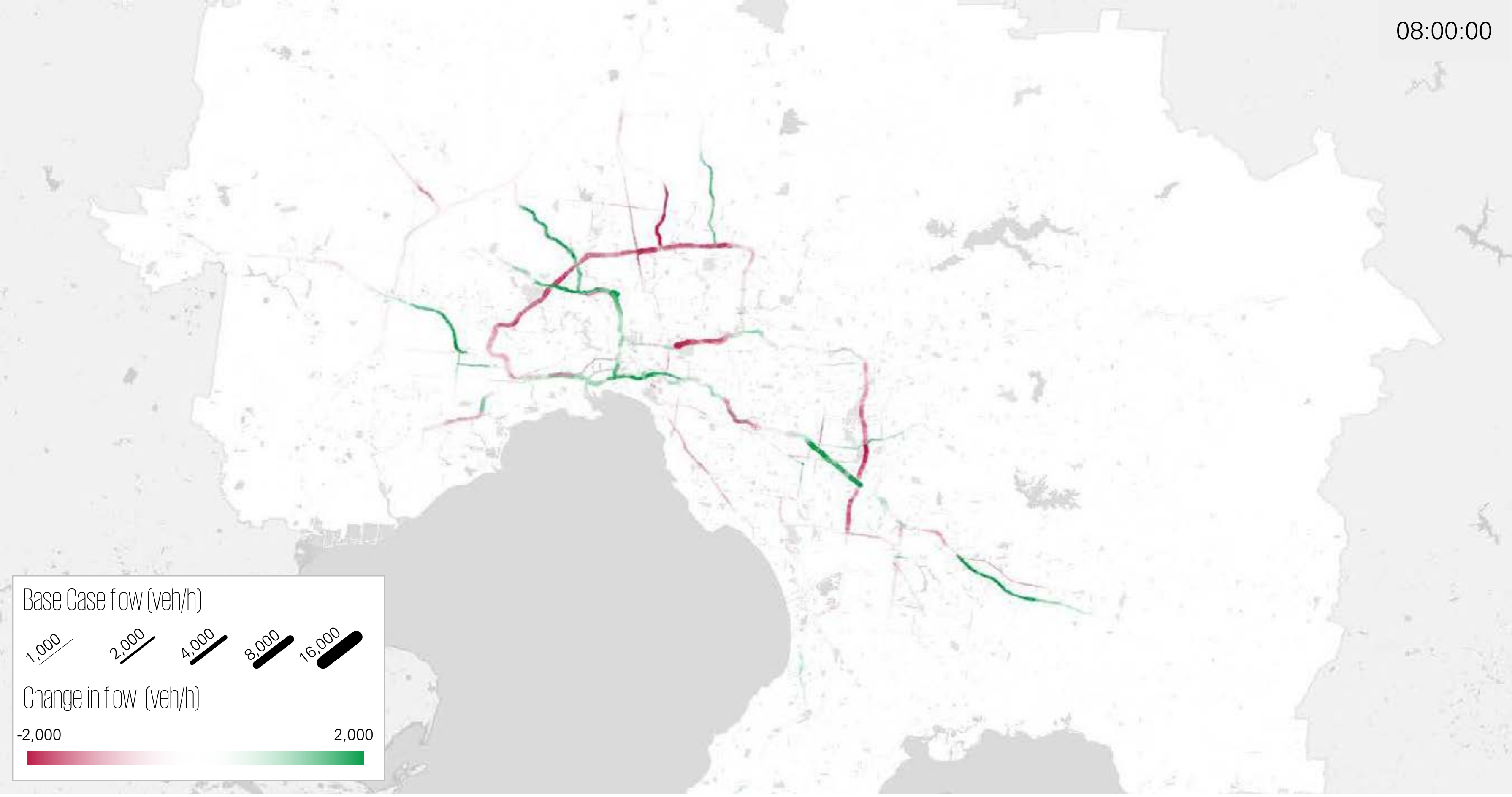


Source: MABM

Change in flow: Private drive, Area based charge vs Private drive, morning peak

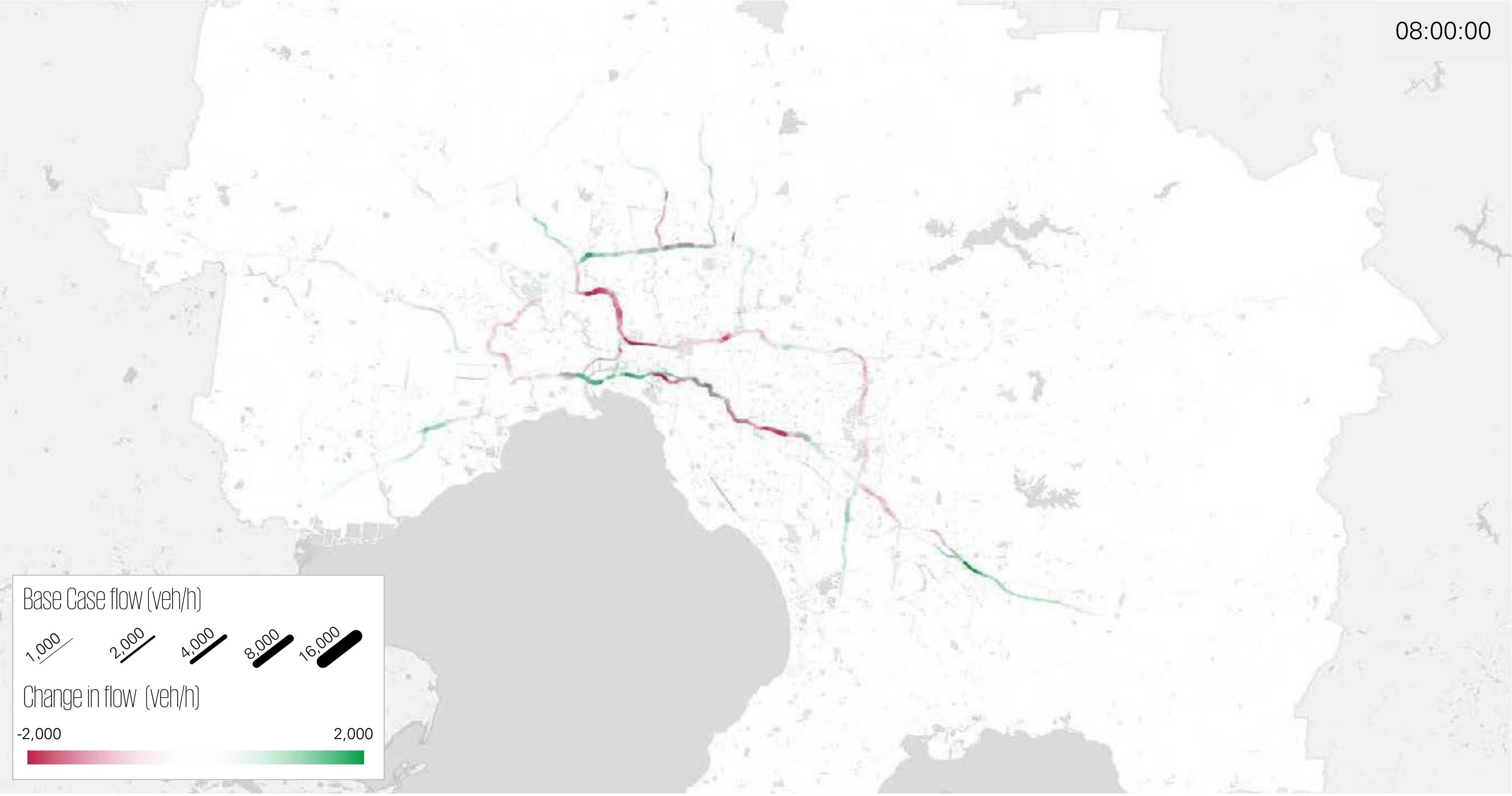
Source: MABM

Change in flow: Private drive, Distance based charge vs Private drive, morning peak



Source: MABM

Change in flow: Private drive, Freight to night vs Private drive, morning peak

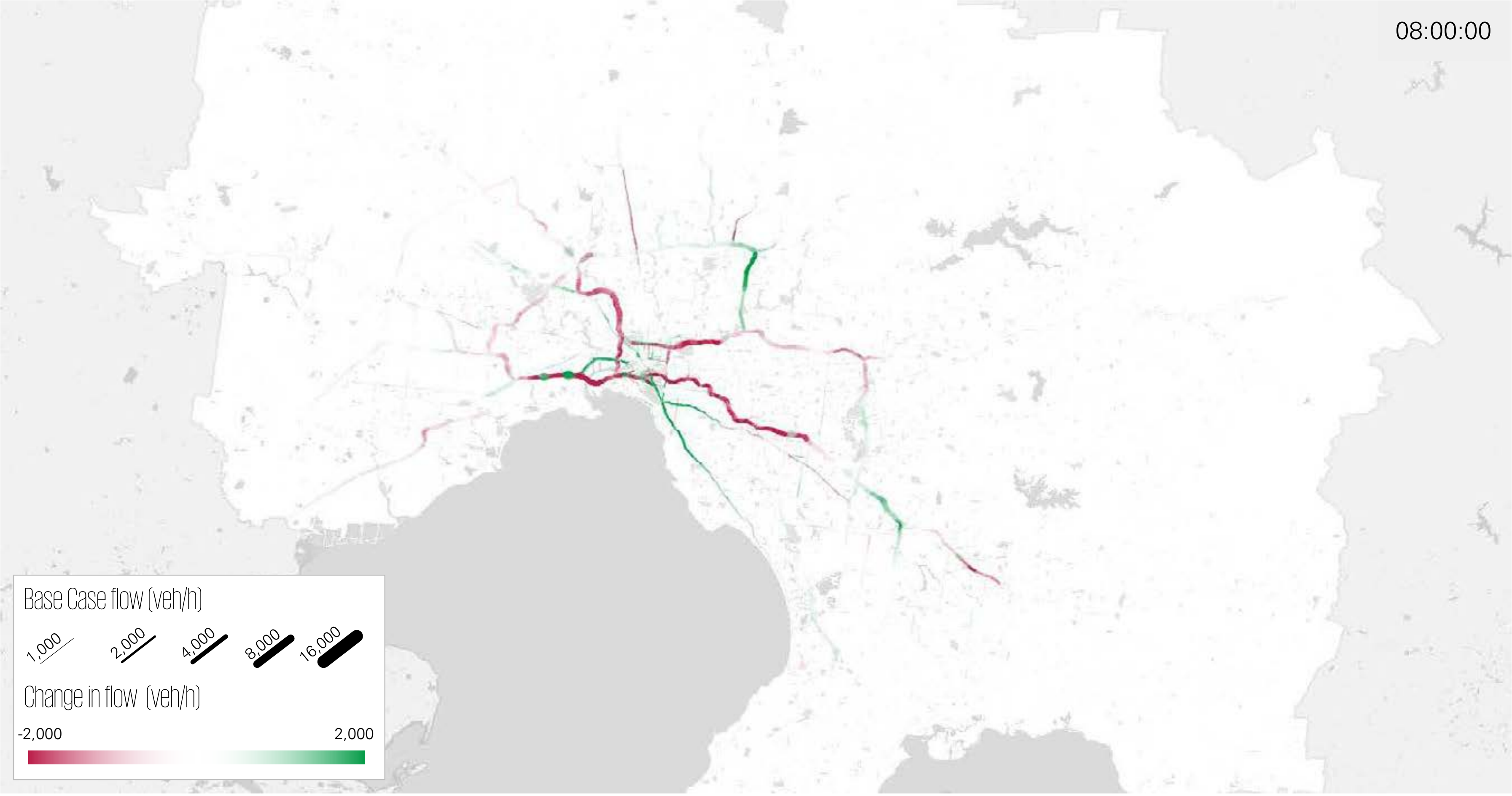


Source: MABM

Change in flow: Private drive, Expanded markets vs Private drive, No empty running, morning peak

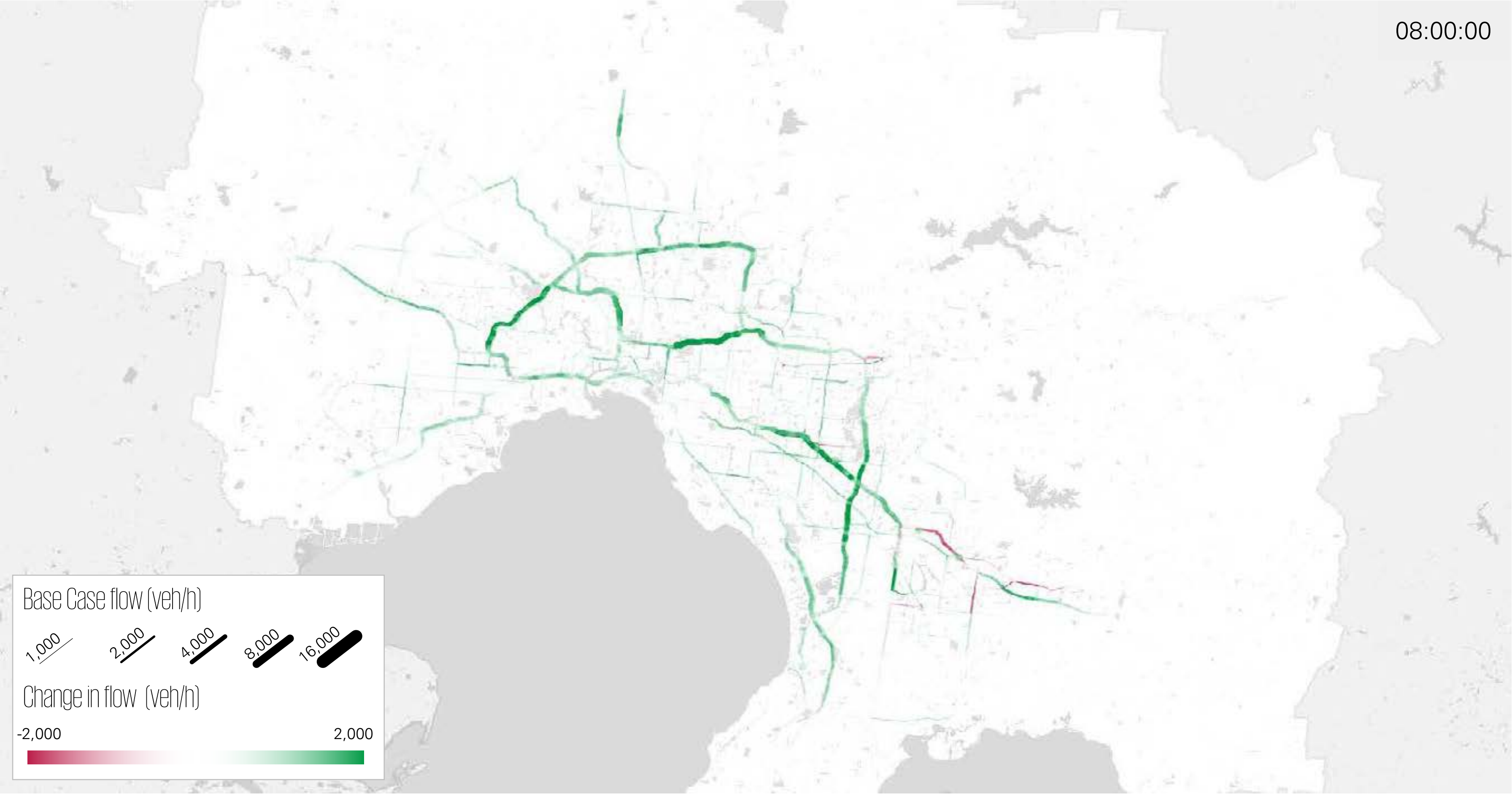
Source: MABM

Change in flow: Private drive, Station drop-off and pick-up vs Private drive, morning peak



Source: MABM

Change in flow: Fleet street, Subscription fare vs Fleet street, morning peak



Source: MABM

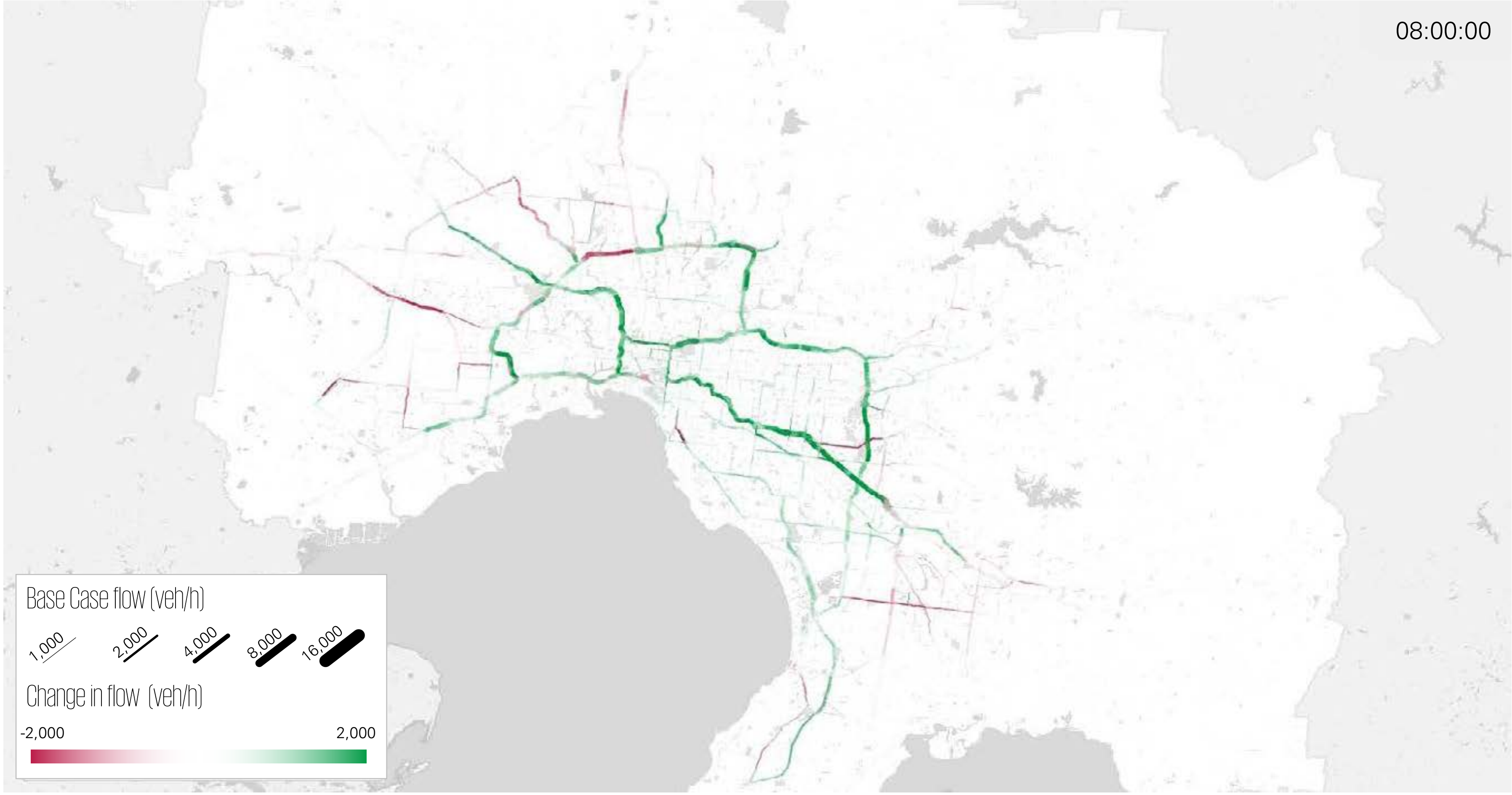
Change in flow: Fleet street, Low MUTT vs Fleet street, morning peak

Source: MABM

Change in flow: Fleet street, Low flow vs Fleet street, morning peak

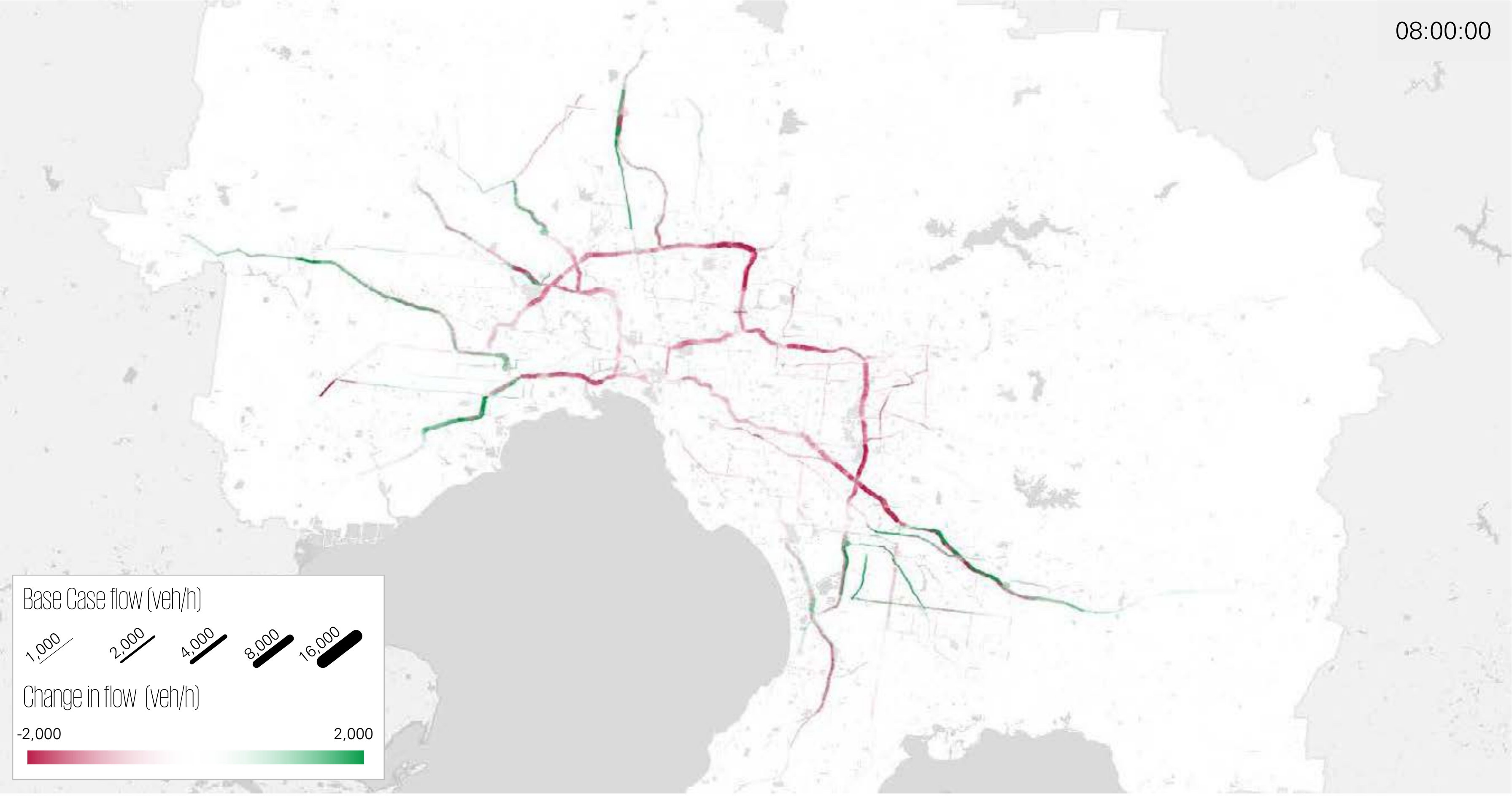
Source: MABM

Change in flow: Fleet street, No mode shift vs Fleet street, morning peak



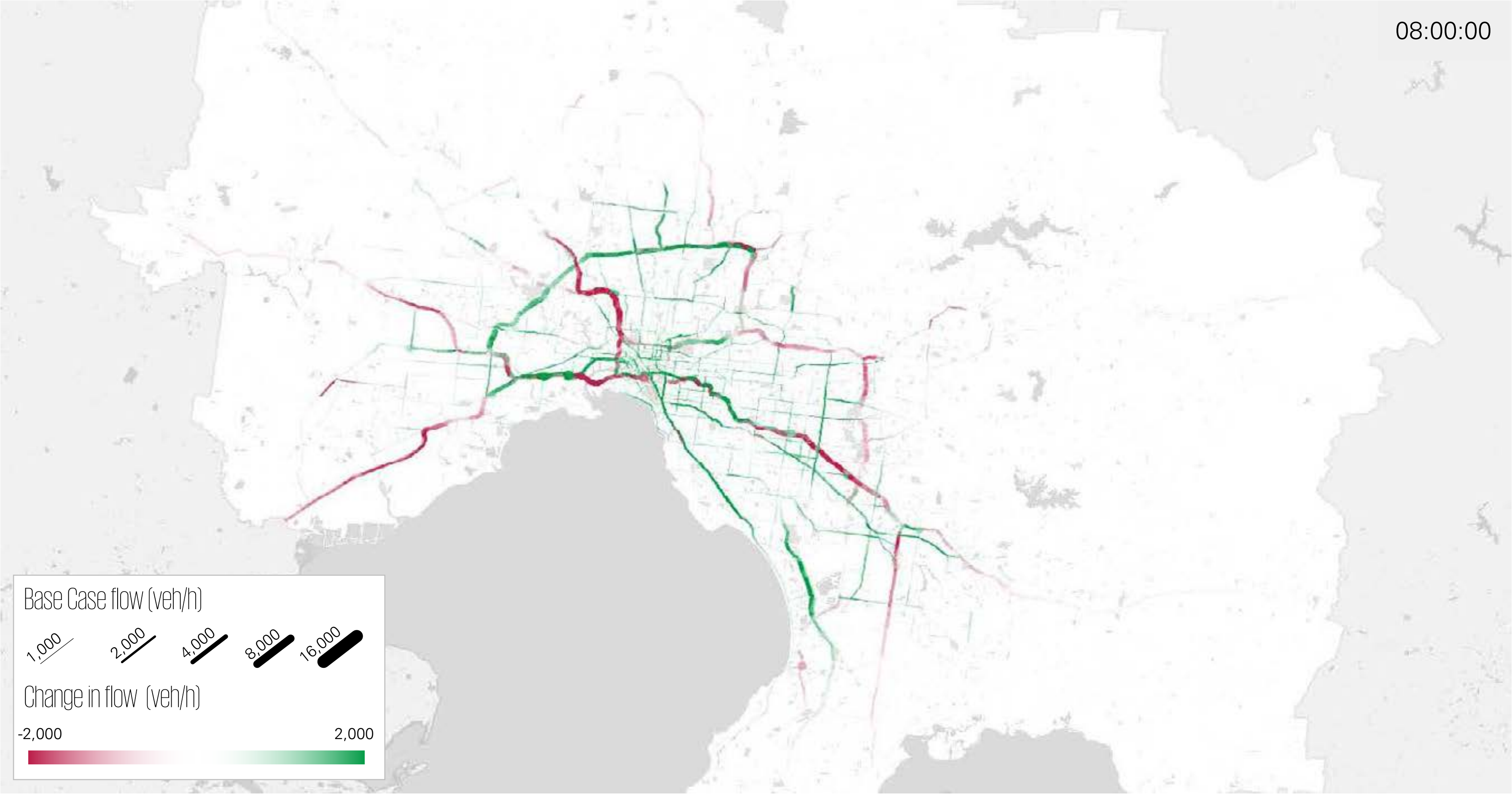
Source: MABM

Change in flow: Fleet street, Calibrated fleet size vs Fleet street, morning peak



Source: MABM

Change in flow: Fleet Street, No new (pre-construction) major road projects vs Fleet street, morning peak



Source: MABM

Change in flow: Slow lane, Low MUTT vs Slow lane, morning peak

Source: MABM

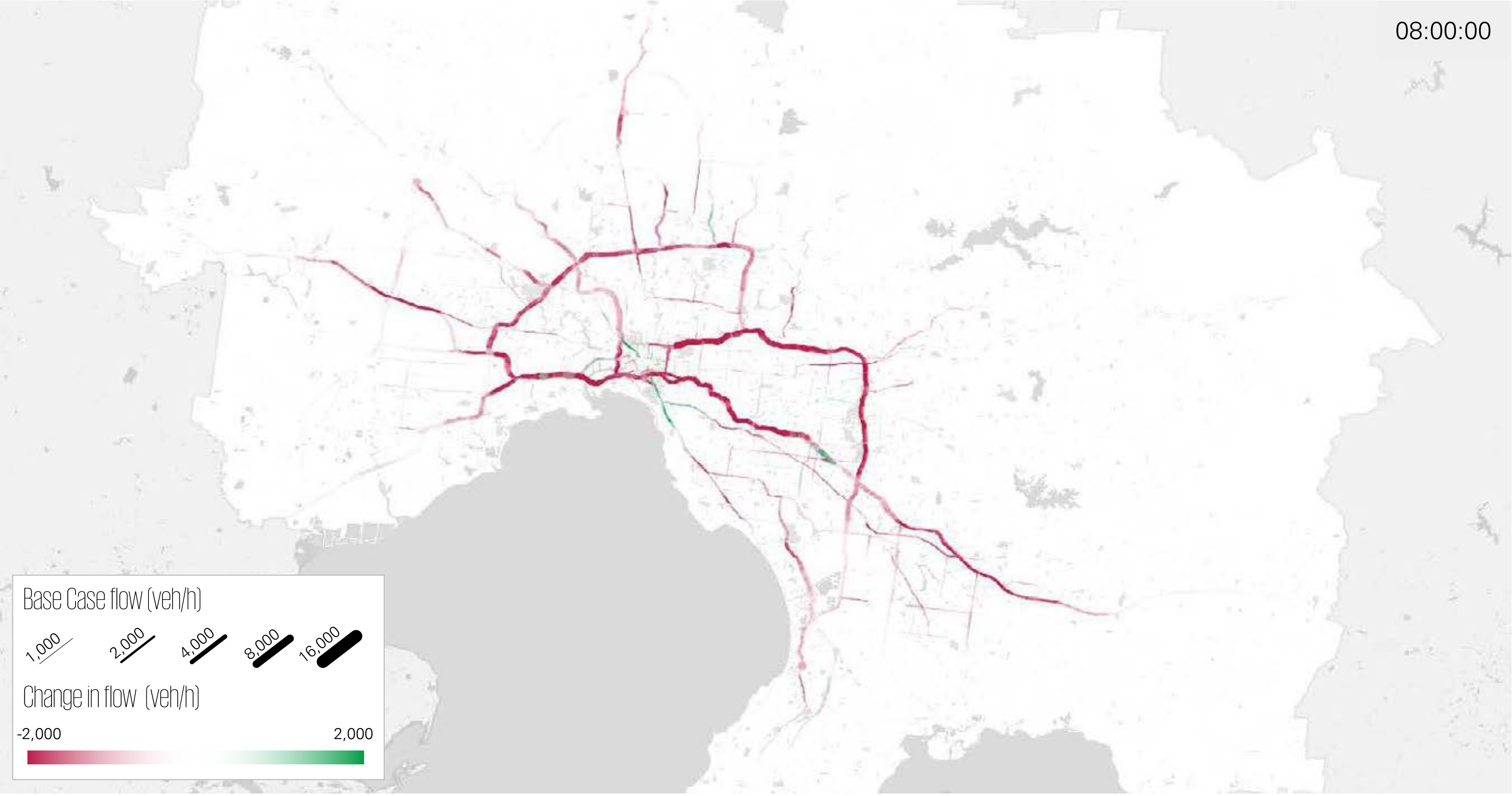
Change in flow: Slow lane, Low flow vs Slow lane, morning peak

Source: MABM

Change in flow: Slow lane, No mode shift vs Slow lane, morning peak

Source: MABM

Change in flow: Slow lane, Private slow lane vs Private drive, morning peak

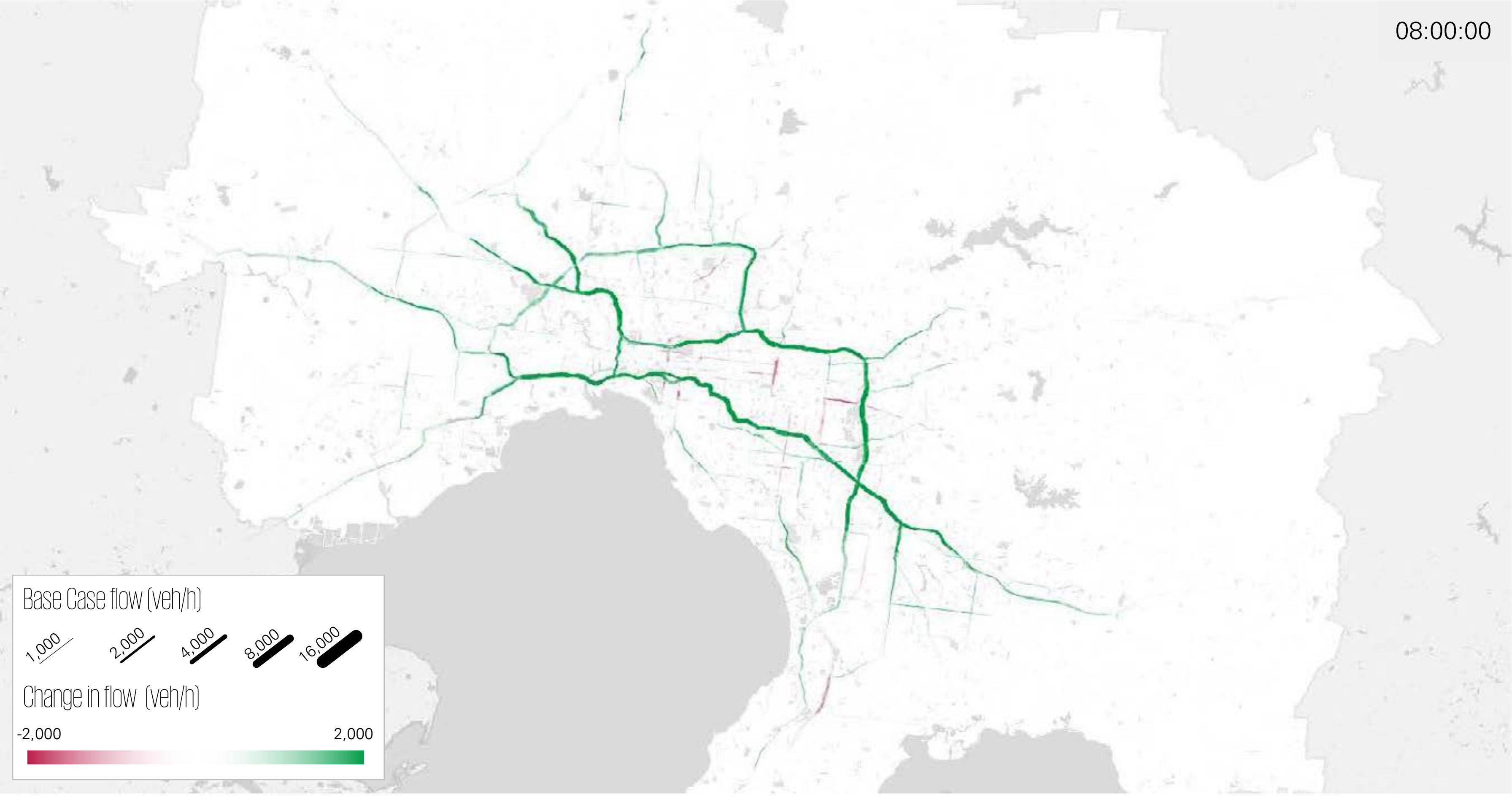


Source: MABM

Change in flow: Hydrogen highway, No empty running vs Hydrogen highway, morning peak

Source: MABM

Change in flow: Mix of scenarios vs Dead end, morning peak



Source: MABM

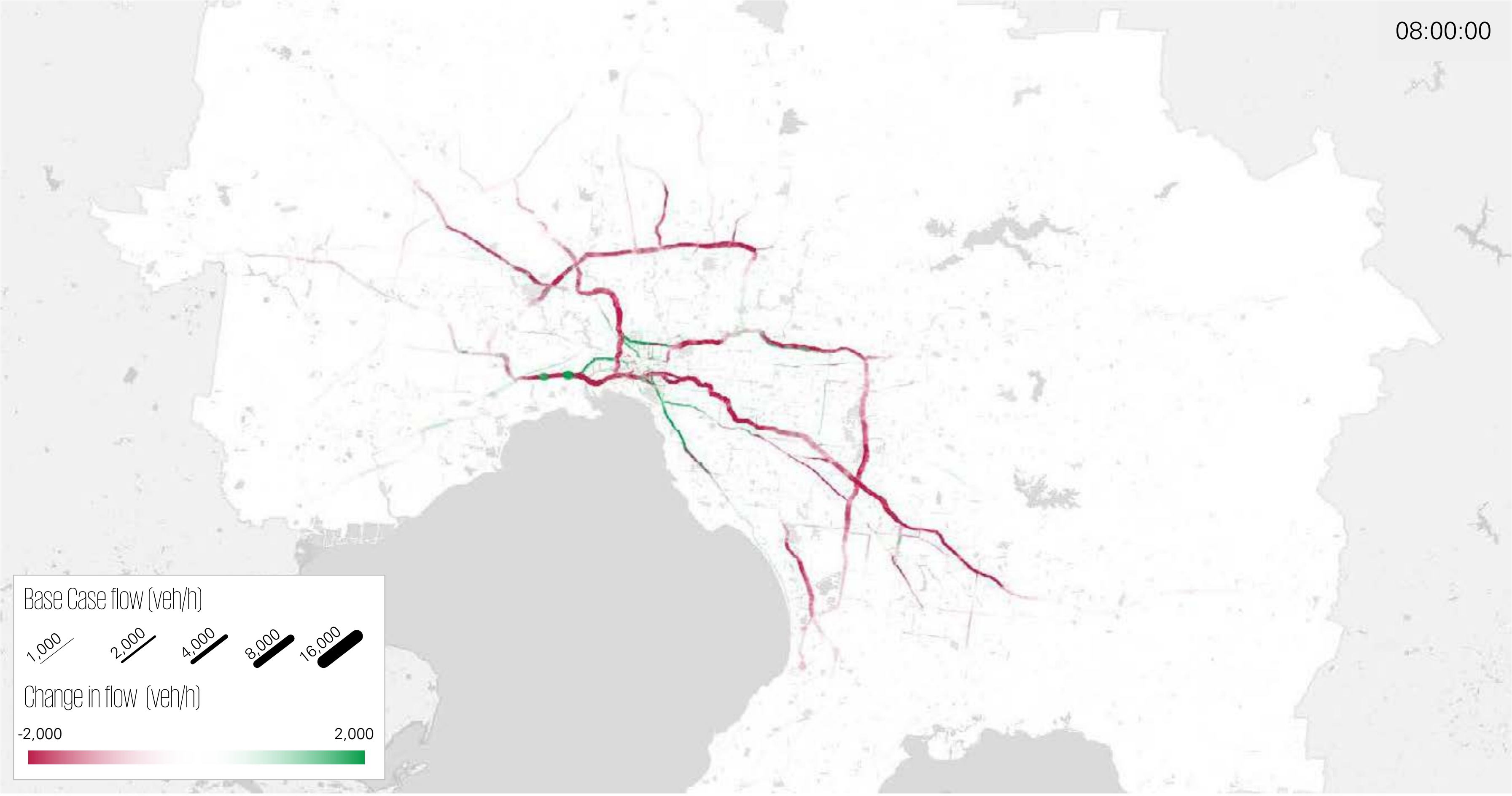
Change in flow: Mix of scenarios, Centralised land use vs Mixed scenario, morning peak

Source: MABM

Change in flow: Mix of scenarios, Expanded land use vs Mixed scenario, morning peak

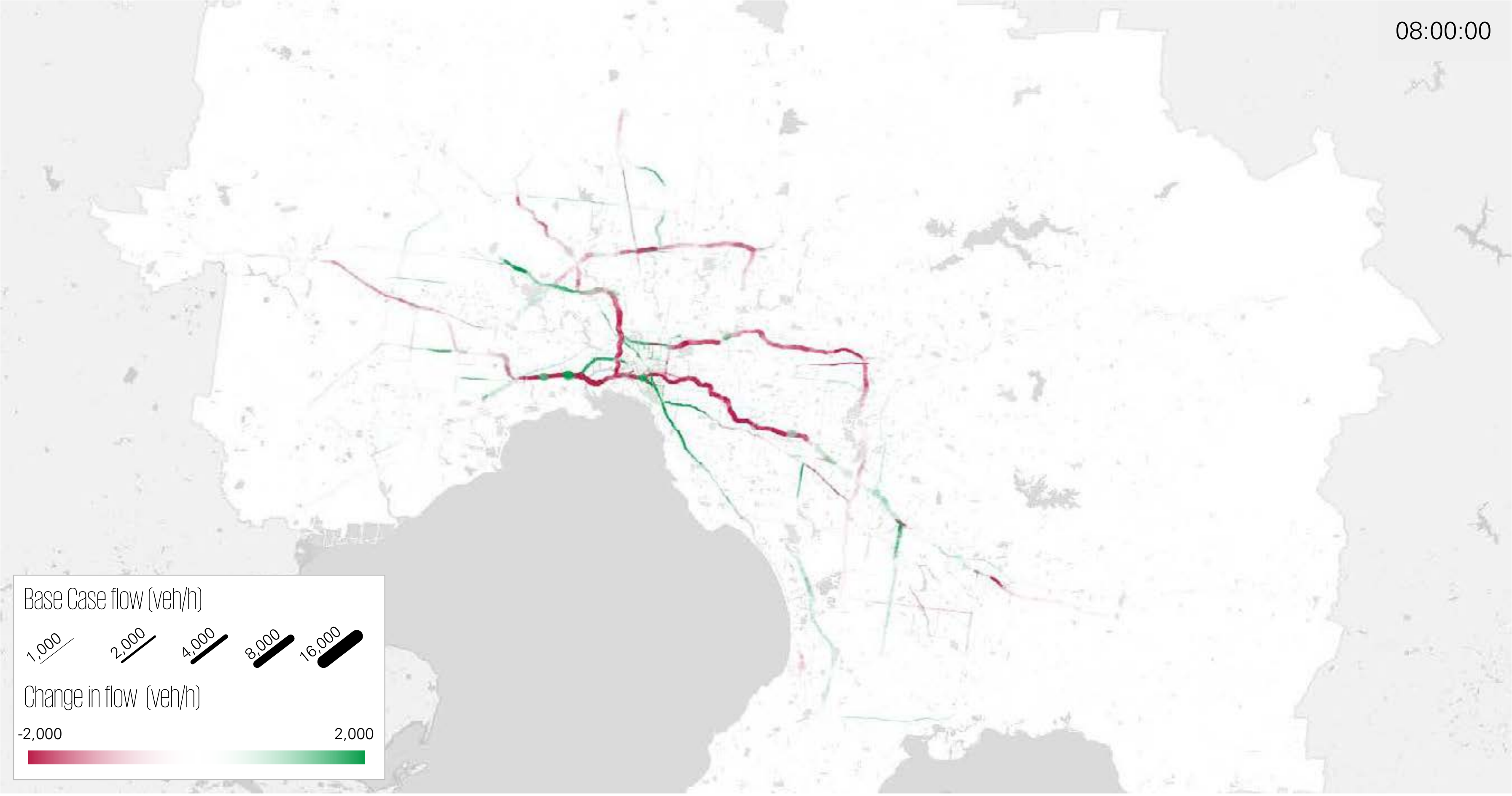
Source: MABM

Change in flow: Private drive, Centralised land use vs Private drive, Dead Running, morning peak



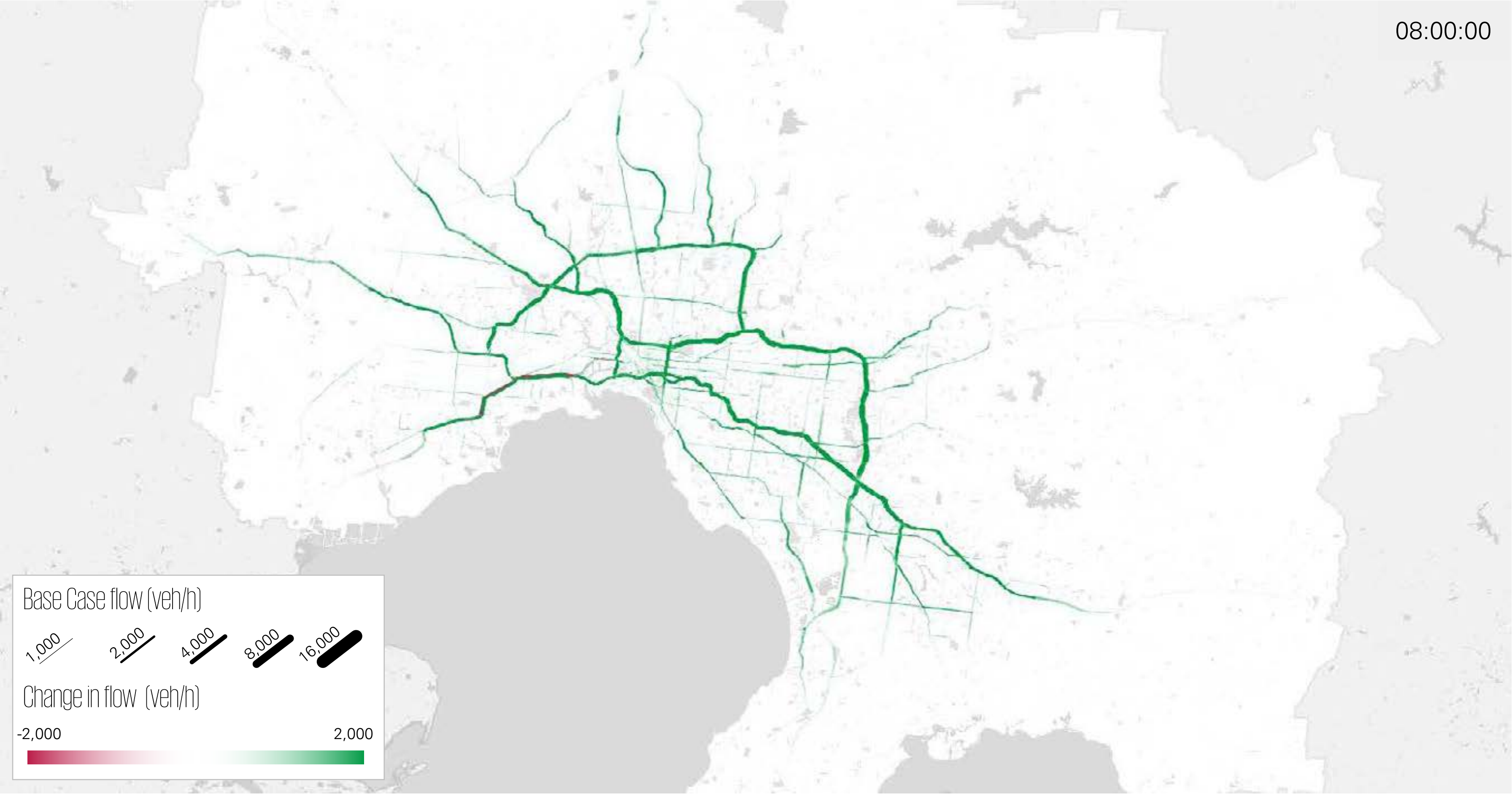
Source: MABM

Change in flow: Private drive, Expanded land use vs Private drive, Dead Running, morning peak



Source: MABM

Change in flow: Private drive vs Dead end, afternoon peak



Source: MABM

Change in flow: Fleet street vs Dead end, afternoon peak

Source: MABM

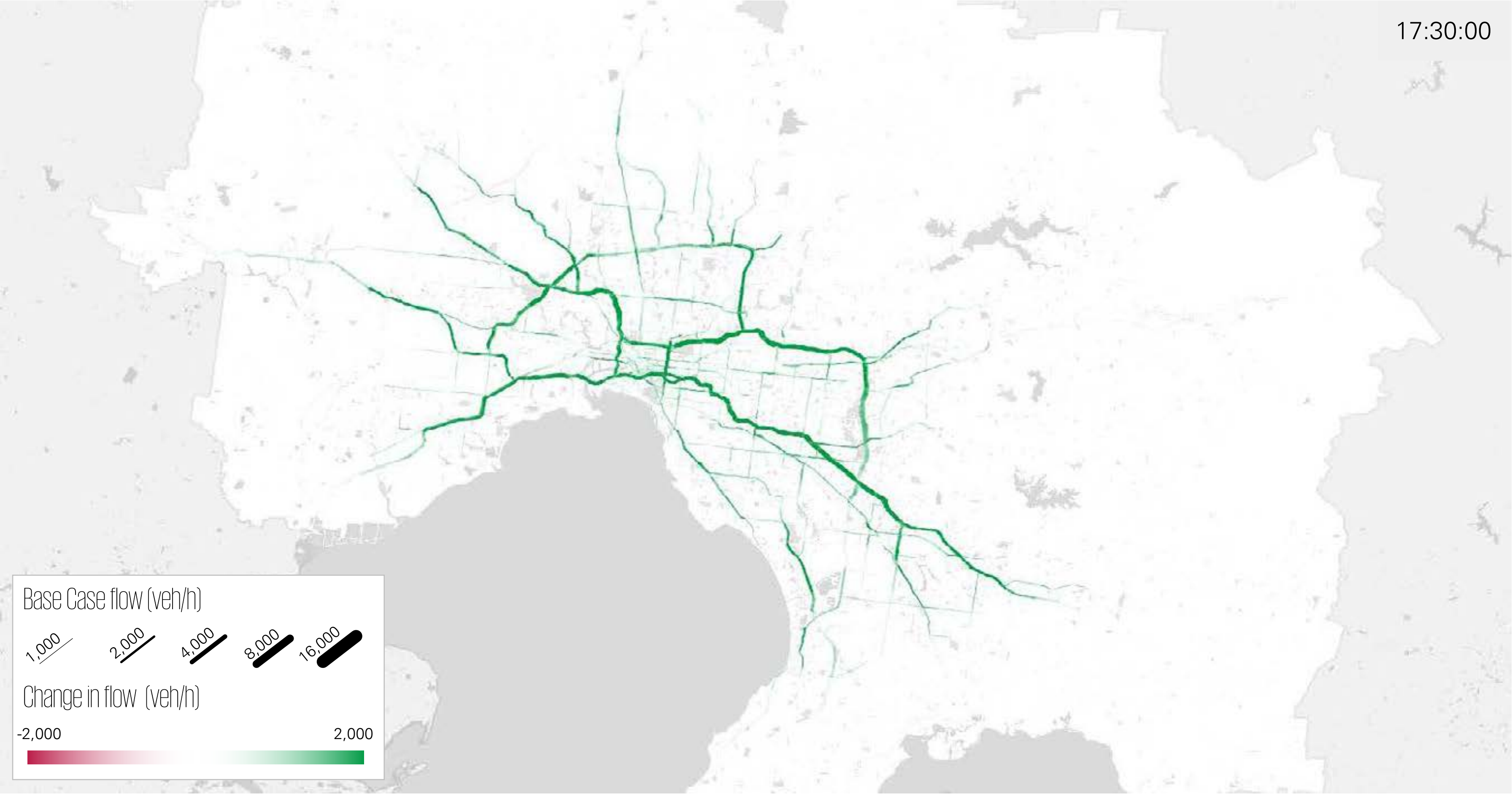
Change in flow: Slow lane vs Dead end, afternoon peak

Source: MABM

Change in flow: Electric avenue vs Dead end, afternoon peak

Source: MABM

Change in flow: Hydrogen highway vs Dead end, afternoon peak



Source: MABM

Change in flow: Private drive, No empty running vs Private drive, afternoon peak

Source: MABM

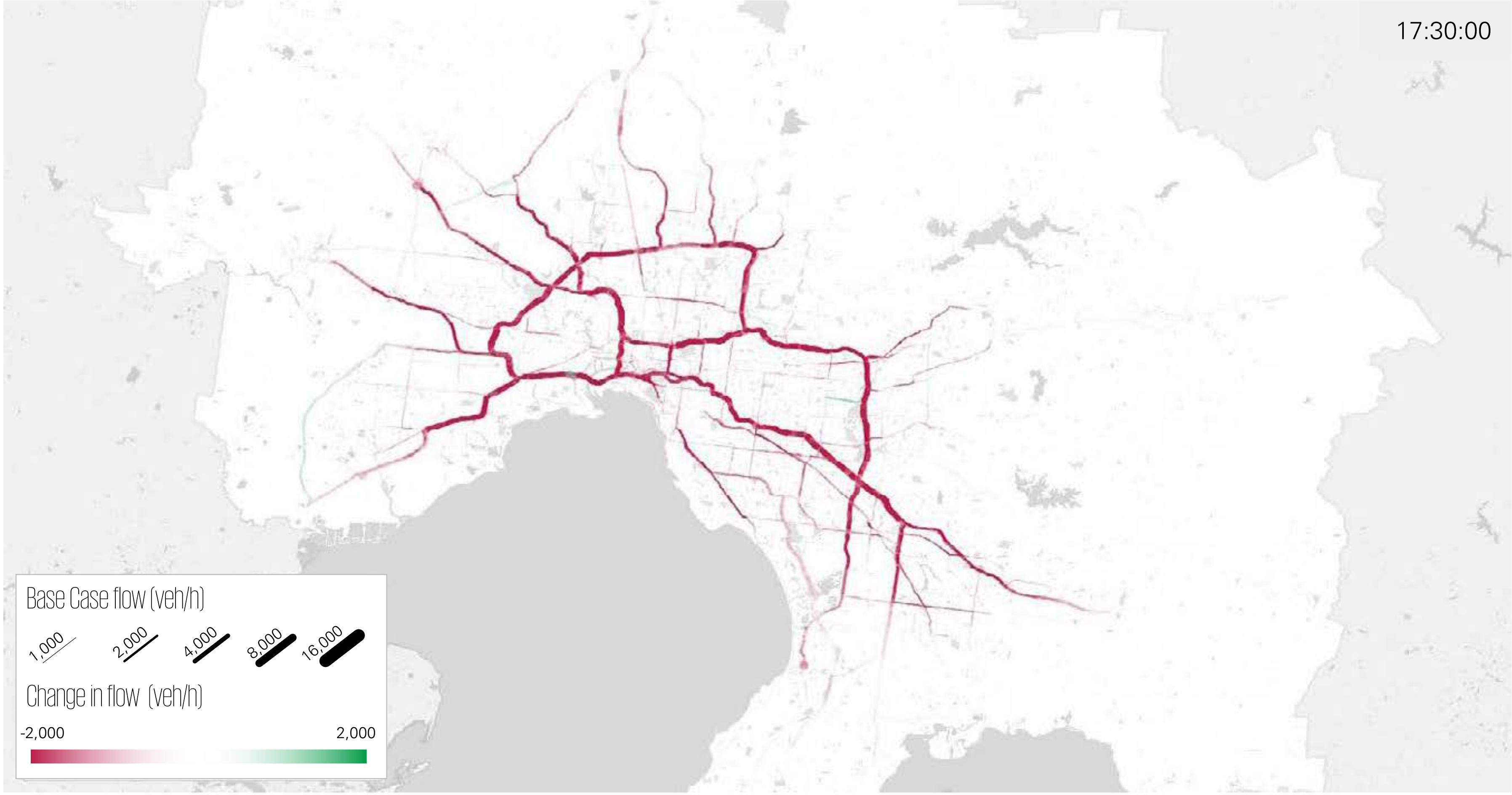
Change in flow: Private drive, Low MUTT vs Private drive, No empty running, afternoon peak

Source: MABM

Change in flow: Private drive, Low flow vs Private drive, No empty running, afternoon peak

Source: MABM

Change in flow: Private drive, No mode shift vs Private drive, No empty running, afternoon peak

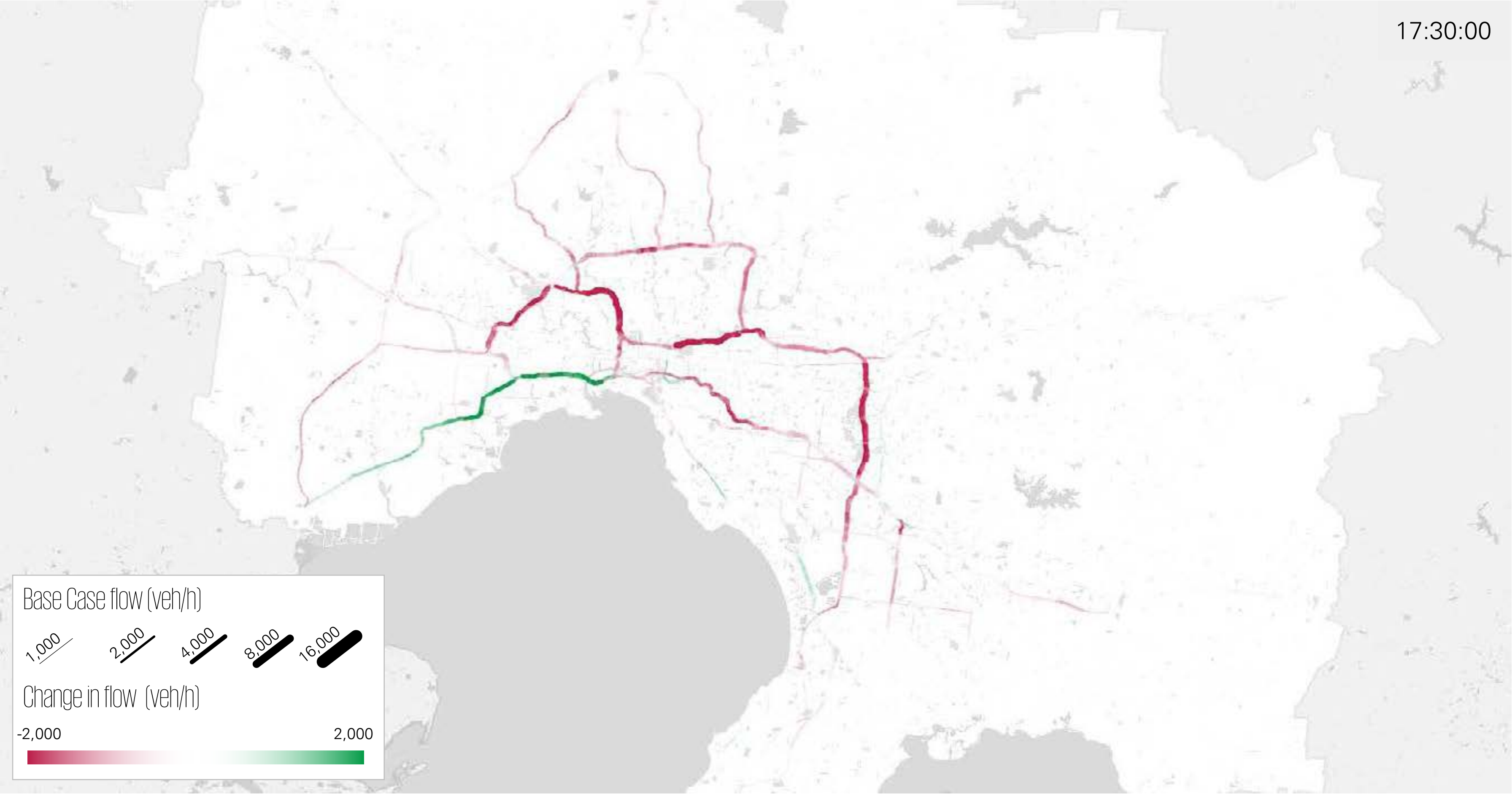


Source: MABM

Change in flow: Private drive, Area based charge vs Private drive, afternoon peak

Source: MABM

Change in flow: Private drive, Distance based charge vs Private drive, afternoon peak



Source: MABM

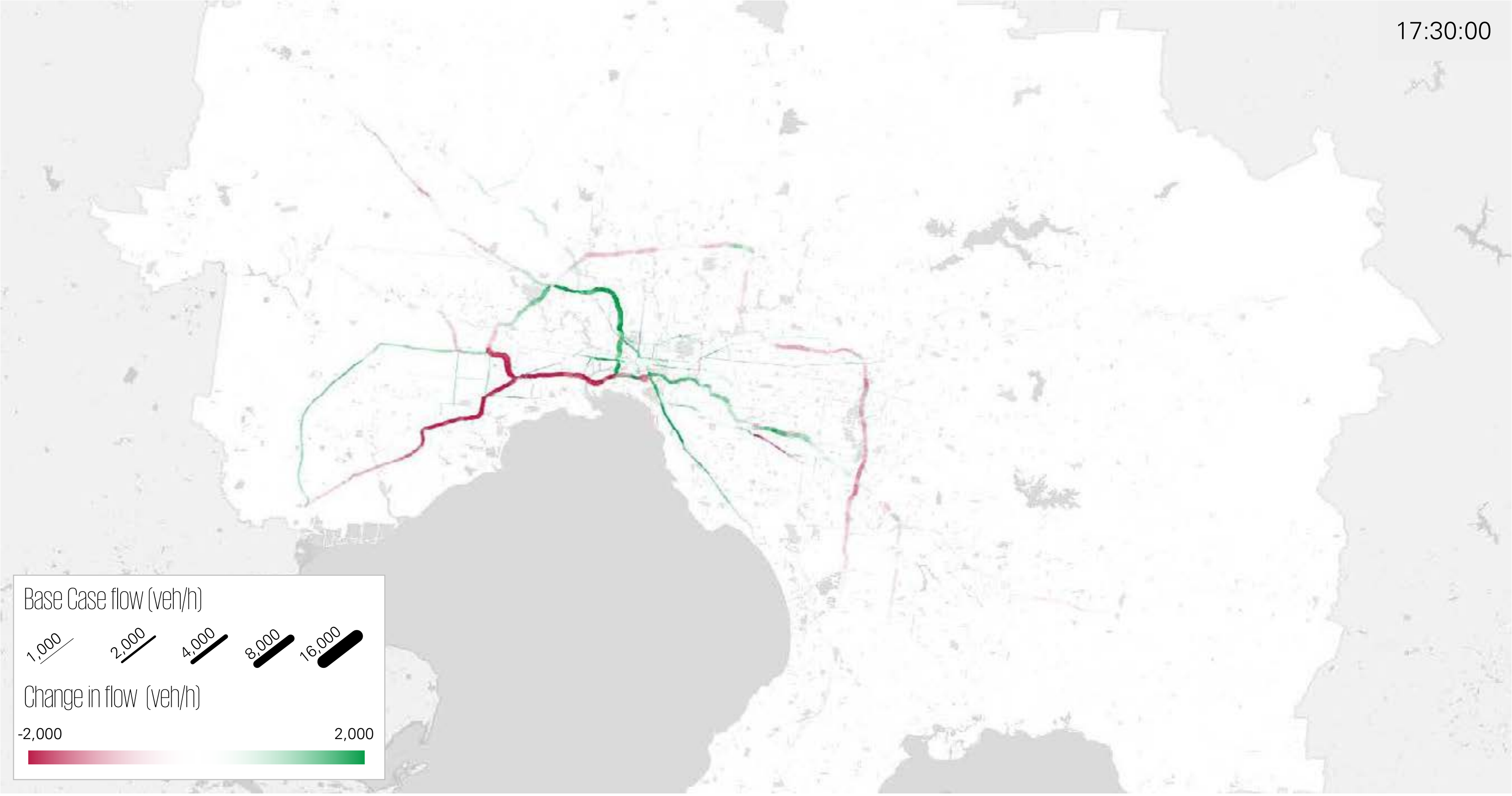
Change in flow: Private drive, Freight to night vs Private drive, afternoon peak

Source: MABM

Change in flow: Private drive, Expanded markets vs Private drive, No empty running, afternoon peak

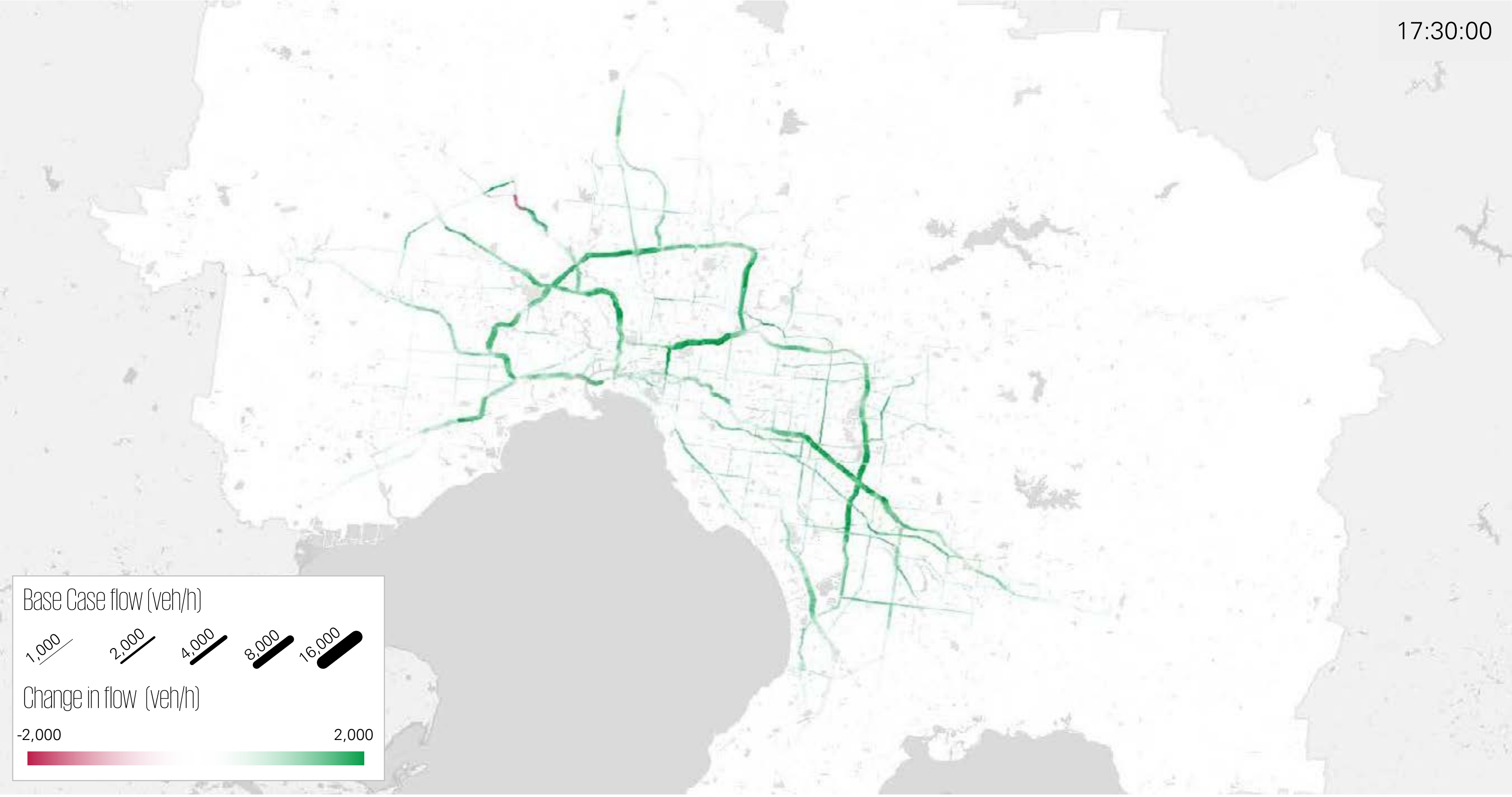
Source: MABM

Change in flow: Private drive, Station drop-off and pick-up vs Private drive, afternoon peak



Source: MABM

Change in flow: Fleet street, Subscription fare vs Fleet street, afternoon peak

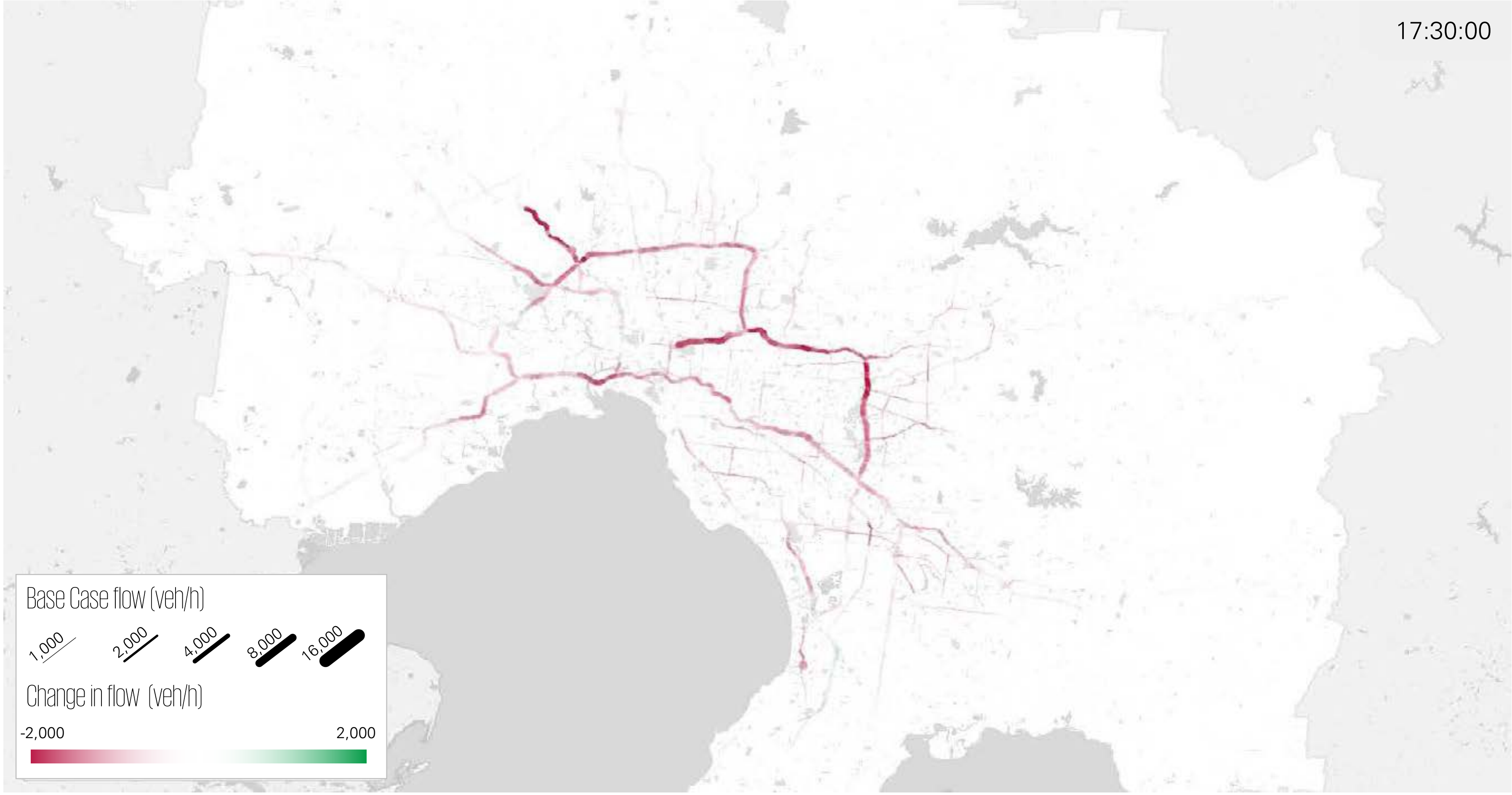


Source: MABM

Change in flow: Fleet street, Low MUTT vs Fleet street, afternoon peak

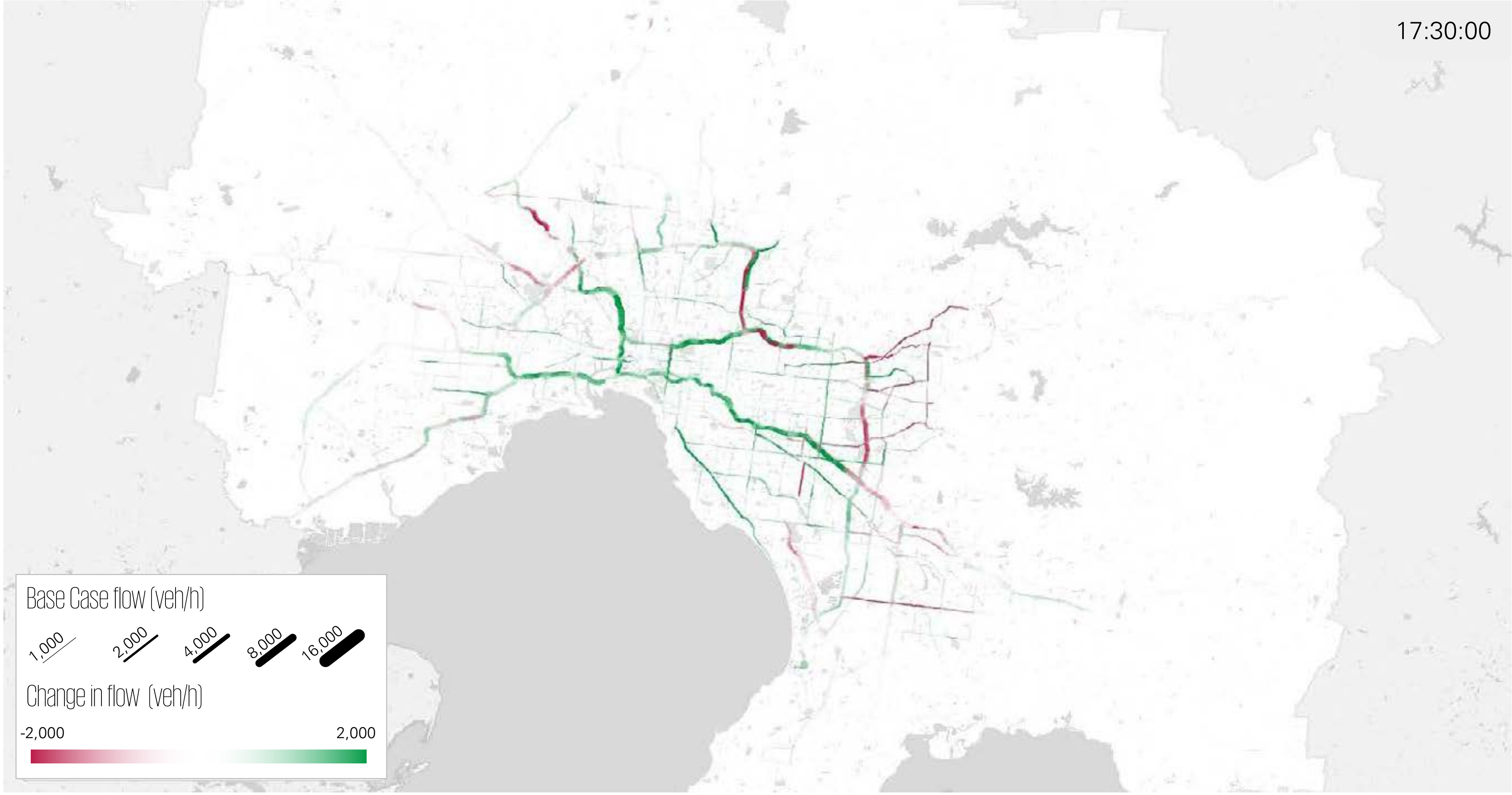
Source: MABM

Change in flow: Fleet street, Low flow vs Fleet street, afternoon peak



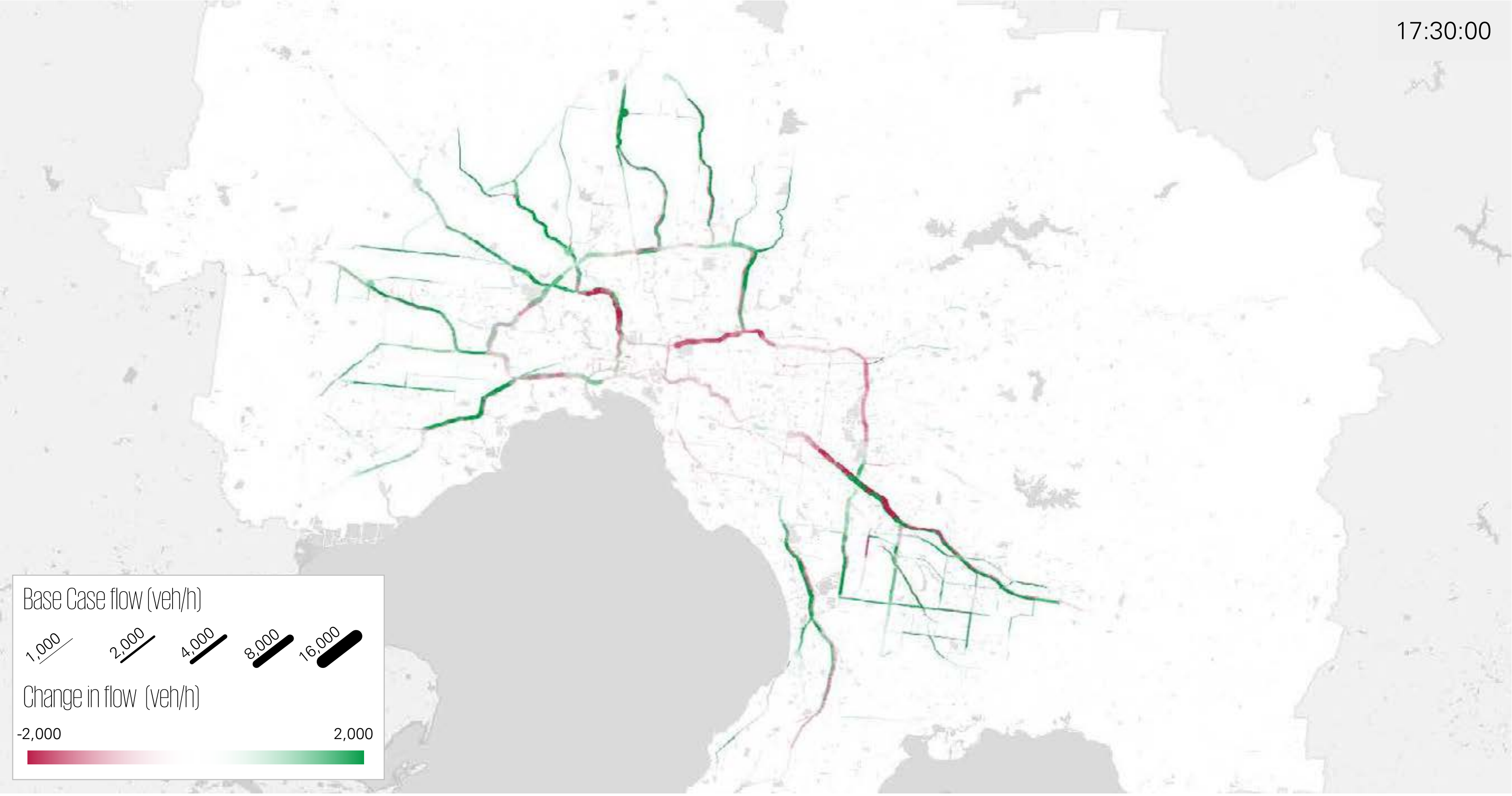
Source: MABM

Change in flow: Fleet street, No mode shift vs Fleet street, afternoon peak



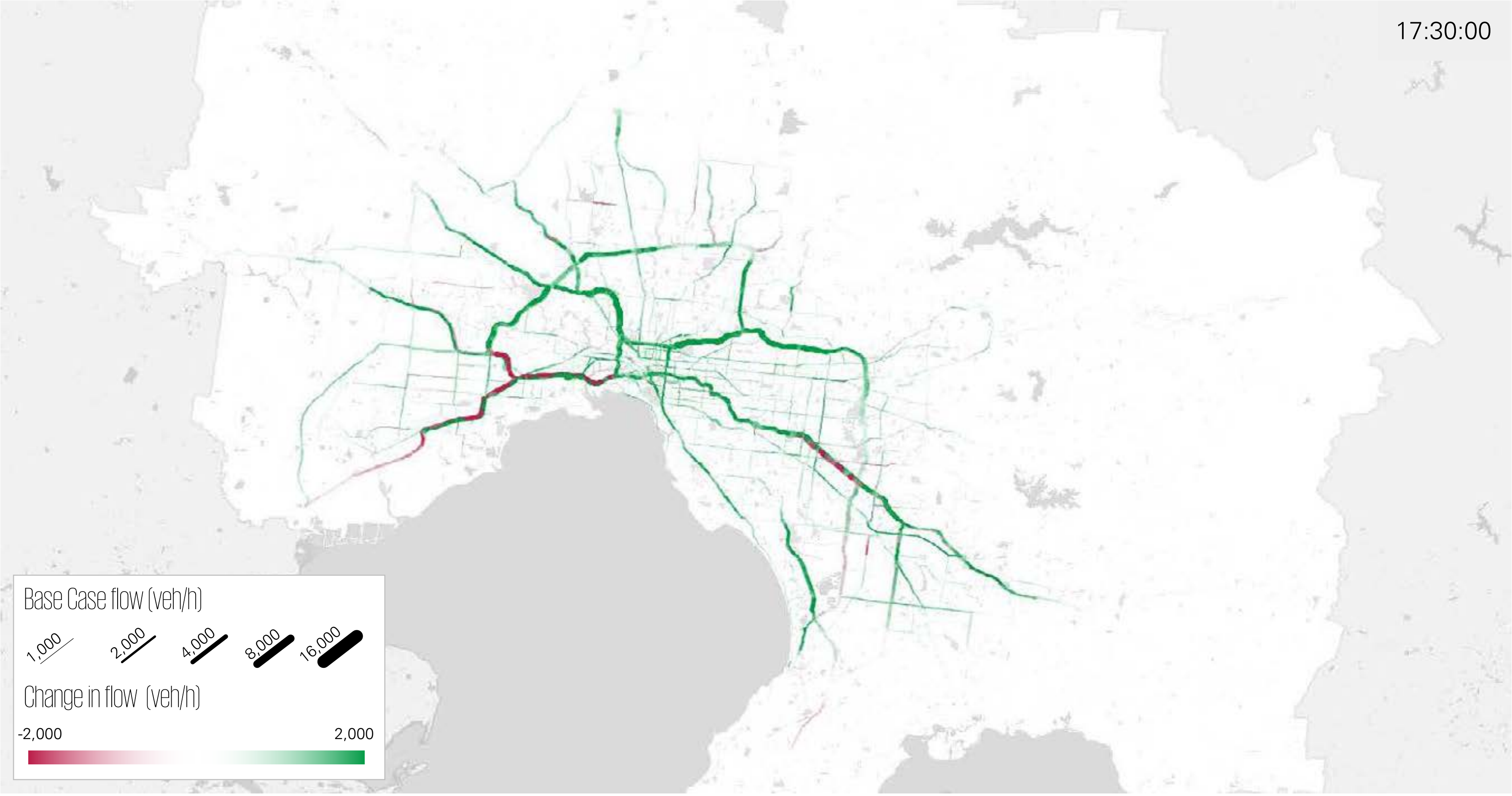
Source: MABM

Change in flow: Fleet street, Calibrated fleet size vs Fleet street, afternoon peak



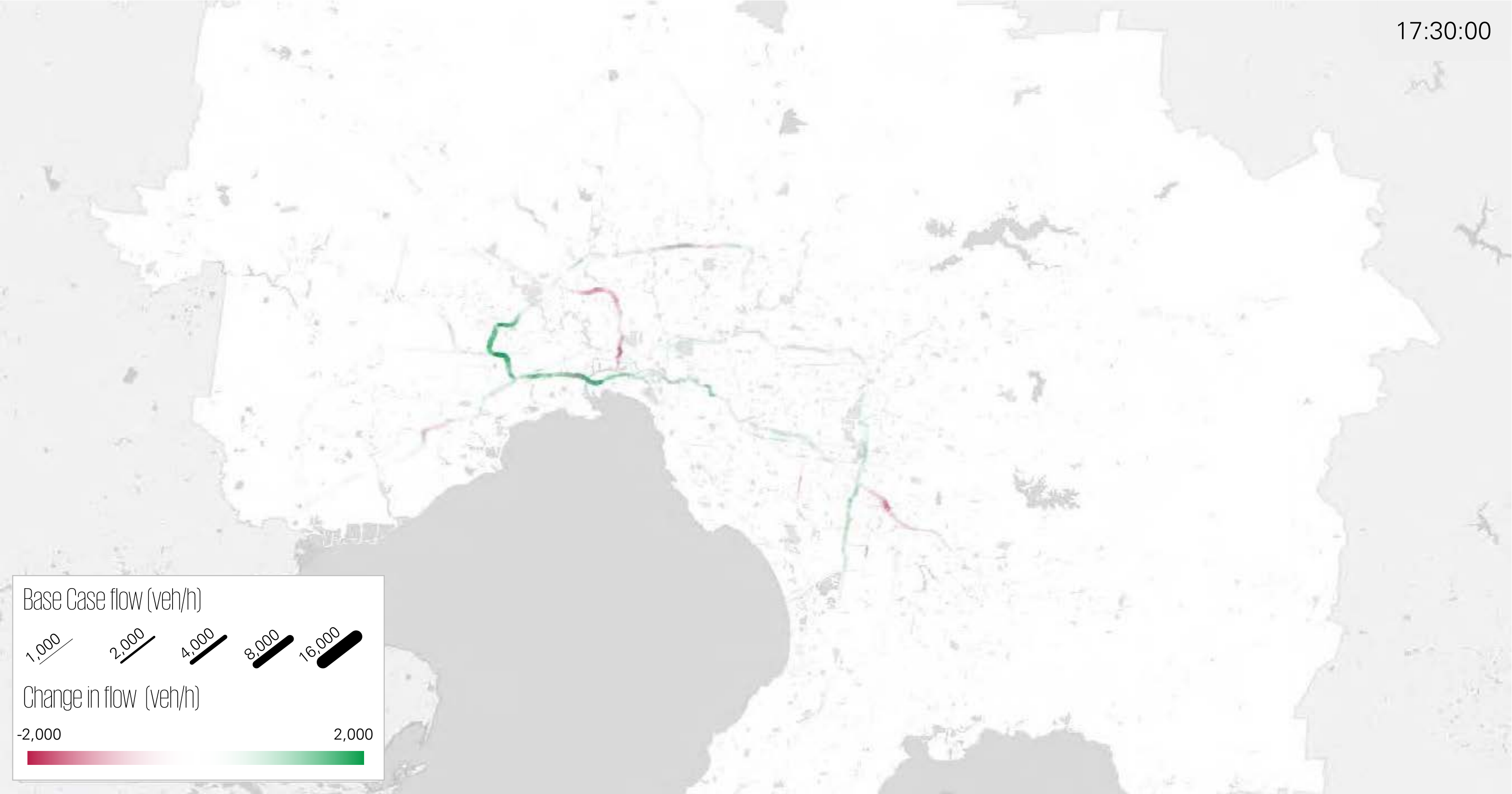
Source: MABM

Change in flow: Fleet Street, No new (pre-construction) major road projects vs Fleet street, afternoon peak



Source: MABM

Change in flow: Slow lane, Low MUTT vs Slow lane, afternoon peak



Source: MABM

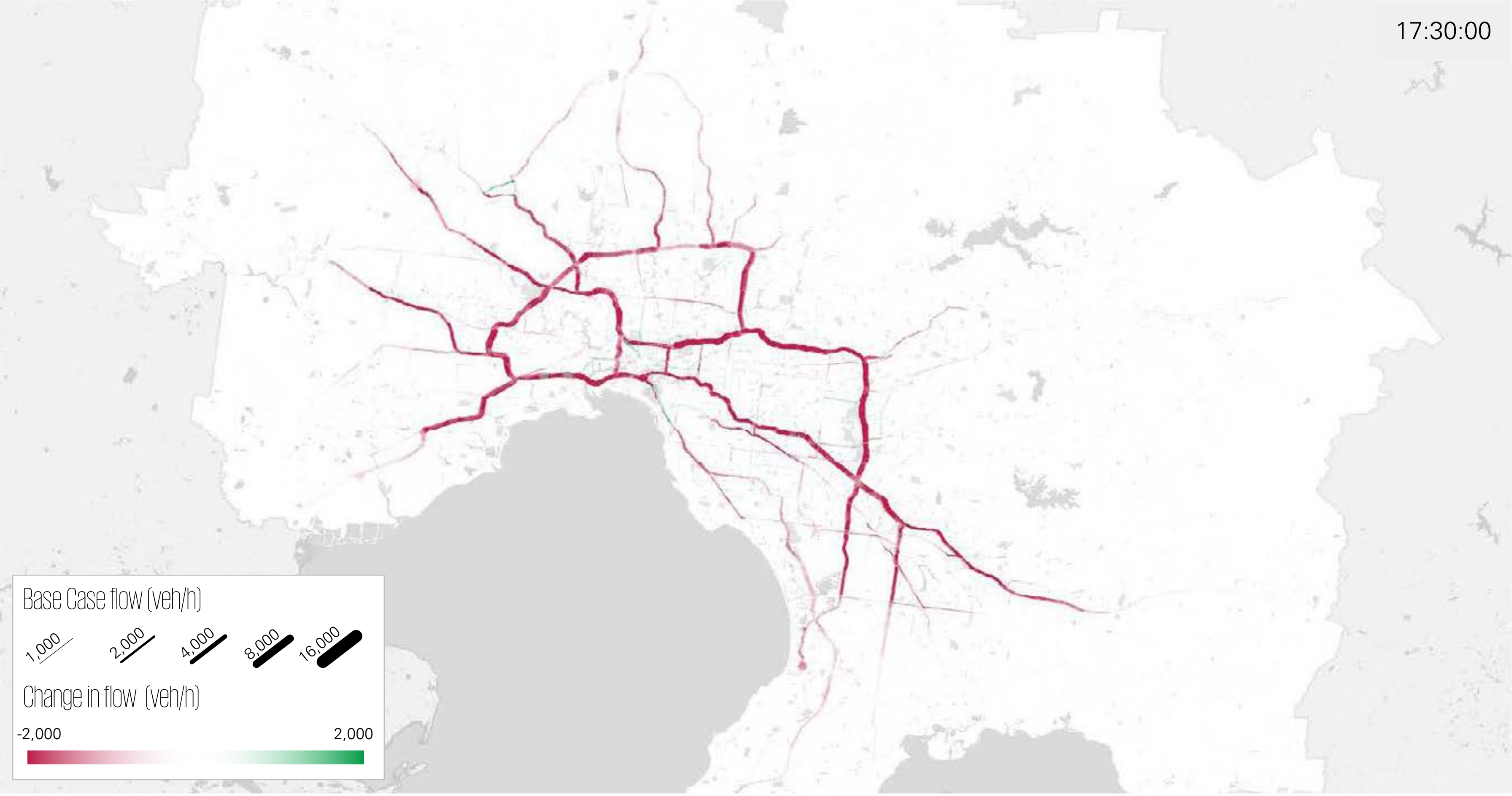
Change in flow: Slow lane, Low flow vs Slow lane, afternoon peak

Source: MABM

Change in flow: Slow lane, No mode shift vs Slow lane, afternoon peak

Source: MABM

Change in flow: Slow lane, Private slow lane vs Private drive, afternoon peak

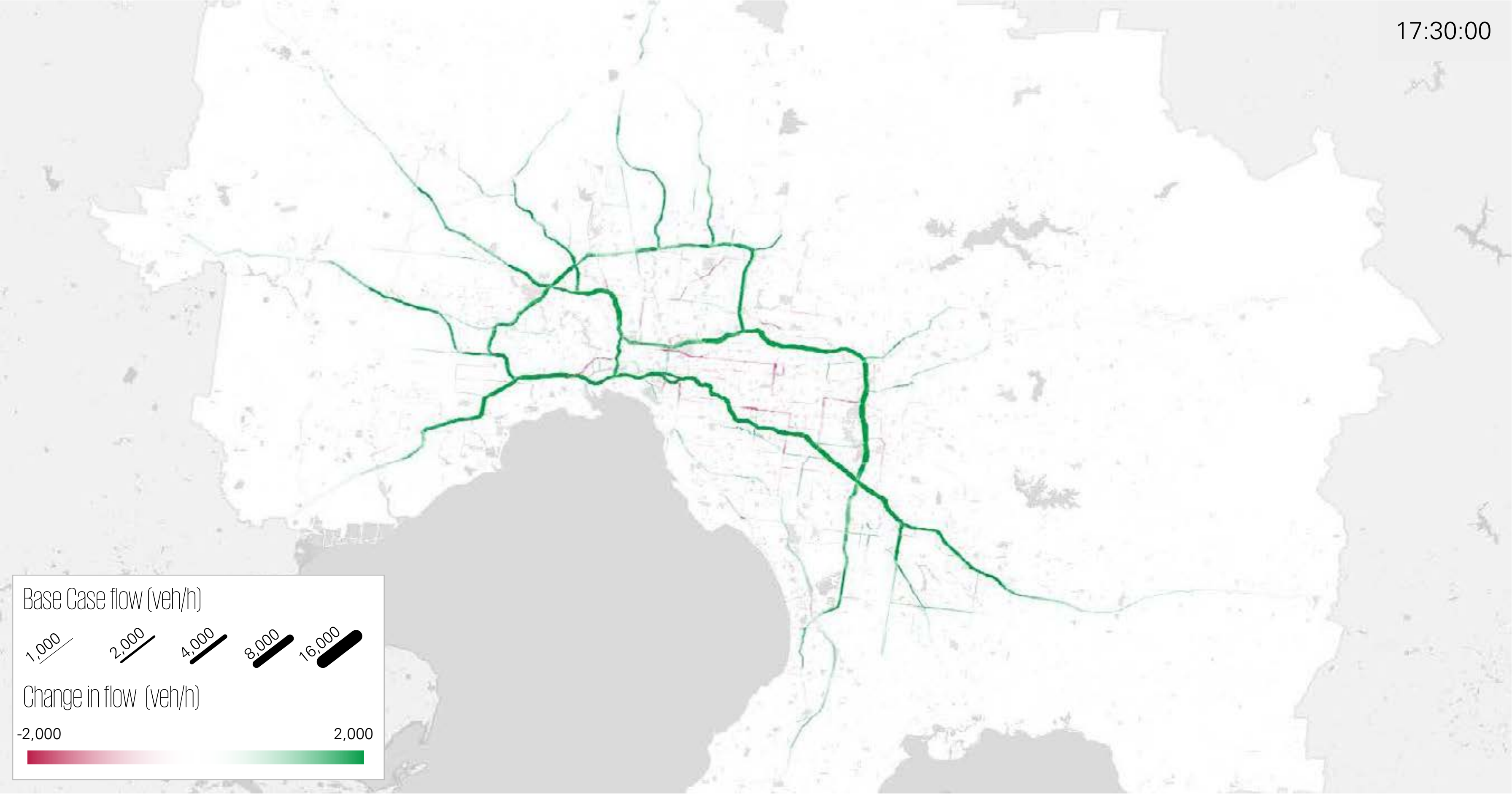


Source: MABM

Change in flow: Hydrogen highway, No empty running vs Hydrogen highway, afternoon peak

Source: MABM

Change in flow: Mix of scenarios vs Dead end, afternoon peak



Source: MABM

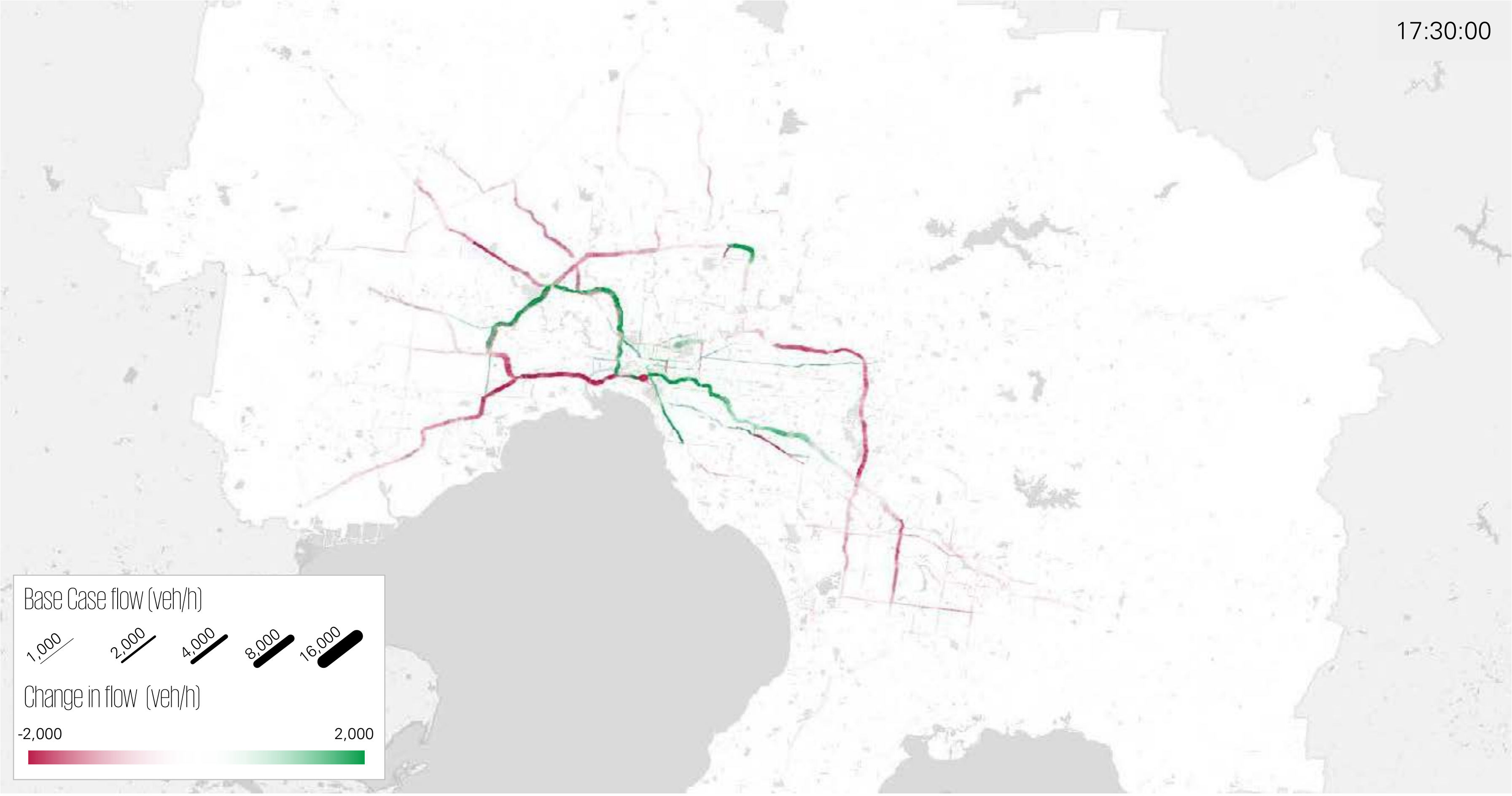
Change in flow: Mix of scenarios, Centralised land use vs Mixed scenario, afternoon peak

Source: MABM

Change in flow: Mix of scenarios, Expanded land use vs Mixed scenario, afternoon peak

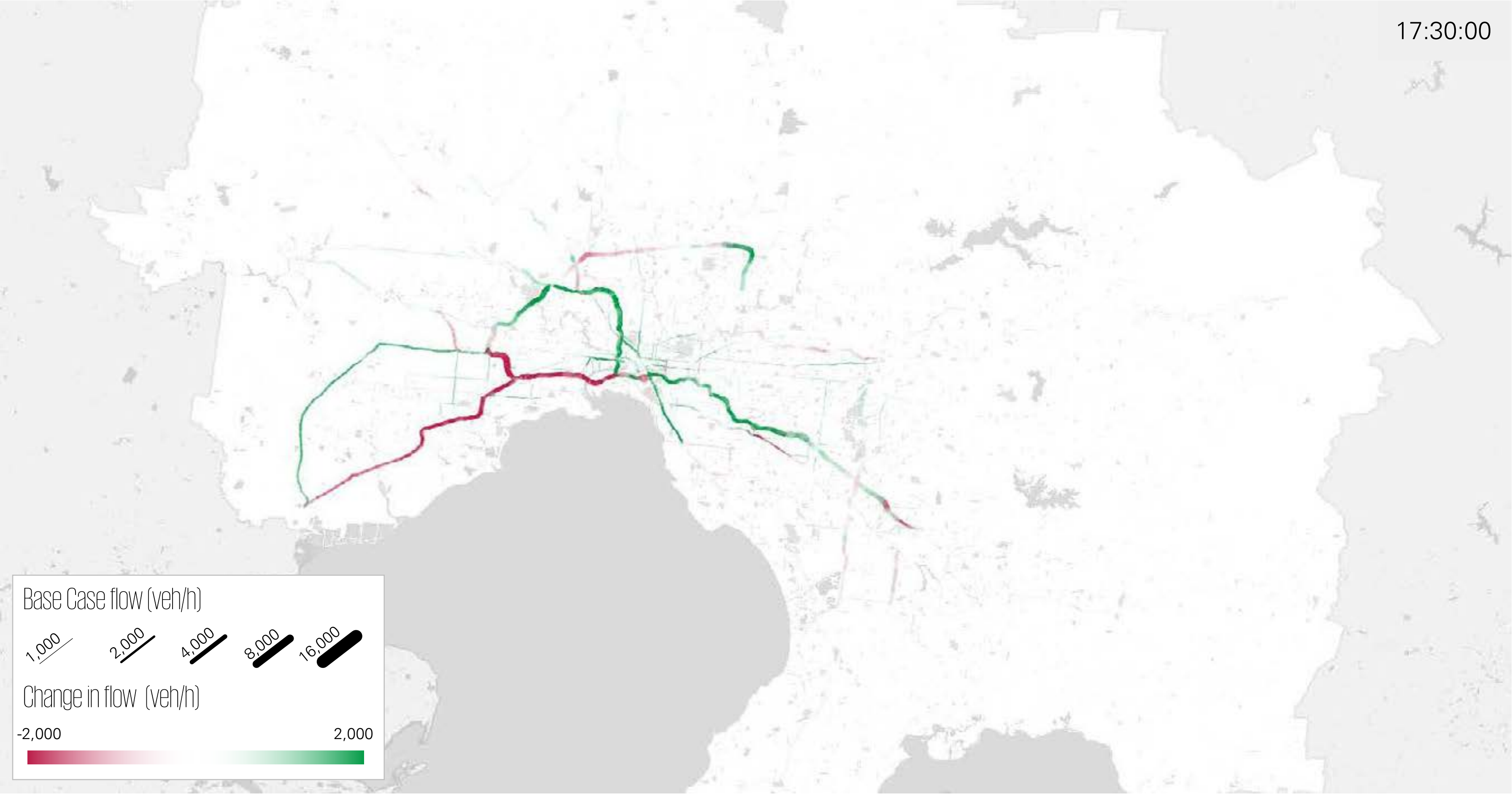
Source: MABM

Change in flow: Private drive, Centralised land use vs Private drive, Dead Running, afternoon peak



Source: MABM

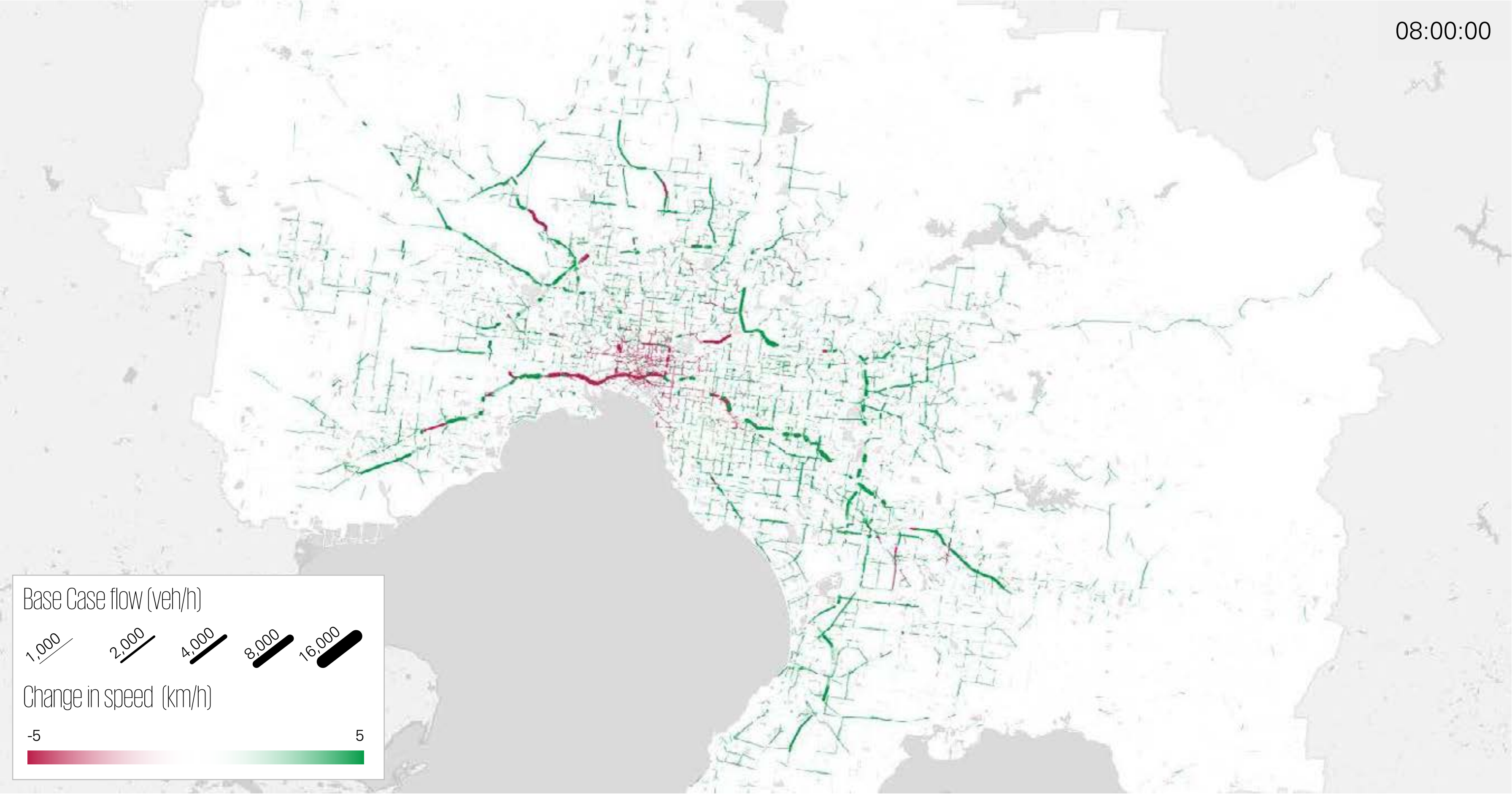
Change in flow: Private drive, Expanded land use vs Private drive, Dead Running, afternoon peak



Source: MABM

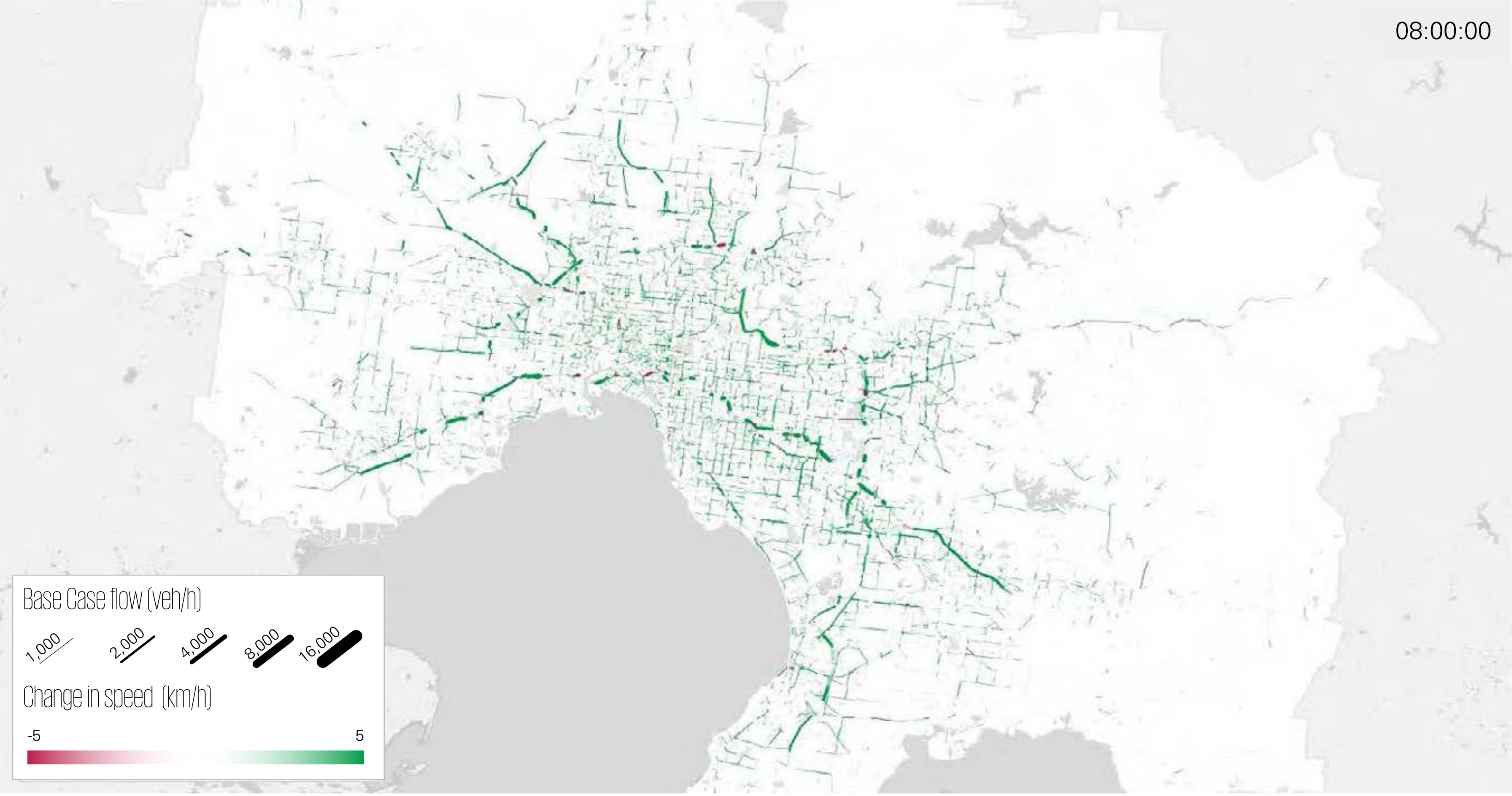
Appendix F: Vehicle speed plots

Change in speed: Private drive vs Dead end, morning peak



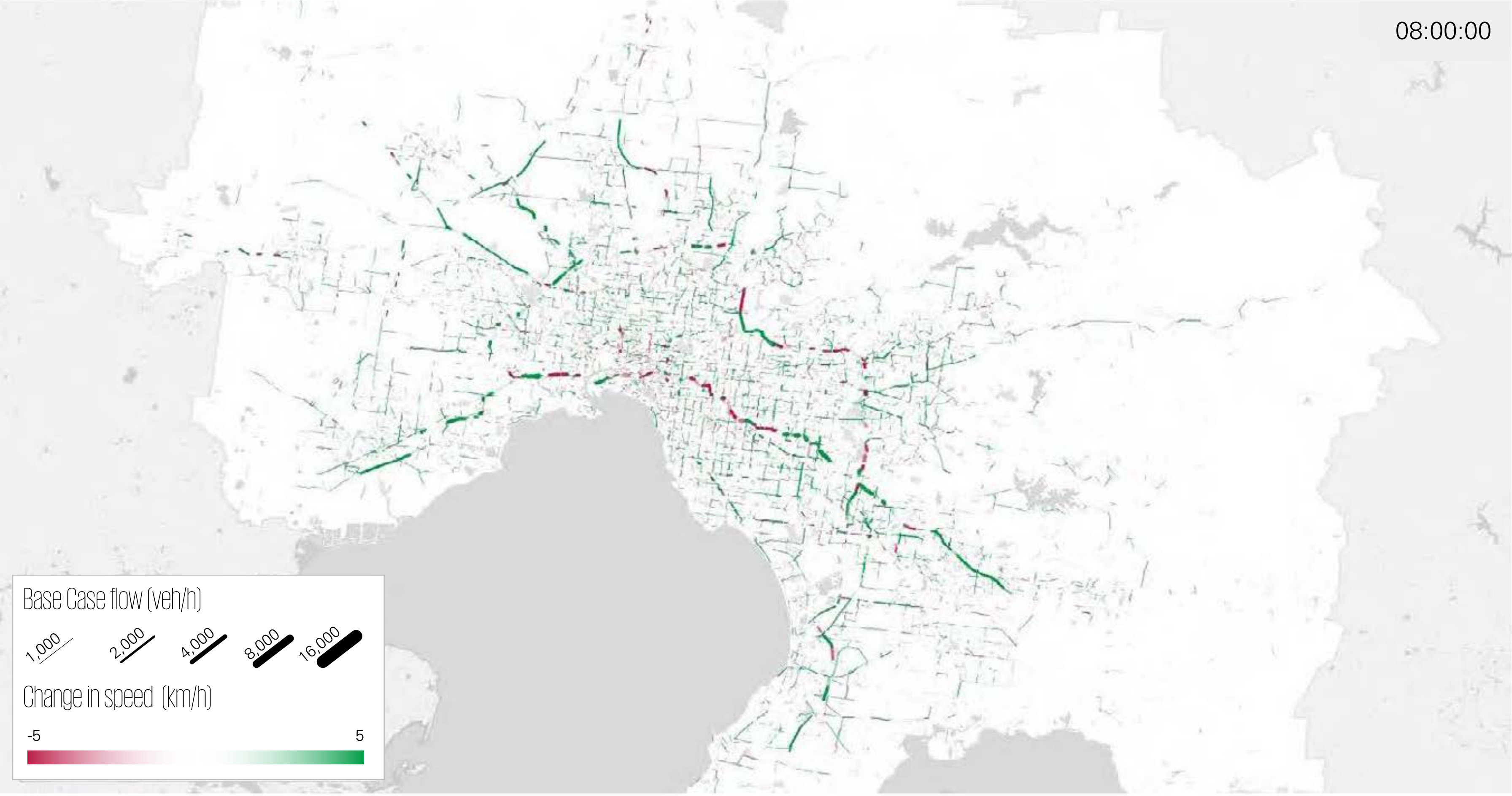
Source: MABM

Change in speed: Fleet street vs Dead end, morning peak



Source: MABM

Change in speed: Slow lane vs Dead end, morning peak

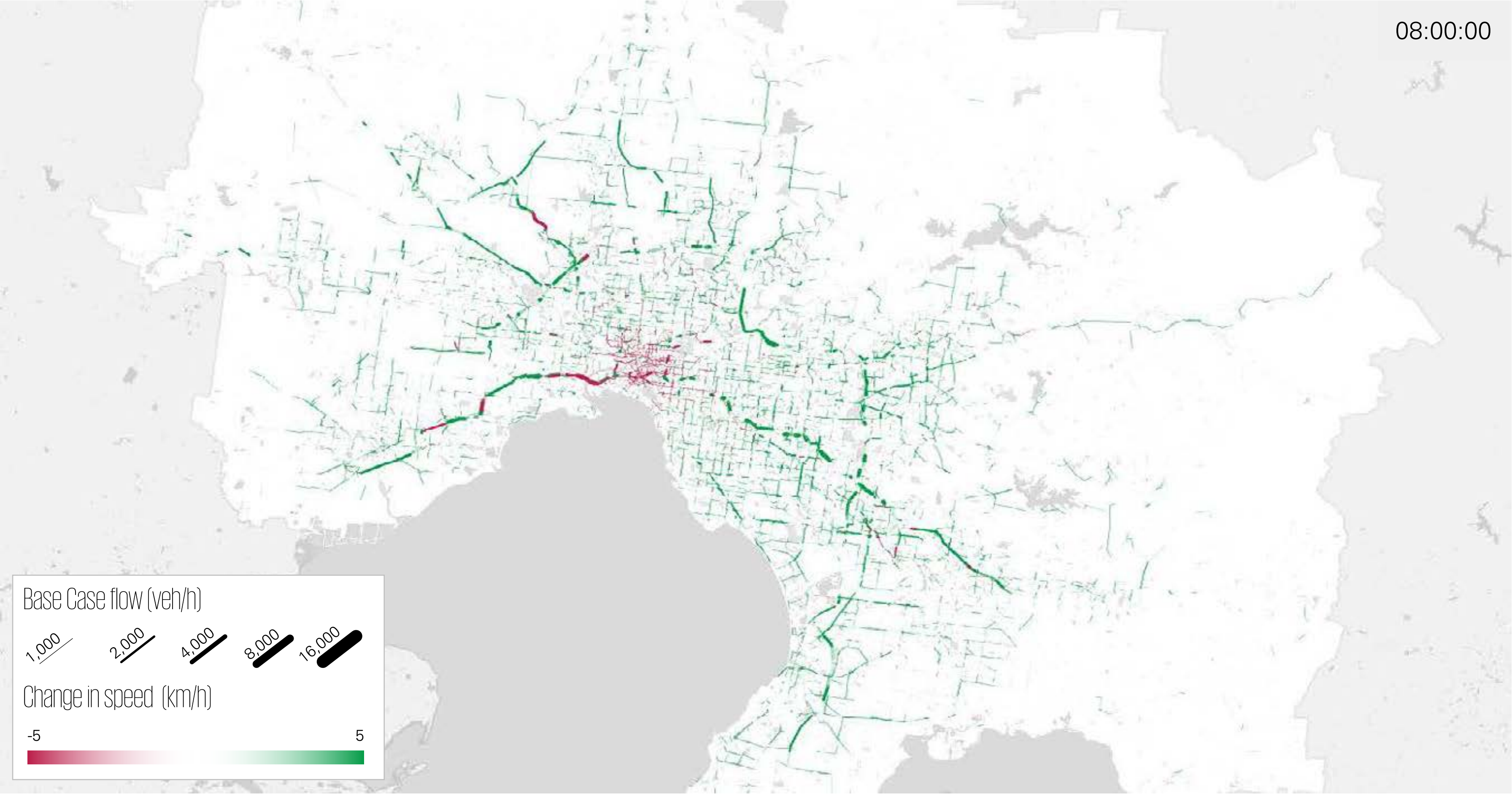


Source: MABM

Change in speed: Electric avenue vs Dead end, morning peak

Source: MABM

Change in speed: Hydrogen highway vs Dead end, morning peak



Source: MABM

Change in speed: Private drive, No empty running vs Private drive, morning peak

Source: MABM

Change in speed: Private drive, Low MUTT vs Private drive, No empty running, morning peak

Source: MABM

Change in speed: Private drive, Low flow vs Private drive, No empty running, morning peak

Source: MABM

Change in speed: Private drive, No mode shift vs Private drive, No empty running, morning peak

Source: MABM

Change in speed: Private drive, Area based charge vs Private drive, morning peak

Source: MABM

Change in speed: Private drive, Distance based charge vs Private drive, morning peak

Source: MABM

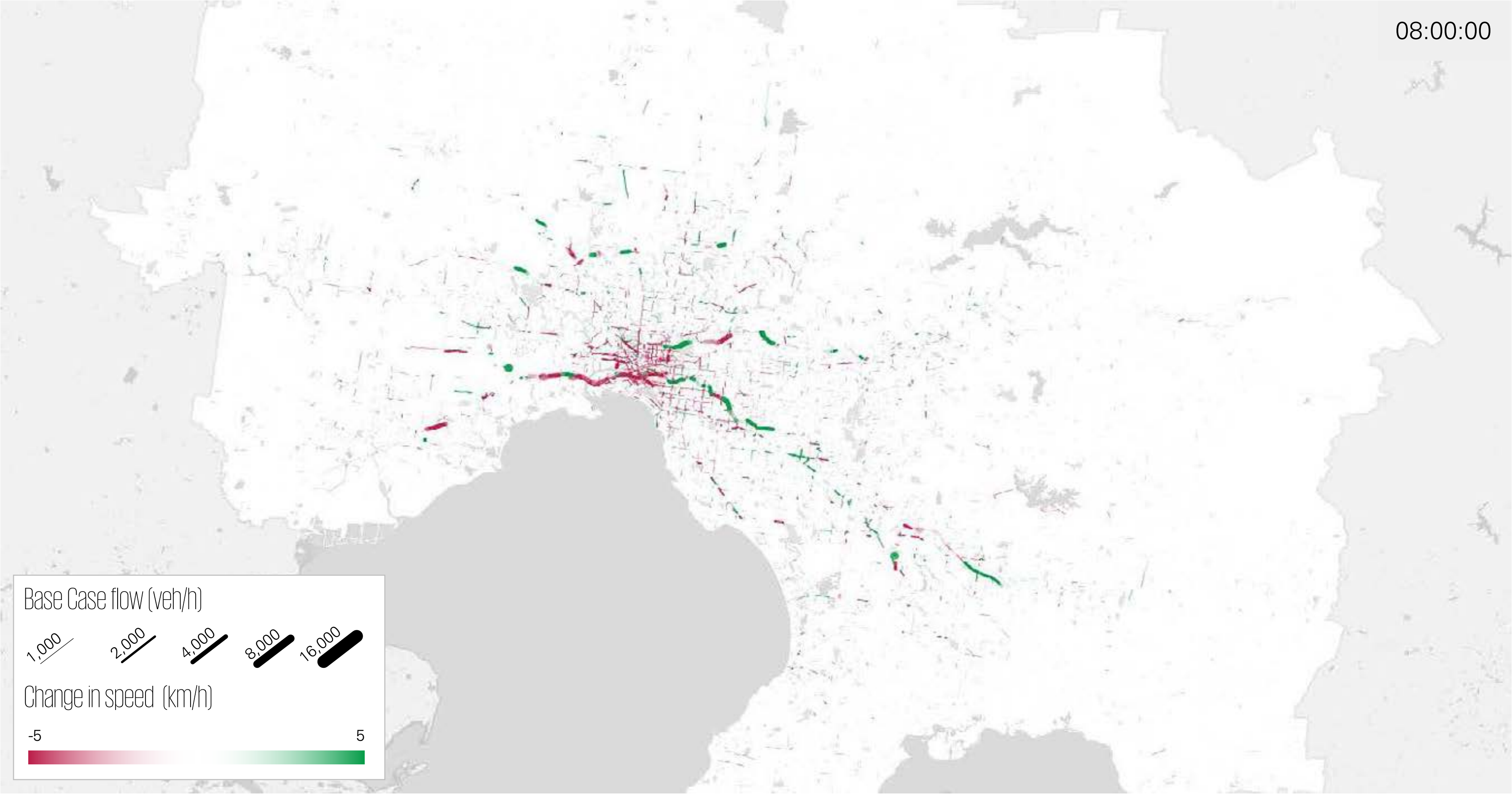
Change in speed: Private drive, Freight to night vs Private drive, morning peak

Source: MABM

Change in speed: Private drive, Expanded markets vs Private drive, No empty running morning peak

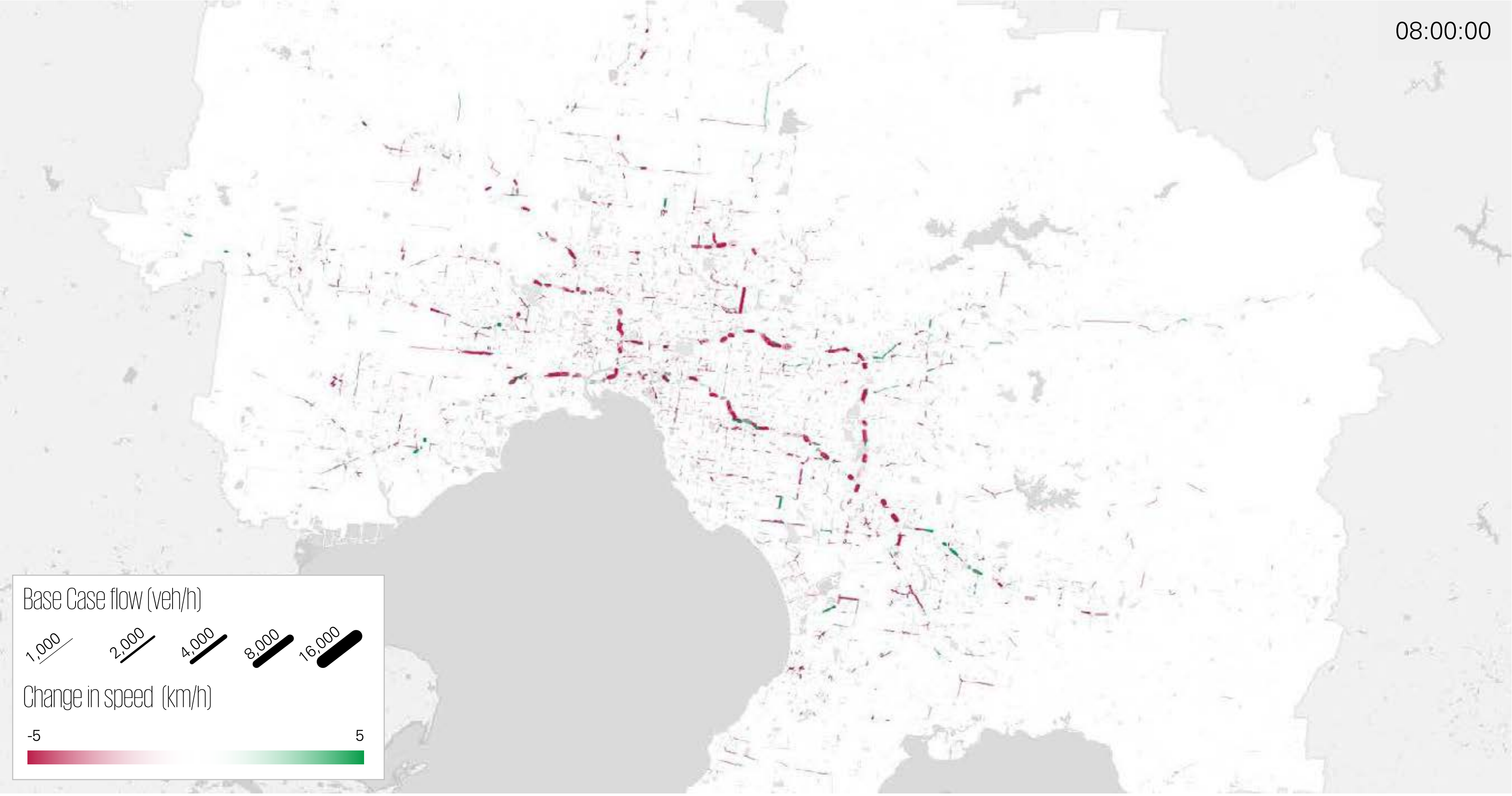
Source: MABM

Change in speed: Private drive, Station drop-off and pick-up vs Private drive, morning peak



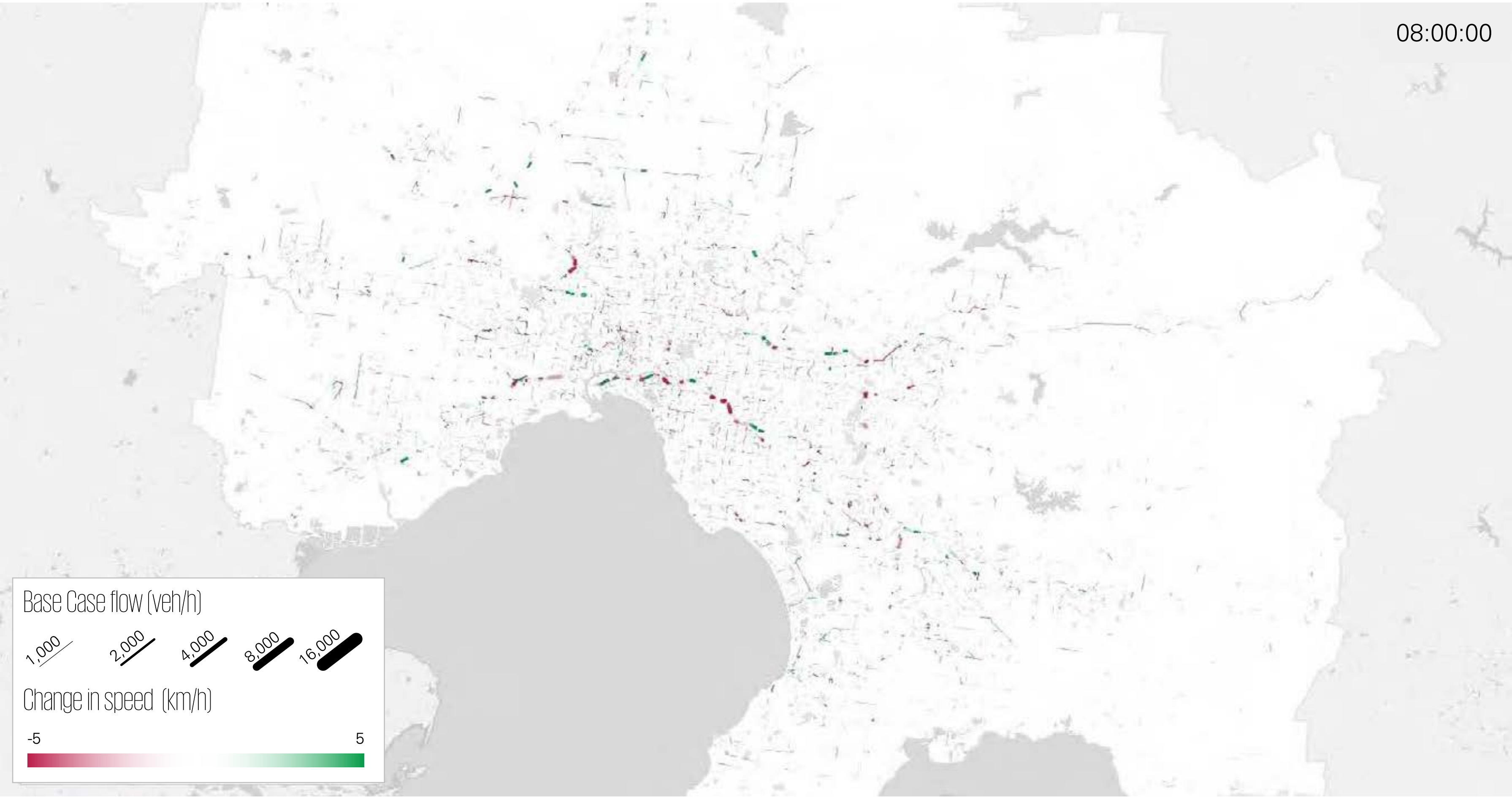
Source: MABM

Change in speed: Fleet street, Subscription fare vs Fleet street, morning peak



Source: MABM

Change in speed: Fleet street, Low MUTT vs Fleet street, morning peak



Source: MABM

Change in speed: Fleet street, Low flow vs Fleet street, morning peak

Source: MABM

Change in speed: Fleet street, No mode shift vs Fleet street, morning peak

Source: MABM

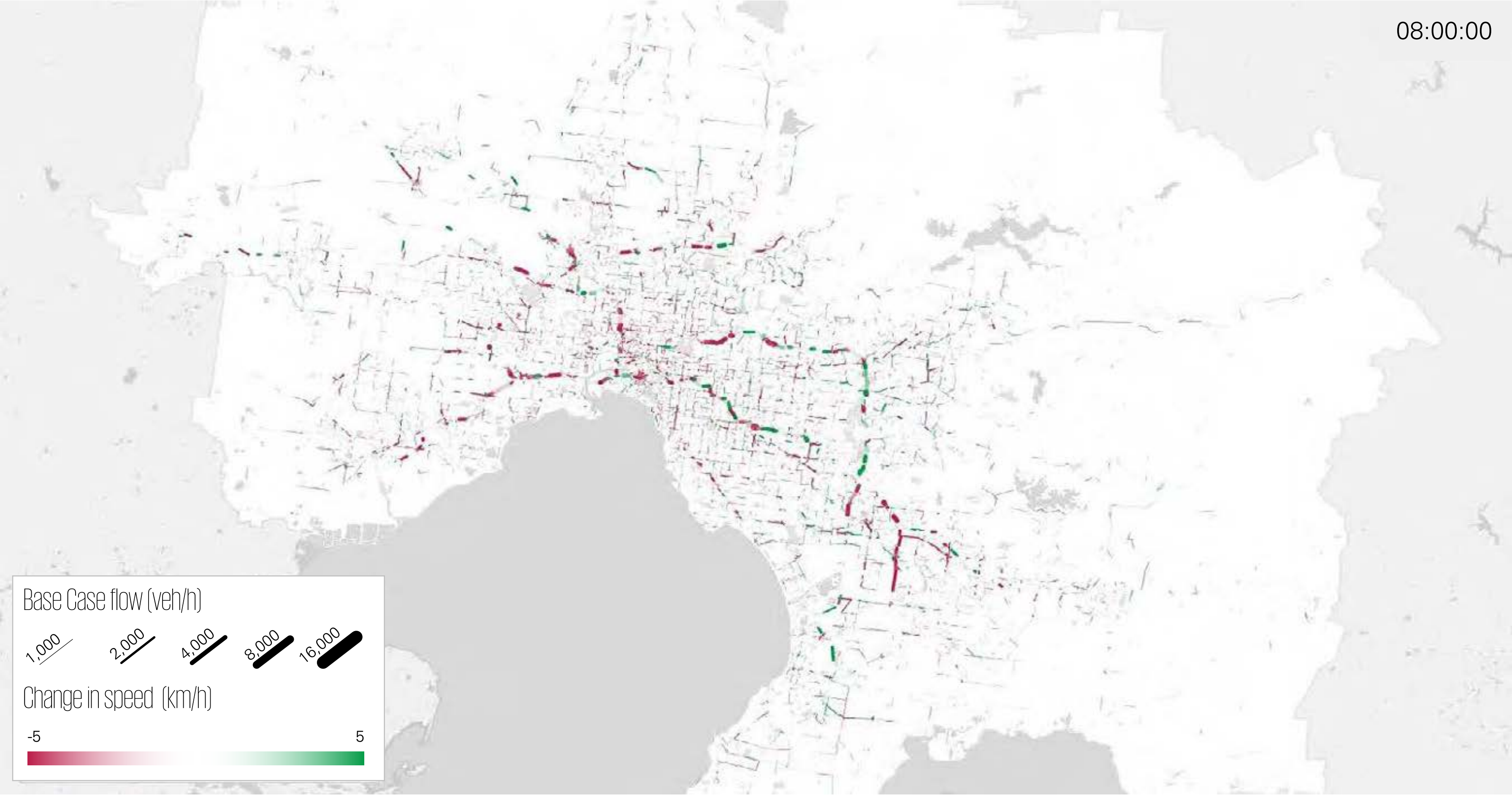
Change in speed: Fleet street, Calibrated fleet size vs Fleet street, morning peak

Source: MABM

Change in speed: Fleet Street, No new (pre-construction) major road projects vs Fleet street, morning peak

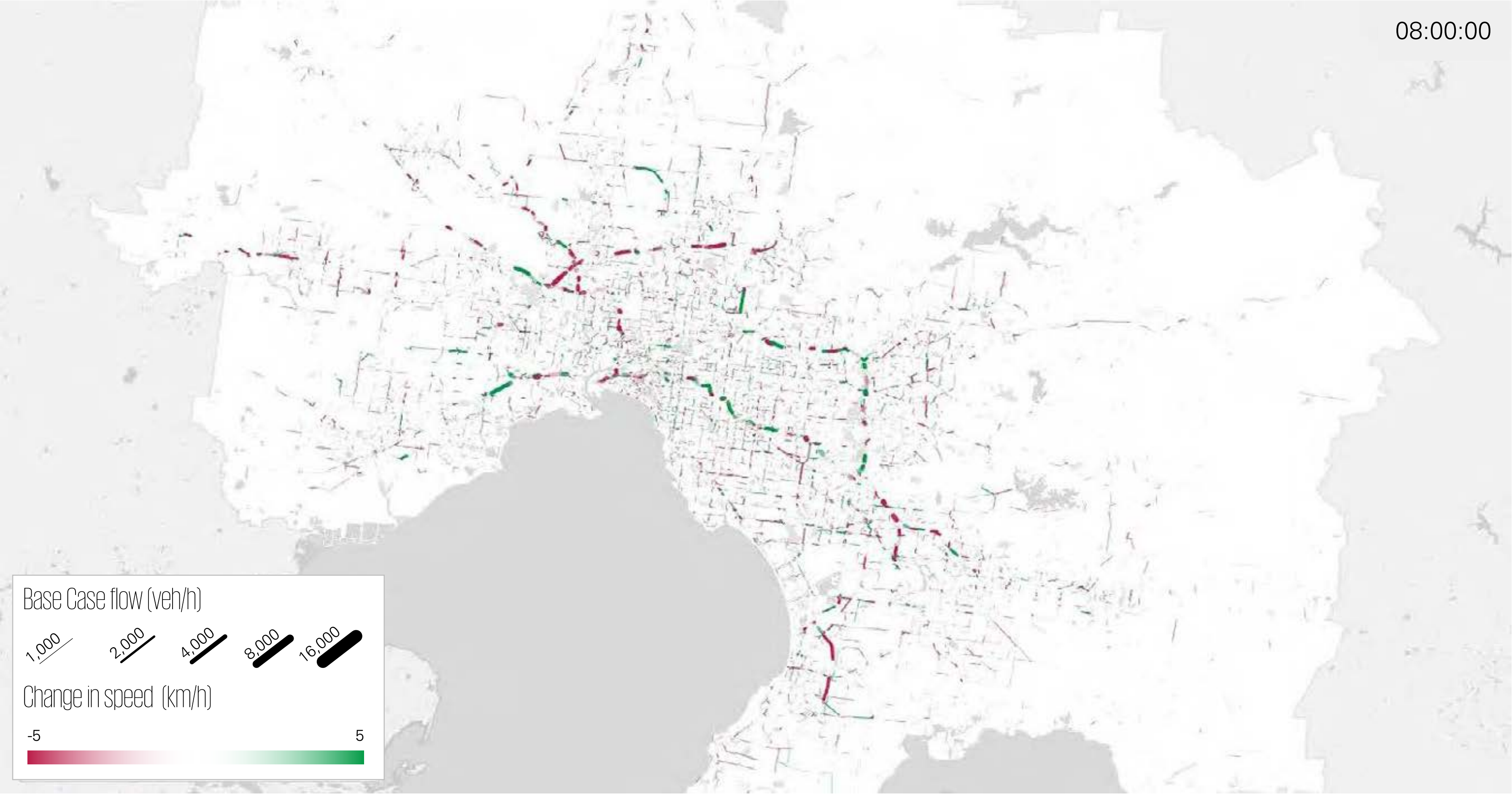
Source: MABM

Change in speed: Slow lane, Low MUTT vs Slow lane, morning peak



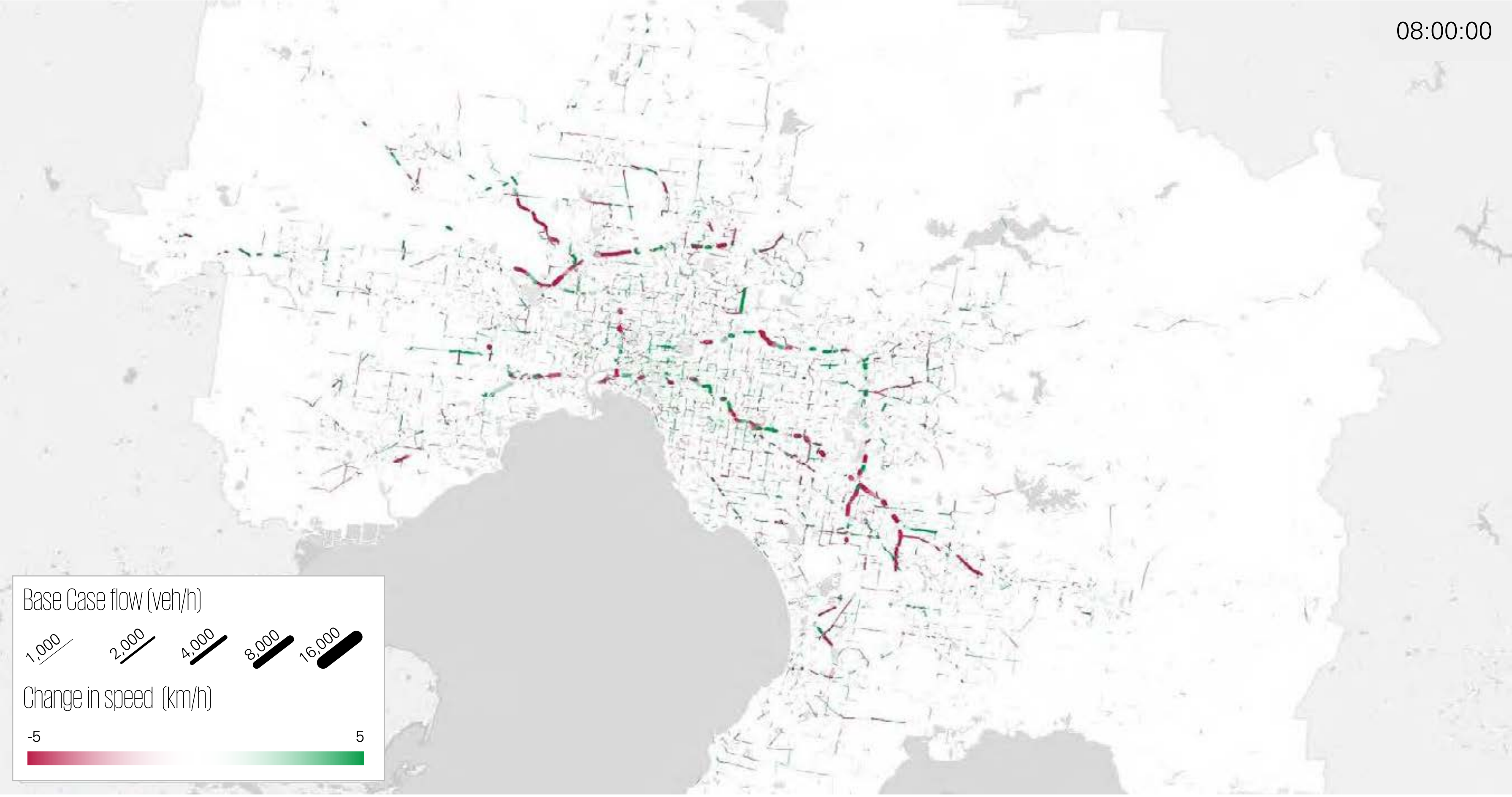
Source: MABM

Change in speed: Slow lane, Low flow vs Private drive, morning peak



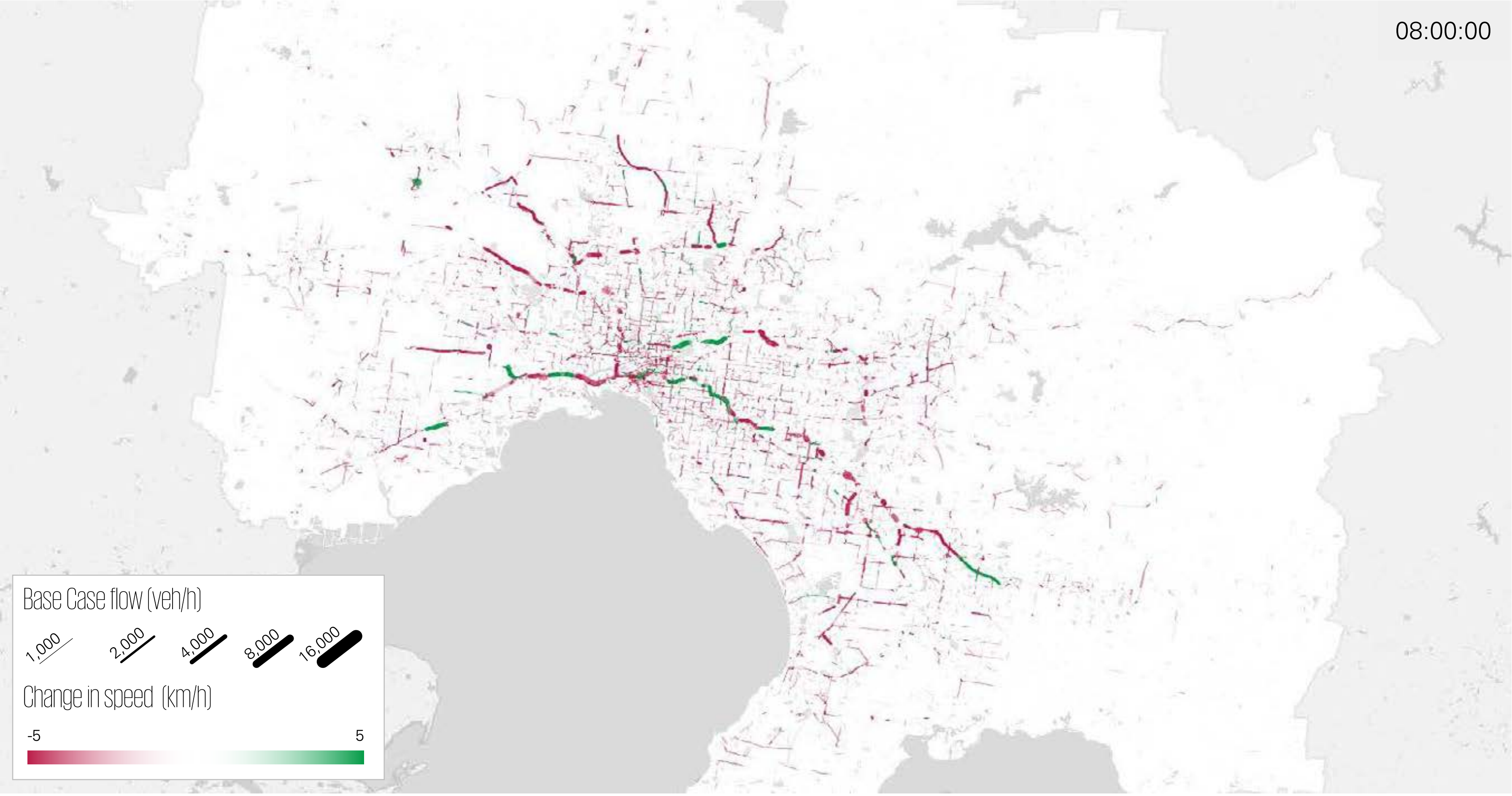
Source: MABM

Change in speed: Slow lane, No mode shift vs Slow lane, morning peak



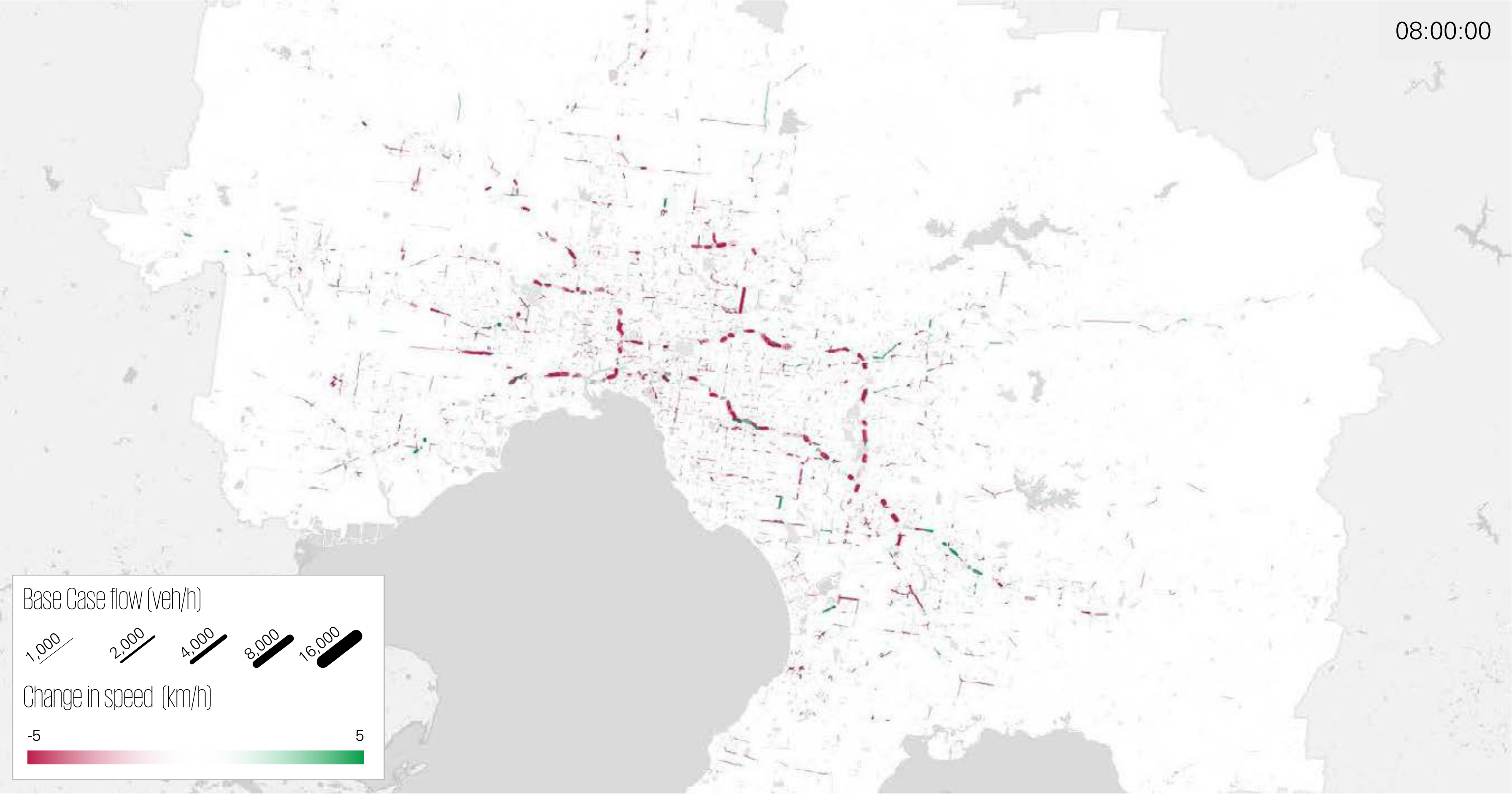
Source: MABM

Change in speed: Slow lane, Private slow lane vs Private drive, morning peak



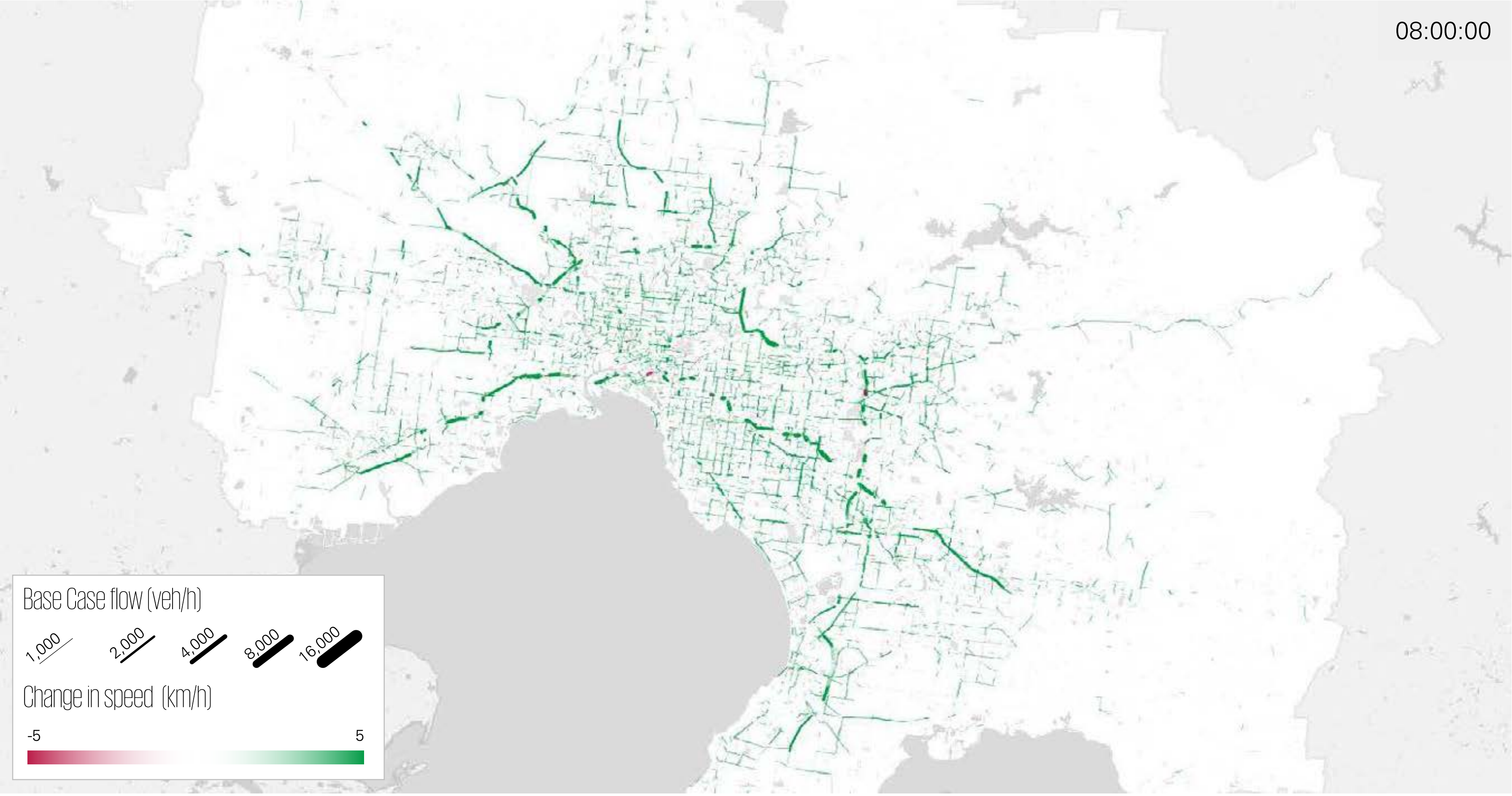
Source: MABM

Change in speed: Hydrogen highway, No empty running vs Hydrogen highway, morning peak



Source: MABM

Change in speed: Mix of scenarios vs Dead end, morning peak

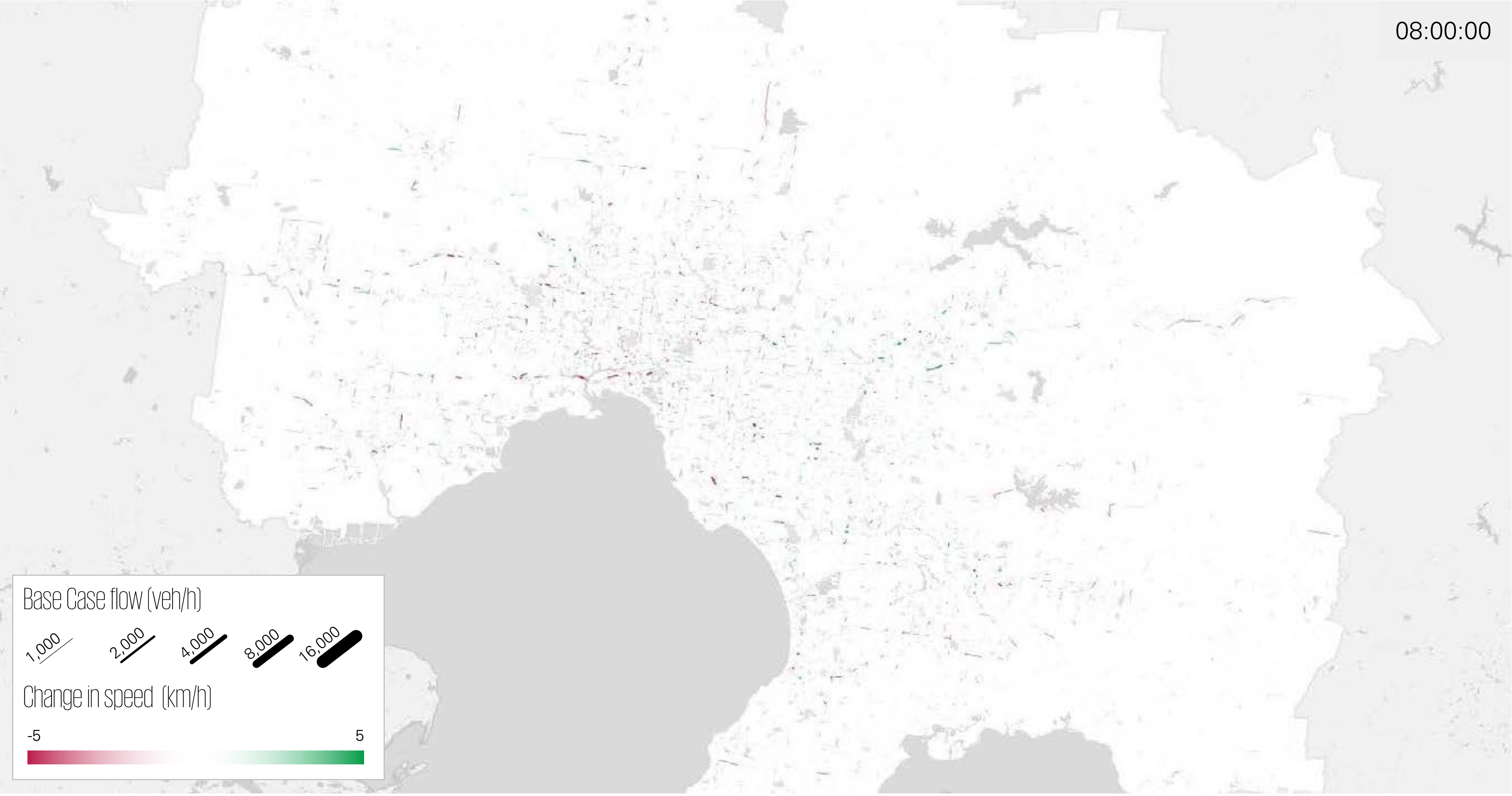


Source: MABM

Change in speed: Mix of scenarios, Centralised land use vs Mixed scenario, morning peak

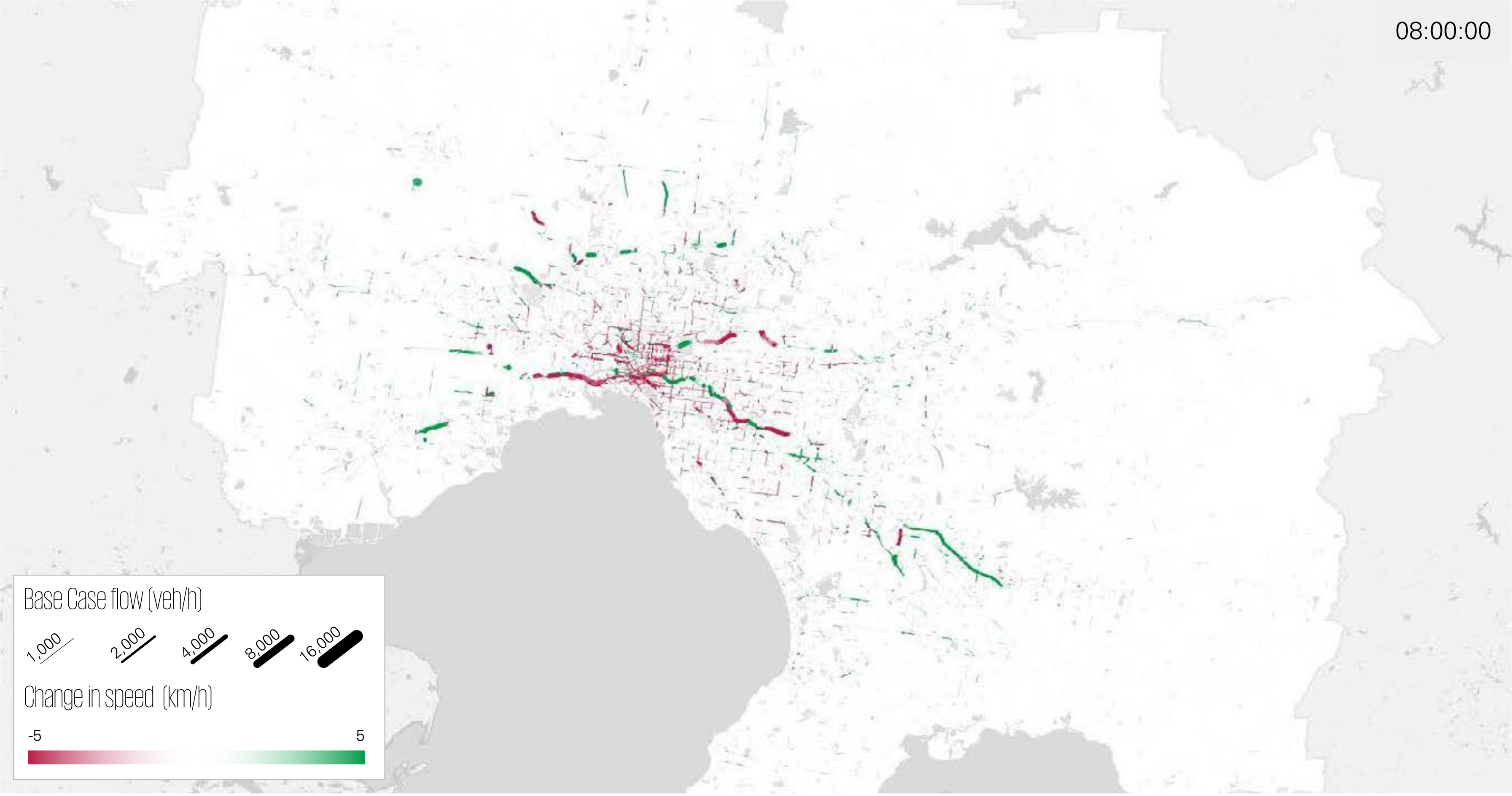
Source: MABM

Change in speed: Mix of scenarios, Expanded land use vs Mixed scenario, morning peak



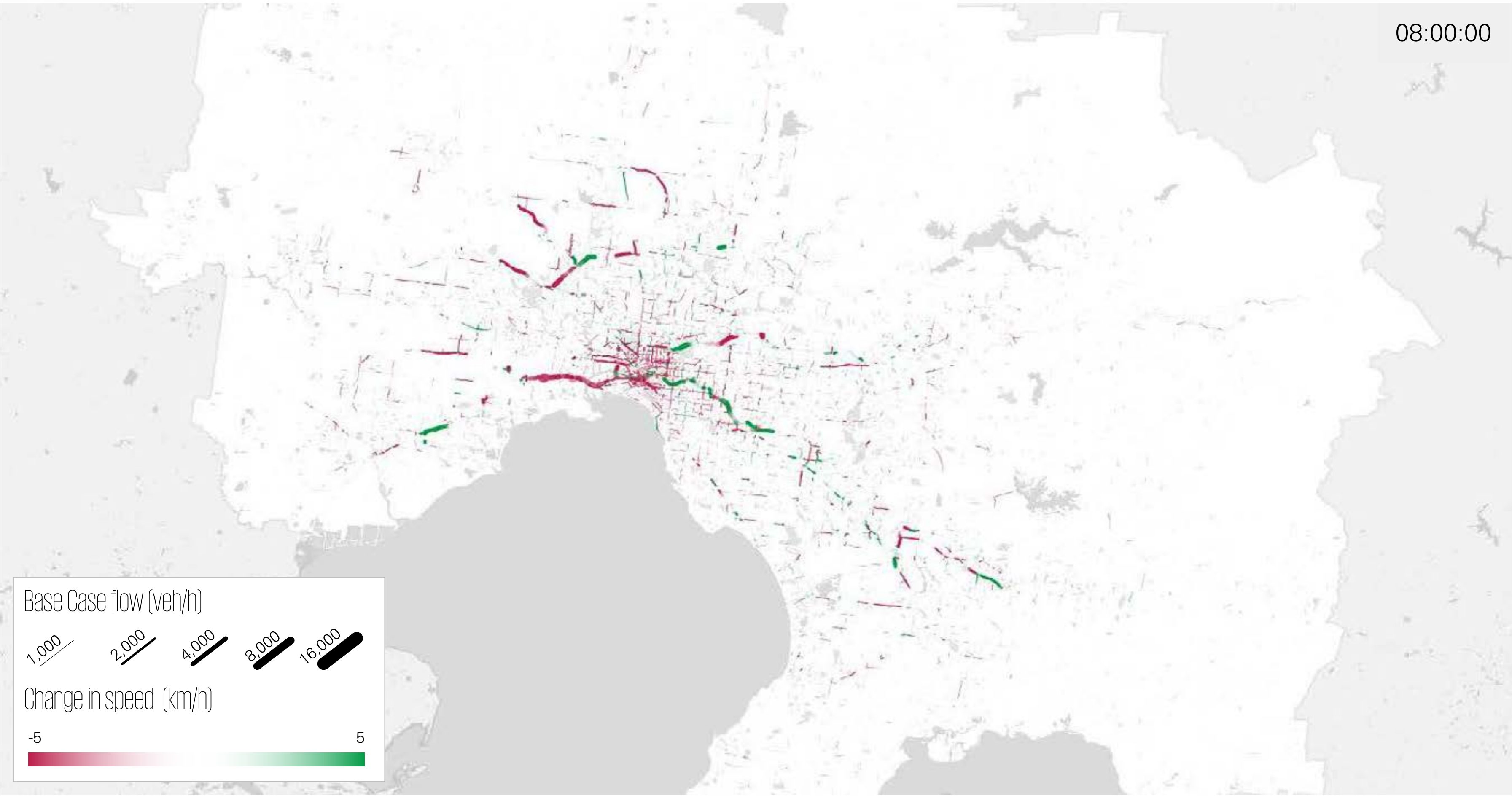
Source: MABM

Change in speed: Private drive, Centralised land use vs Private drive, Dead Running, morning peak



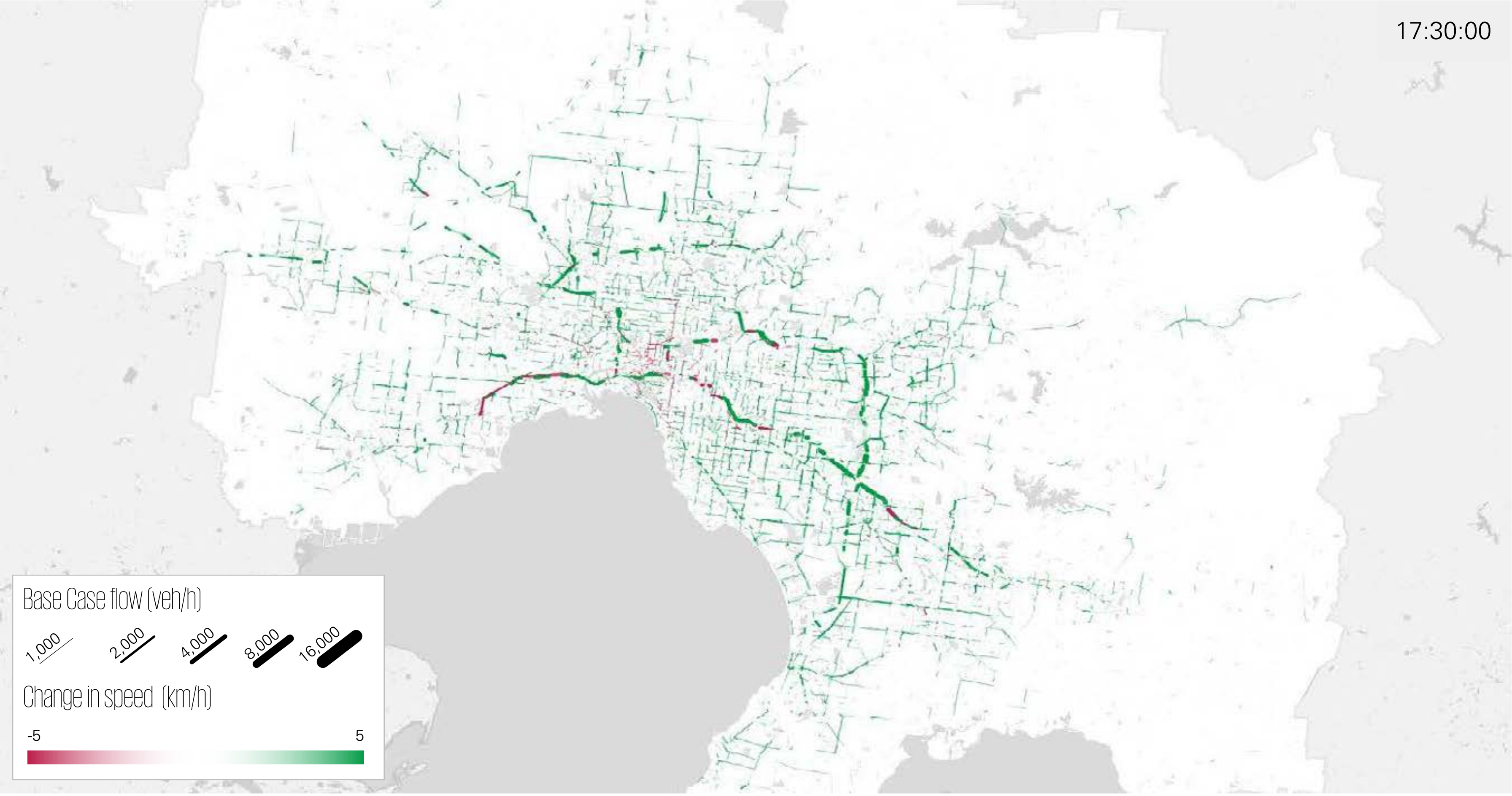
Source: MABM

Change in speed: Private drive, Expanded land use vs Private drive, Dead Running, morning peak



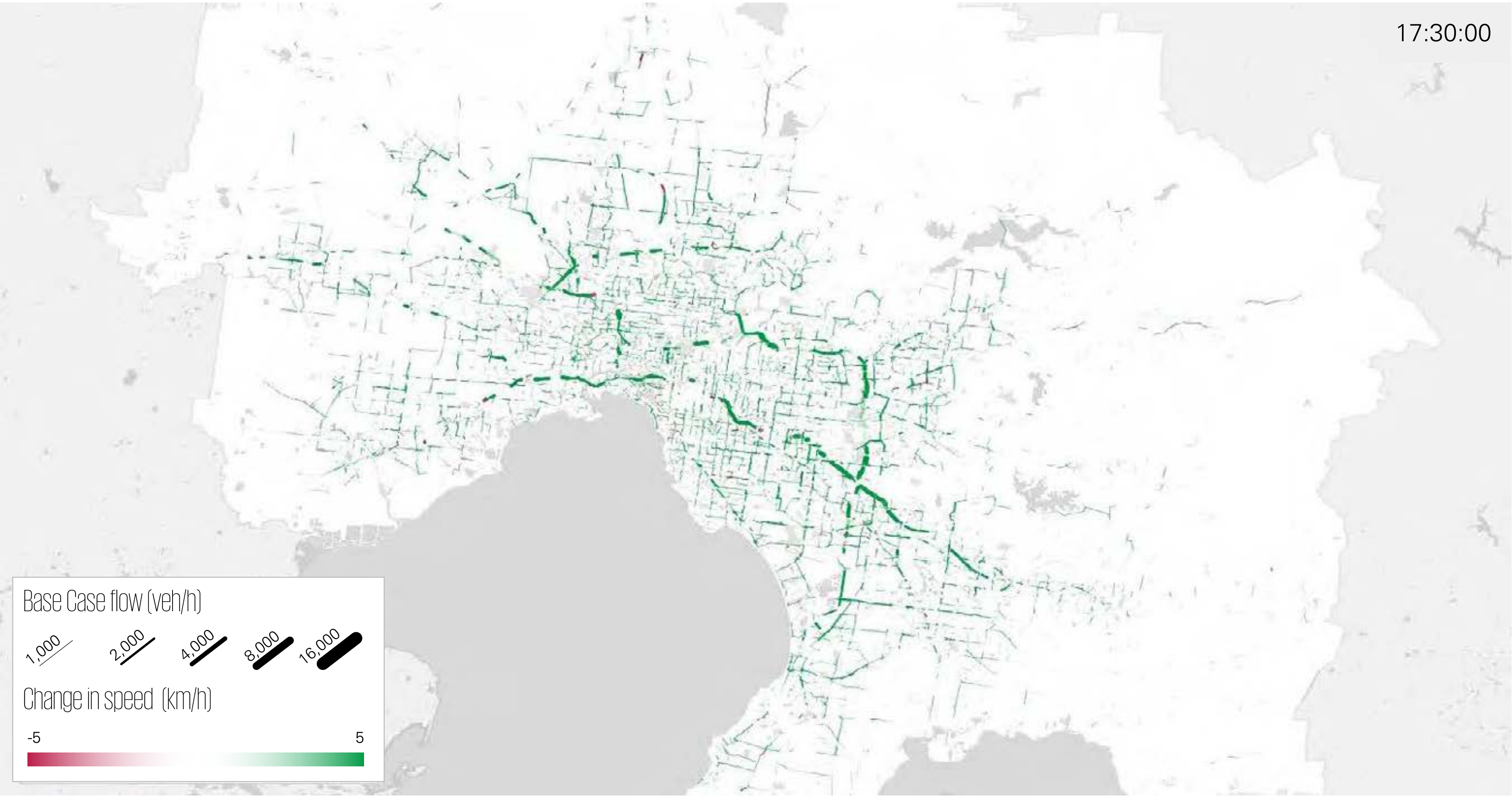
Source: MABM

Change in speed: Private drive vs Dead end, afternoon peak



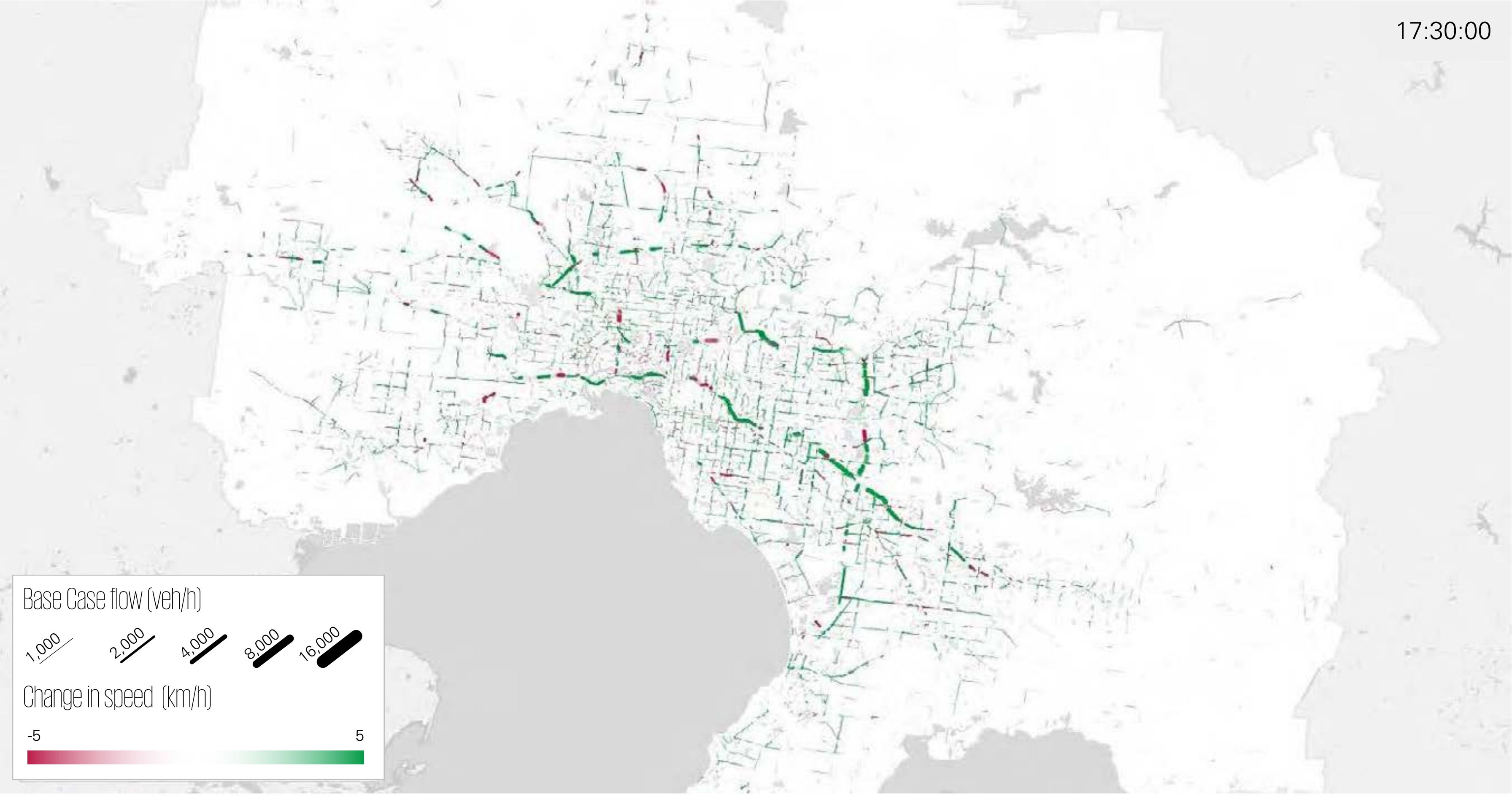
Source: MABM

Change in speed: Fleet street vs Dead end, afternoon peak



Source: MABM

Change in speed: Slow lane vs Dead end, afternoon peak

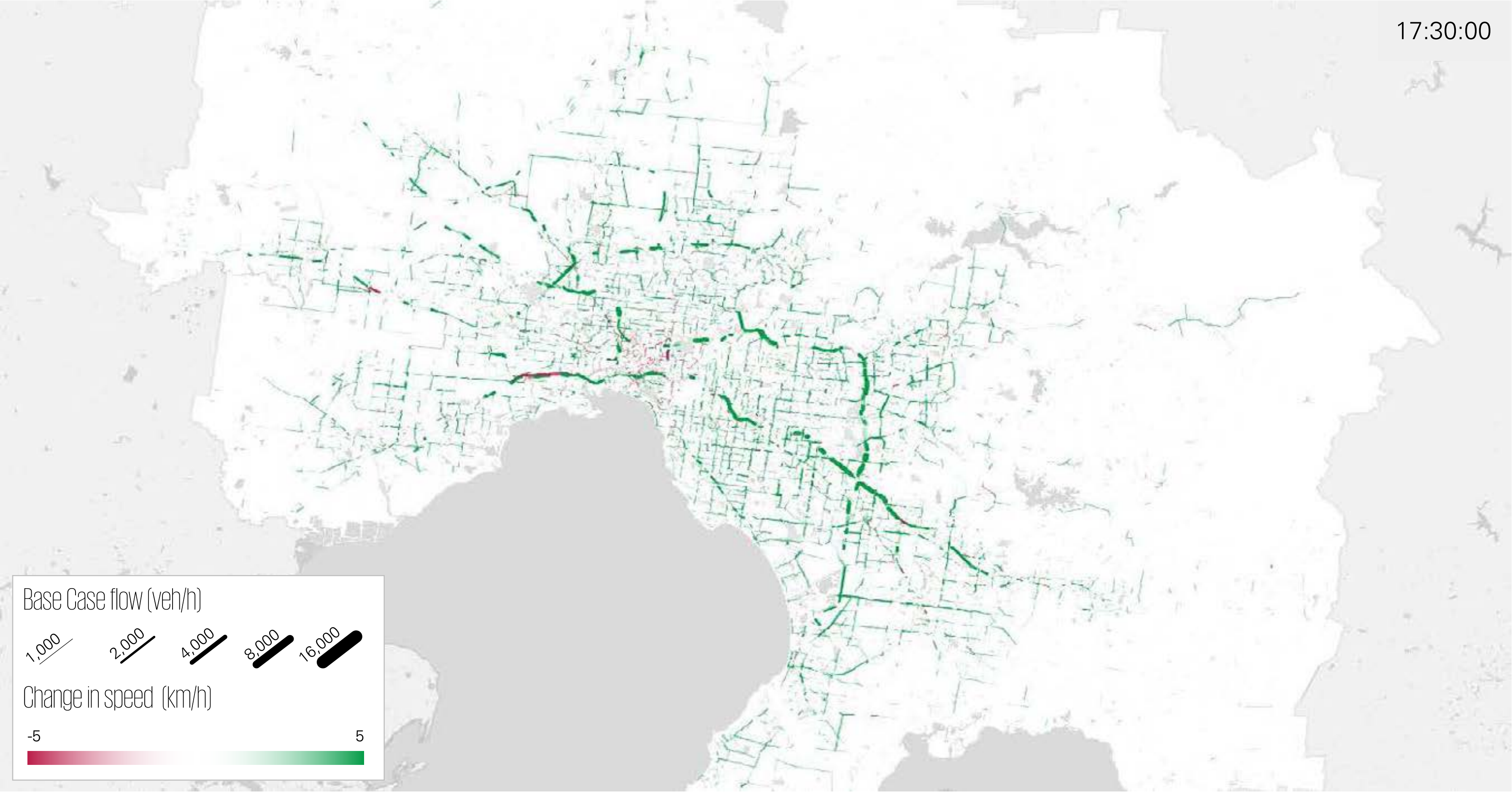


Source: MABM

Change in speed: Electric avenue vs Dead end, afternoon peak

Source: MABM

Change in speed: Hydrogen highway vs Dead end, afternoon peak



Source: MABM

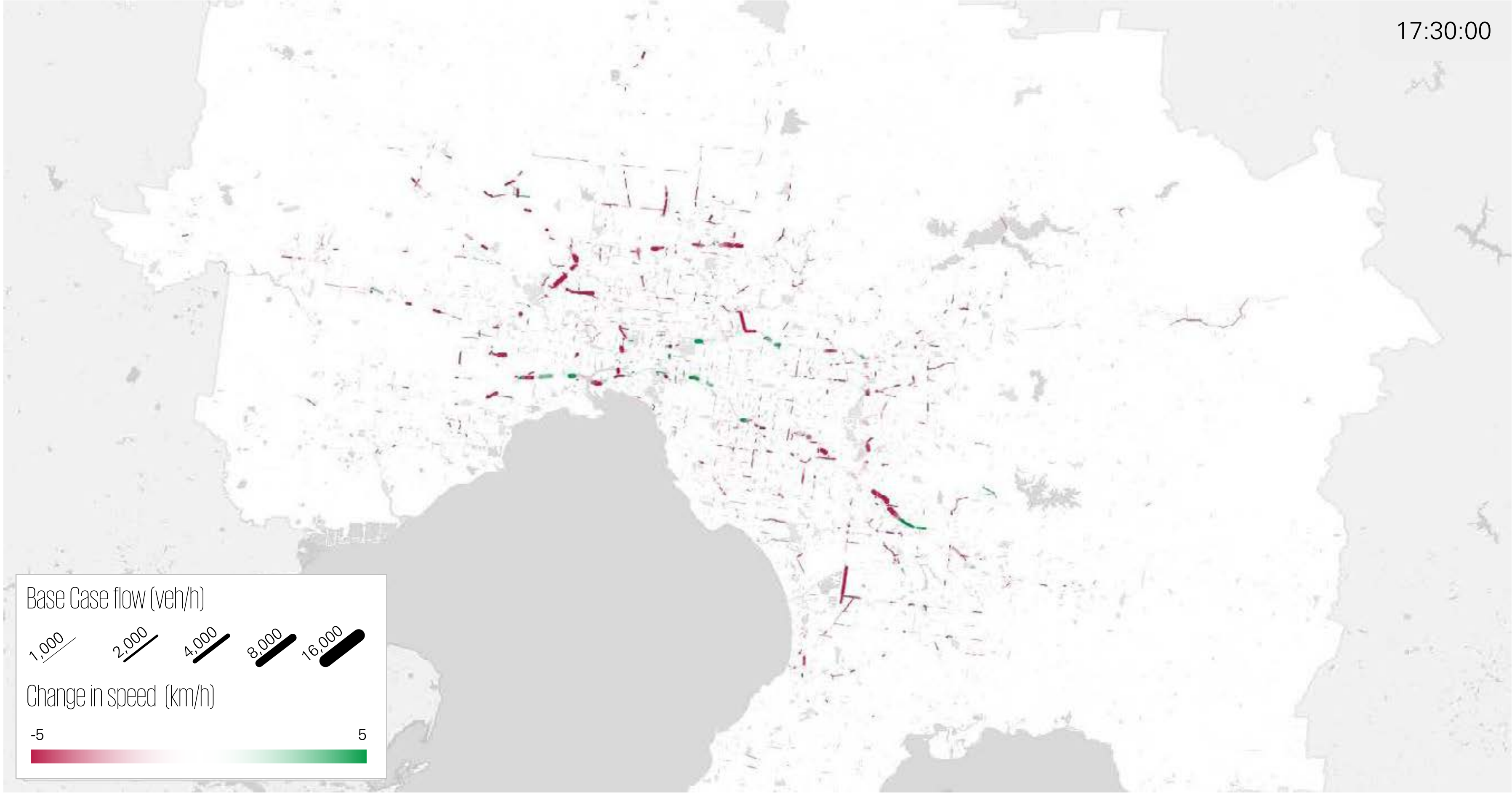
Change in speed: Private drive, No empty running vs Private drive, afternoon peak

Source: MABM

Change in speed: Private drive, Low MUTT vs Private drive, No empty running, afternoon peak

Source: MABM

Change in speed: Private drive, Low flow vs Private drive, No empty running, afternoon peak



Source: MABM

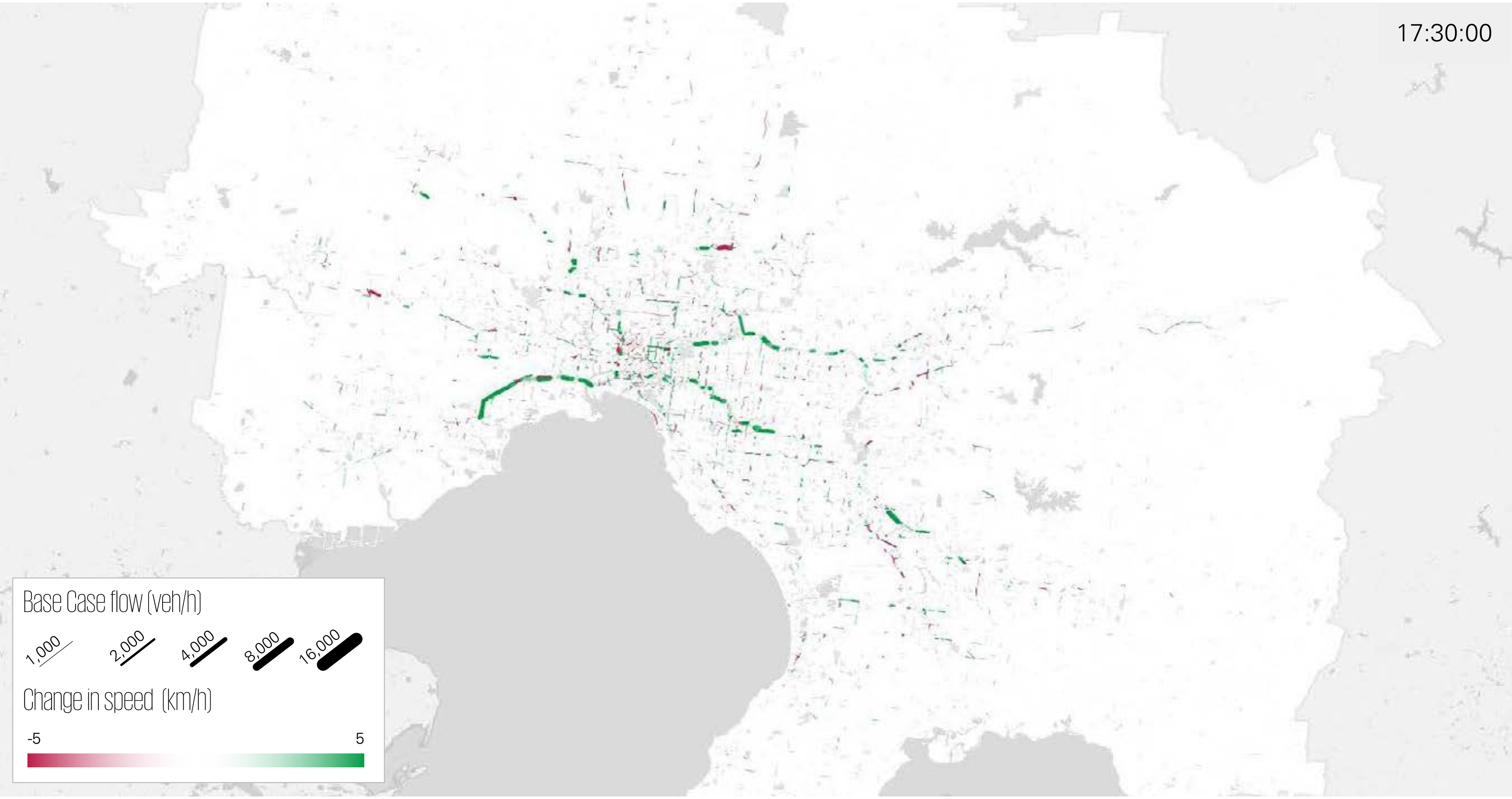
Change in speed: Private drive, No mode shift vs Private drive, No empty running, afternoon peak

Source: MABM

Change in speed: Private drive, Area based charge vs Private drive, afternoon peak

Source: MABM

Change in speed: Private drive, Distance based charge vs Private drive, afternoon peak



Source: MABM

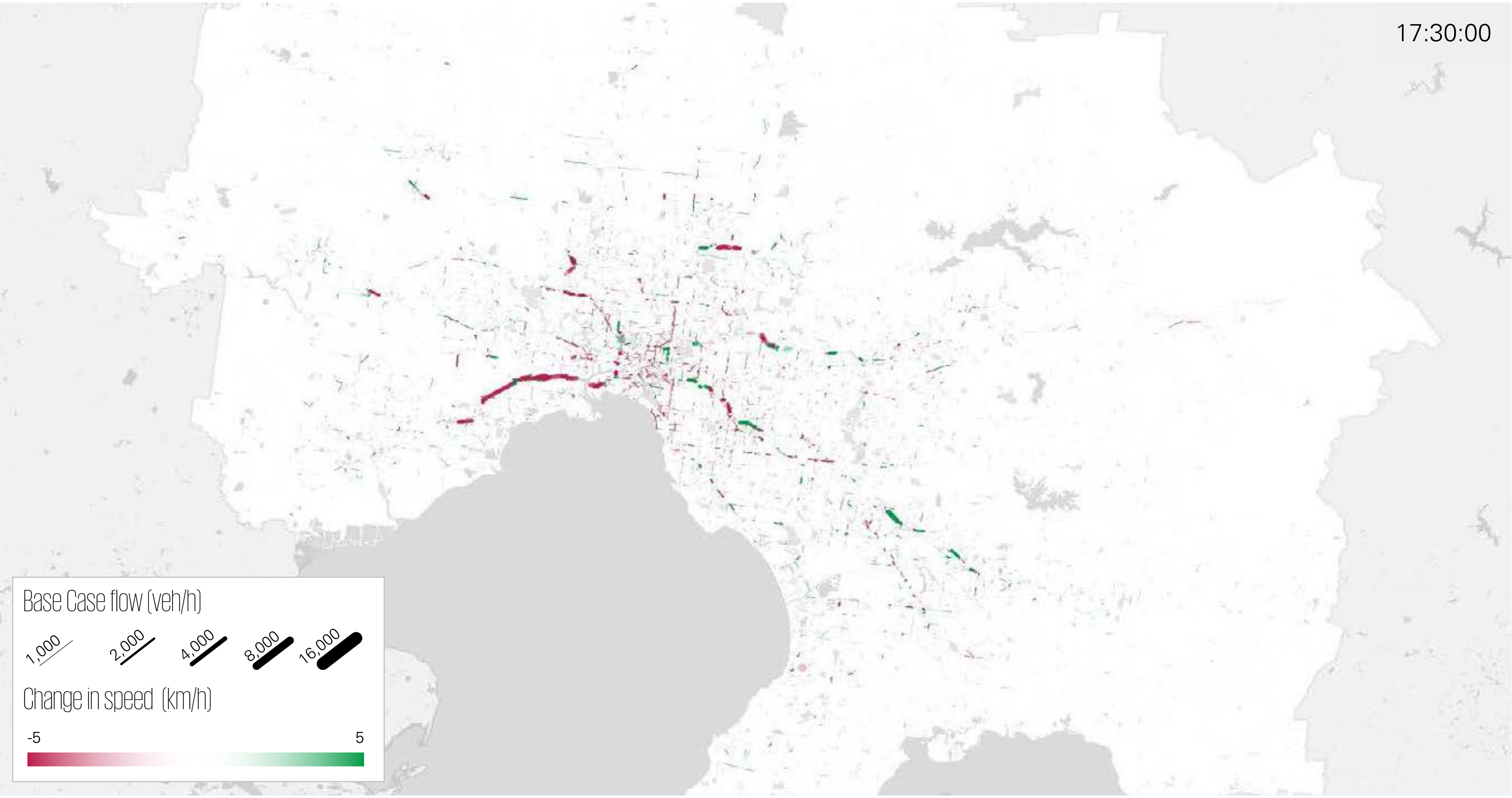
Change in speed: Private drive, Freight to night vs Private drive, afternoon peak

Source: MABM

Change in speed: Private drive, Expanded markets vs Private drive, No empty running, afternoon peak

Source: MABM

Change in speed: Private drive, Station drop-off and pick-up vs Private drive, afternoon peak



Source: MABM

Change in speed: Fleet street, Subscription fare vs Fleet street, afternoon peak

Source: MABM

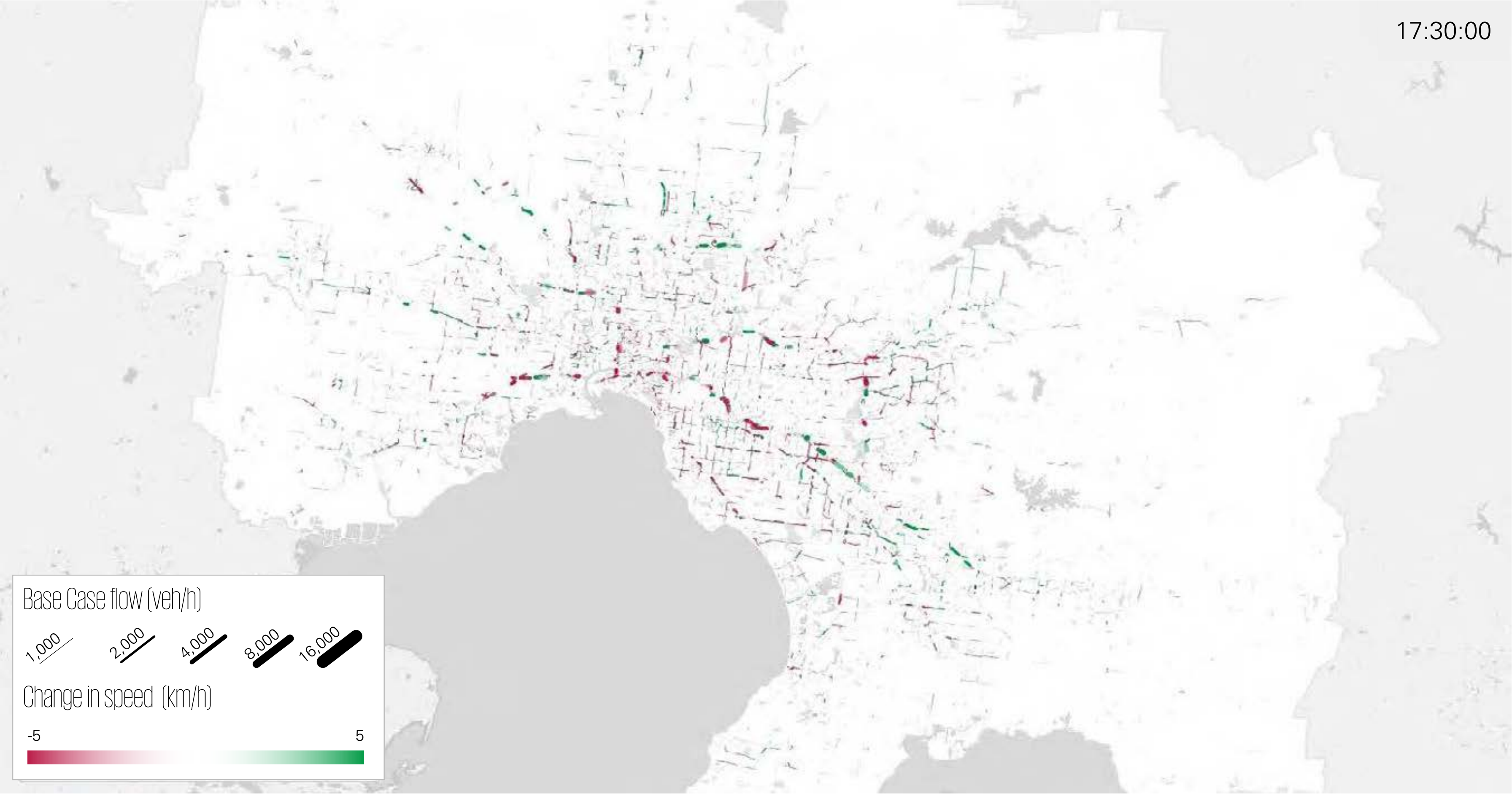
Change in speed: Fleet street, Low MUTT vs Fleet street, afternoon peak

Source: MABM

Change in speed: Fleet street, Low flow vs Fleet street, afternoon peak

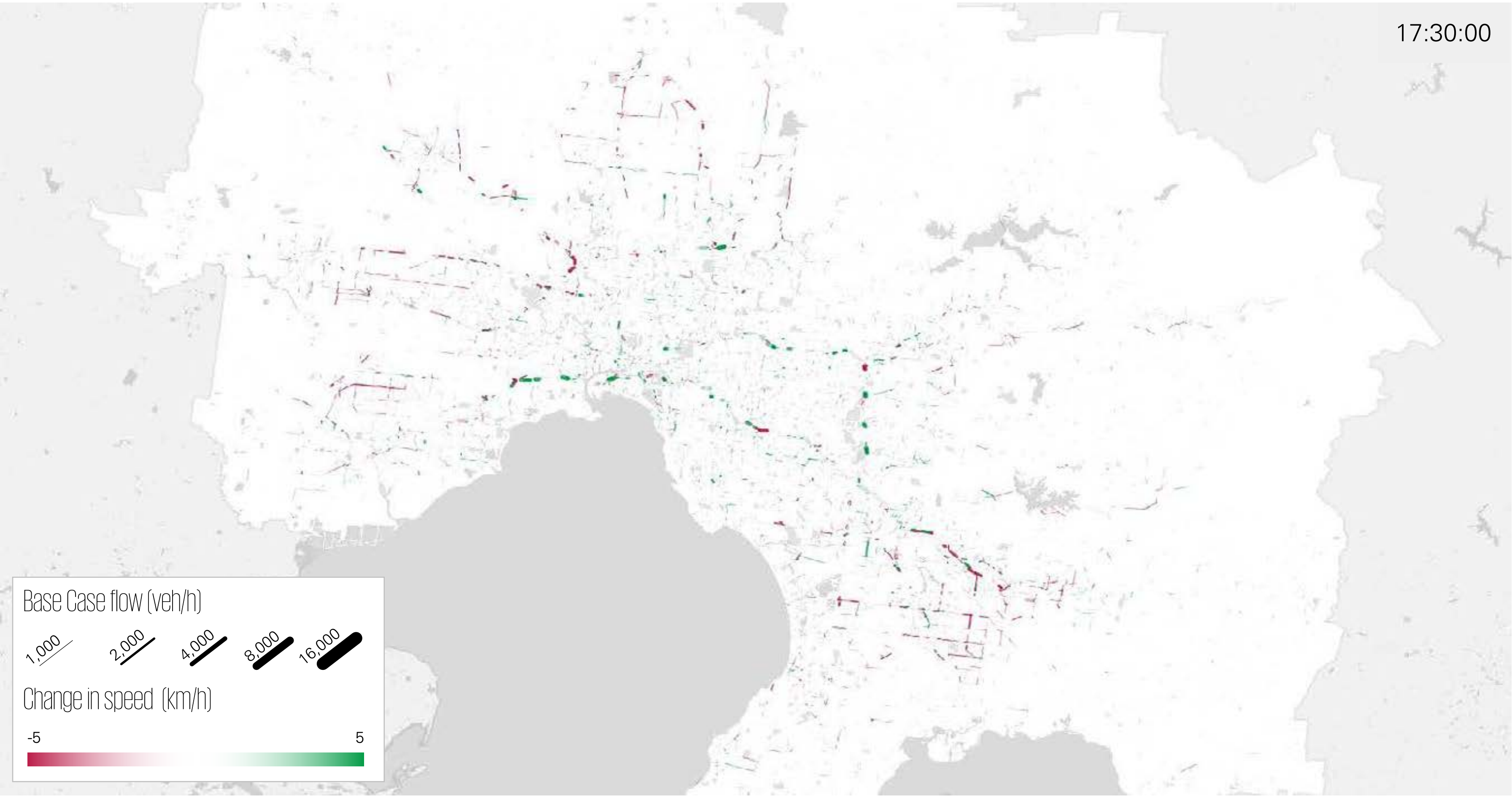
Source: MABM

Change in speed: Fleet street, No mode shift vs Fleet street, afternoon peak



Source: MABM

Change in speed: Fleet street, Calibrated fleet size vs Fleet street, afternoon peak

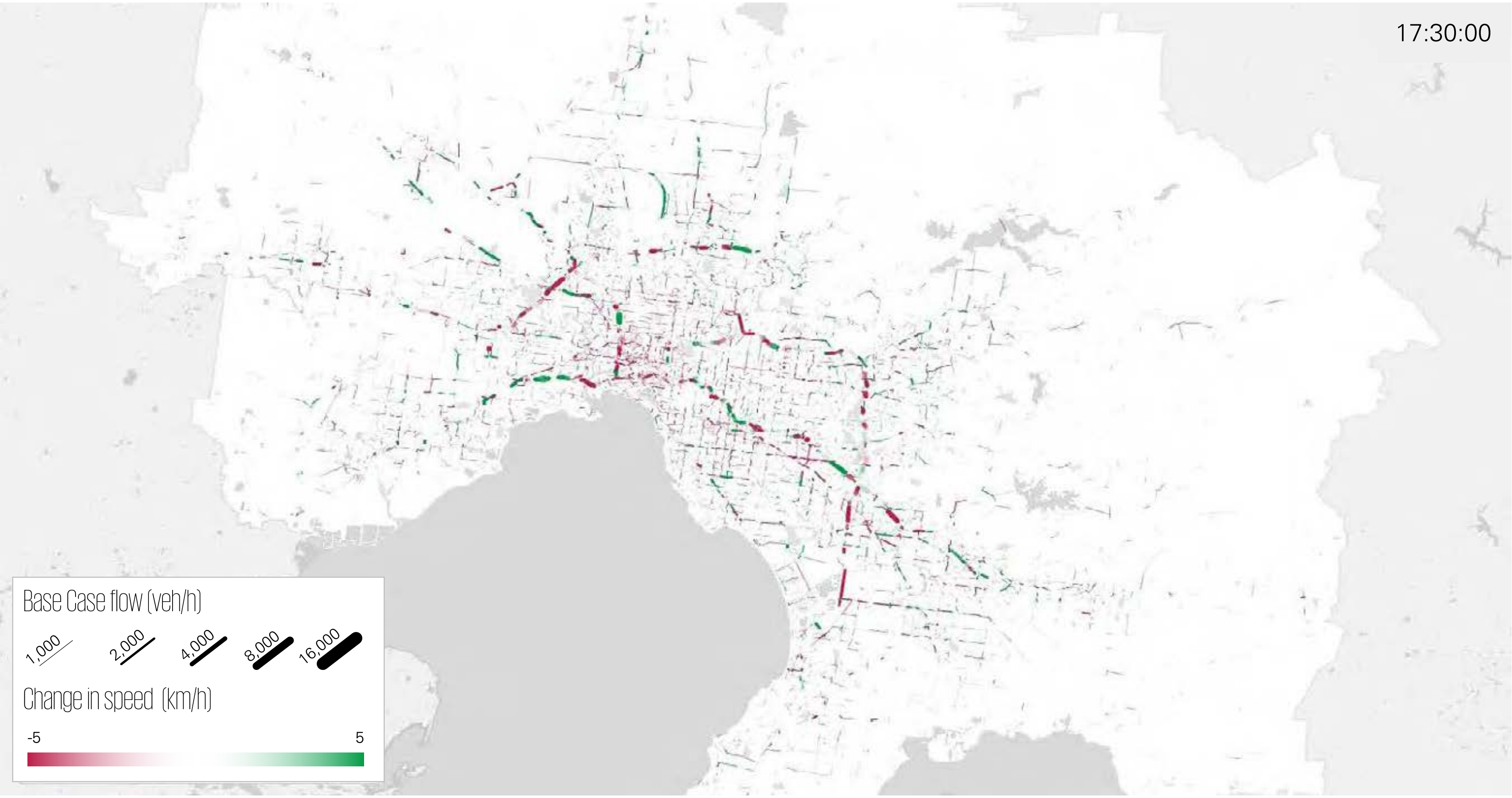


Source: MABM

Change in speed: Fleet Street, No new (pre-construction) major road projects vs Fleet street, afternoon peak

Source: MABM

Change in speed: Slow lane, Low MUTT vs Slow lane, afternoon peak



Source: MABM

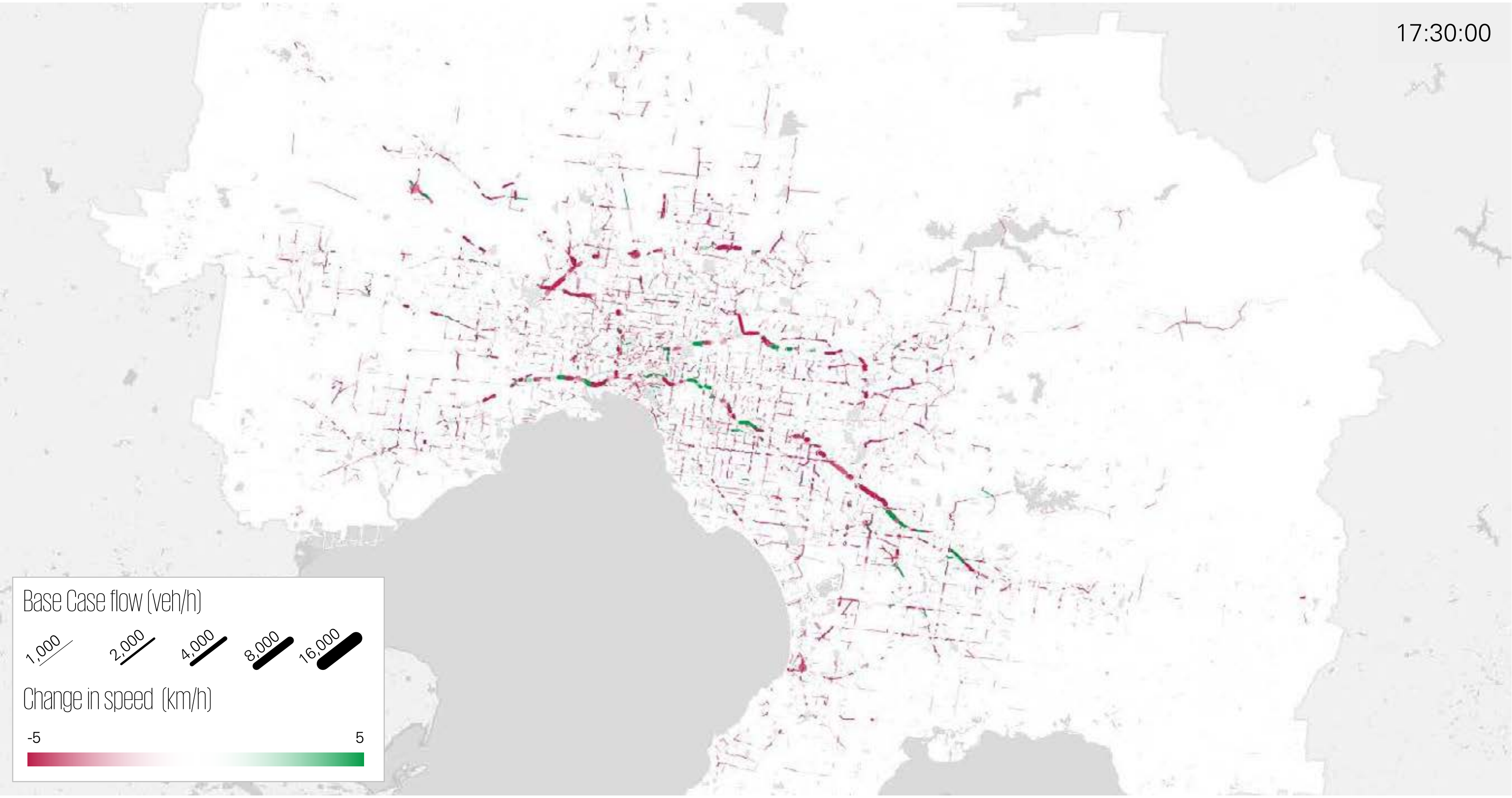
Change in speed: Slow lane, Low flow vs Slow lane, afternoon peak

Source: MABM

Change in speed: Slow lane, No mode shift vs Slow lane, afternoon peak

Source: MABM

Change in speed: Slow lane, Private slow lane vs Private drive, afternoon peak

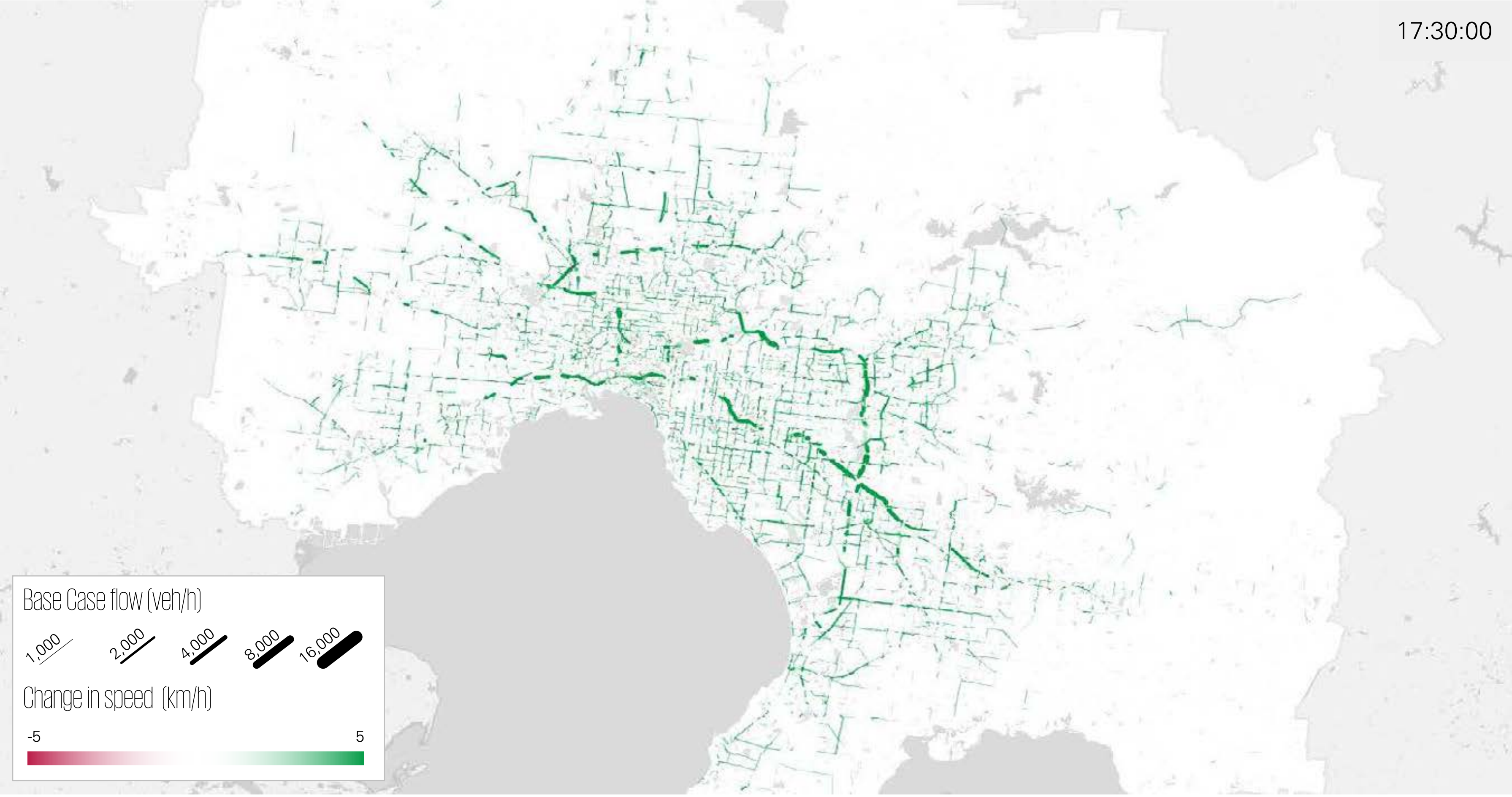


Source: MABM

Change in speed: Hydrogen highway, No empty running vs Hydrogen highway, afternoon peak

Source: MABM

Change in speed: Mix of scenarios vs Dead end, afternoon peak



Source: MABM

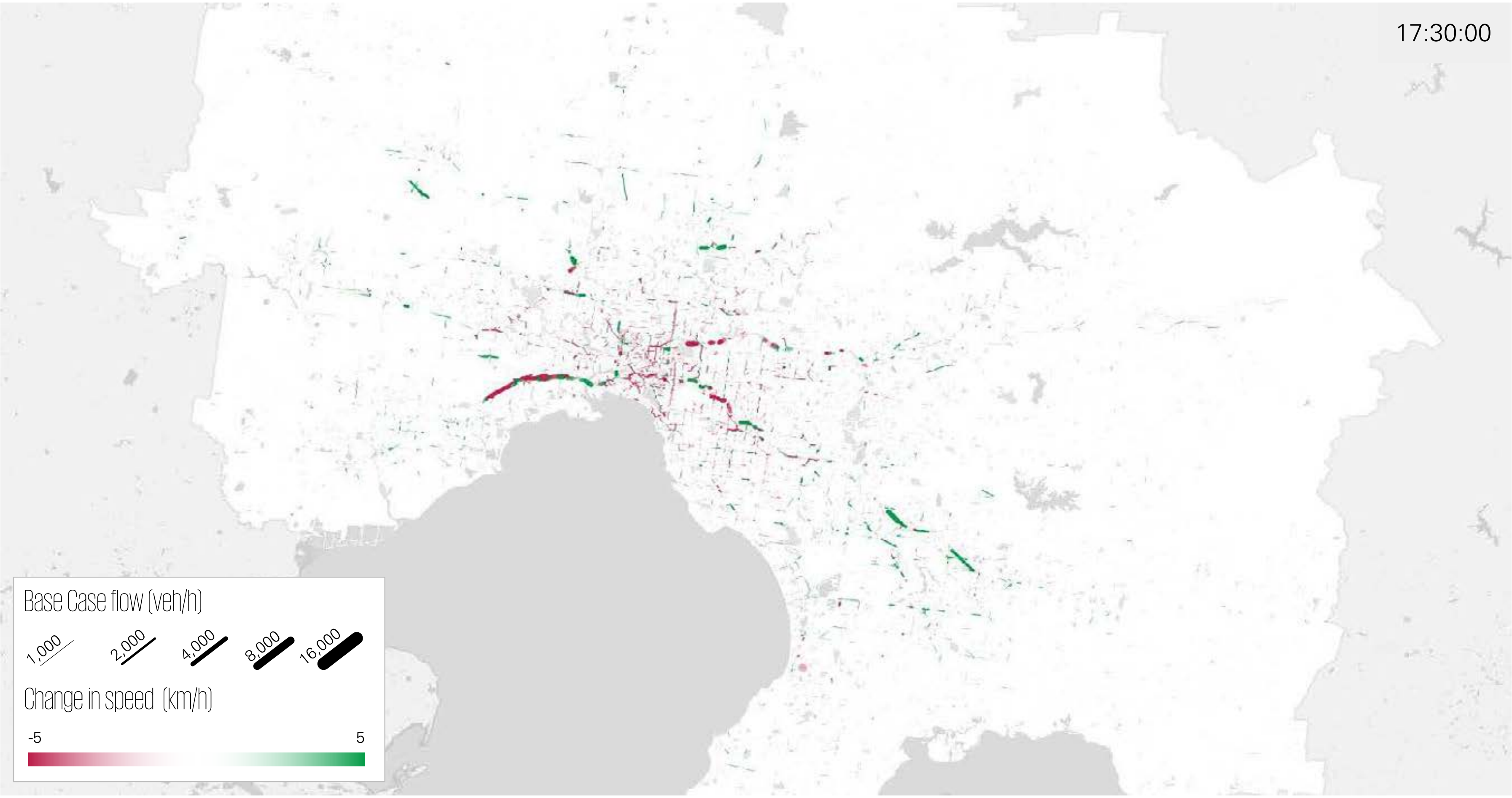
Change in speed: Mix of scenarios, Centralised land use vs Mixed scenario, afternoon peak

Source: MABM

Change in speed: Mix of scenarios, Expanded land use vs Mixed scenario, afternoon peak

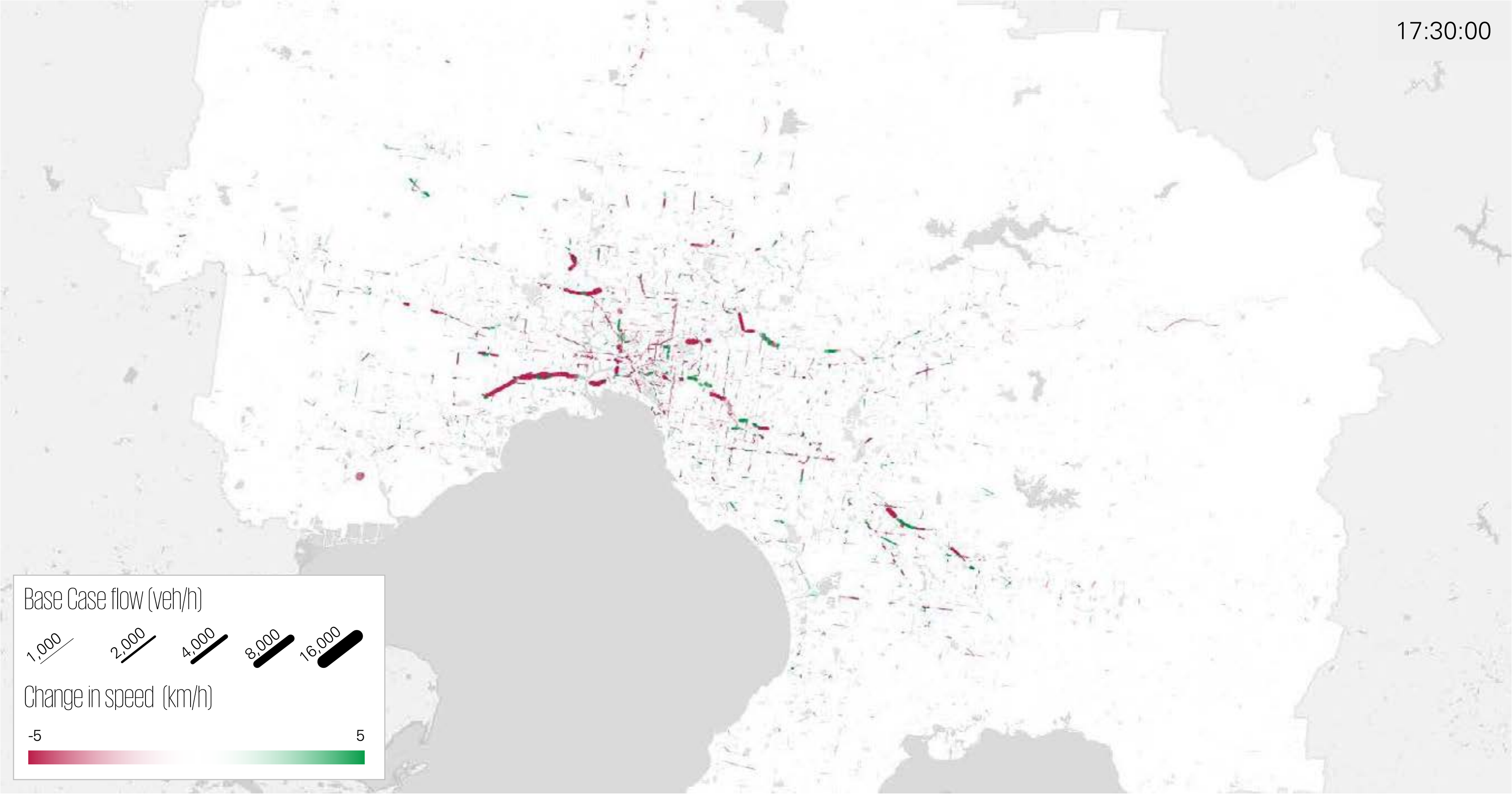
Source: MABM

Change in speed: Private drive, Centralised land use vs Private drive, Dead Running, afternoon peak



Source: MABM

Change in speed: Private drive, Expanded land use vs Private drive, Dead Running, afternoon peak



Source: MABM

Appendix G: Statewide analysis

Appendix G: Statewide analysis

Background

The analysis and recommendations presented in this report are based on the modelling undertaken with the MABM, an activity and agent based model that covers the Melbourne metropolitan area. The MABM enables the modelling of automated vehicles, including on-demand vehicles and the complexities of routing vehicles on demand and empty running in a way that is not possible with a traditional four step transport demand model.

The current version of the MABM only covers the Melbourne metropolitan area. Therefore, in order to provide estimates of the potential impacts of automated vehicles across areas outside of metropolitan Melbourne information from the Victorian Integrated Transport Model (VITM) was used in conjunction with information from the MABM to extrapolate the results from the Melbourne metropolitan area across the entire state of Victoria.

The primary analysis required from the statewide modelling was a set of road based demand, distance and travel time matrices, based on SA2 regions for the core scenarios.

Methodology

In order to produce this information the following methodology was use:

- Creating a 2046 Dead end scenario for the entire state using the Statewide version of the VITM with zones aggregated to the SA2 geographies;
- Factoring the highway demand from the 2046 Statewide Dead end scenario according to differences observed between the MABM Dead end scenario and the core scenarios;
- Altering the highway capacities in the Statewide version of the VITM to reflect the capacity changes in the MABM; and
- Re-run the highway assignment from the Statewide version of the VITM to produce new distance and travel time matrices.

The factors used to create estimations of vehicle demand for the core scenarios were derived from observing the differences between the MABM scenarios. These factors are provided below and are based on the changes observed in the Outer North West region within the MABM study area, as this region is assumed to be the most similar with respect to travel characteristics to the rest of Victoria.

Table 1: Factors applied to the Statewide VITM

Scenario	Matrix Factor	Capacity Factor
Dead end	1.00	1.00
Private drive	1.03	1.75
Fleet street	0.83	1.75
Slow lane	0.92	1.30
Electric avenue	1.00	1.00

Outcomes

Rerunning the statewide VITM highway assignments with the factored vehicle demand and factored road capacities produced new travel time and distance SA2 to SA2 matrices. From these matrices the change from the Dead end scenario in the vehicle time travelled and vehicle distance travelled and therefore average speed can be calculated and is shown in the table below.

This indicates that all of the scenarios involving autonomous vehicles produce a reduction in vehicle travel times.

Table 2: Statewide vehicle demand change from the Dead end scenario

Scenario	Change in vehicle distance travelled	Change in vehicle time travelled	Change in average speed
Dead end	-	-	-
Private drive	+3%	-5%	+8%
Fleet street	-18%	-25%	+9%
Slow lane	-9%	-14%	+6%
Electric avenue	0%	0%	0%

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