Submission to the Select Committee on Productivity in Australia

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1. Executive summary

Australia's productivity challenge is often framed in terms of labour supply, skills, or innovation. While these factors are important, they risk obscuring a more fundamental constraint: the quality, predictability, and suitability of the infrastructure that enables technology to be used effectively in practice.

This submission focuses on technology and infrastructure as productivity enablers. It argues that productivity is not determined solely by access to technology, but by how reliably, consistently, and predictably that technology performs under real-world conditions. Where infrastructure introduces high variance, delayed feedback, or operational complexity, organisations and households adapt rationally by building buffers, workarounds, and conservative operating practices that suppress productivity across the economy.

The submission is structured around a set of case studies that illustrate this mechanism at work. Early case studies establish foundational productivity principles - including the role of reliability, variance, and measurement in enabling effective technology use. Subsequent case studies apply the same logic across transport and accessibility infrastructure, demonstrating how similar constraints manifest in different sectors but produce consistent productivity effects.

Across these examples, the productivity opportunity is practical rather than speculative. Addressing infrastructure-driven sources of variance and delayed feedback can reduce waste, improve system self-correction, and increase the usable capacity of labour and capital without requiring continual increases in effort or complexity. The recommendations that follow focus on treating infrastructure as enablement - prioritising reliability, interoperability, and whole-of-system performance as levers for sustainable productivity growth.

2. Framing productivity through technology and infrastructure

Productivity is best understood not as a question of effort or intent, but as a question of translation efficiency: how effectively labour, capital, and technology are converted into useful output.

In modern economies, this translation increasingly depends on digital systems, data flows, and measurement infrastructure. When enabling infrastructure is reliable, predictable, and scalable, technology adoption is straightforward and productivity gains diffuse naturally across firms and sectors [1][2][7]. When infrastructure is variable or constrained, organisations respond rationally by introducing workarounds, redundancy, and conservative design choices that erode productivity over time.

This submission uses that framing consistently. Infrastructure is treated not as a background condition, but as an active determinant of productivity outcomes. From this perspective, infrastructure that performs inconsistently imposes a hidden tax on productivity. The cost does not always appear in national accounts, but is experienced through delay, rework, coordination overhead, and reduced ambition in how technology is used in practice.

Critically, these effects are cumulative rather than isolated. Small, repeated frictions in everyday operations compound across organisations, locations, and decisions, resulting in material economy-wide productivity drag even where individual failures appear minor or tolerable in isolation [7]. Over time, this accumulation shapes operating norms, investment decisions, and the effective productivity ceiling of the economy.

3. Technology diffusion versus innovation focus

Much public discussion of productivity emphasises innovation: research and development, startups, or novel technologies. While innovation remains important, international evidence consistently shows that the largest and most durable productivity gains arise not from invention alone, but from the diffusion and effective use of existing technologies across the broader economy [2][7].

Diffusion is not automatic. It depends on interoperability, standardisation, low friction in adoption, and enabling infrastructure that allows technologies to be used reliably at scale. Where infrastructure is unreliable, asymmetric, or operationally complex, organisations adapt rationally by designing systems around those constraints. Over time, this normalises lower performance ceilings, embeds conservative operating assumptions, and suppresses investment in more advanced digital processes - even when the technologies themselves are available.

This is not an argument against innovation. Rather, it reflects a structural reality: the productivity returns from innovation are realised primarily through diffusion, and diffusion is constrained by infrastructure quality. Infrastructure that introduces variability, uncertainty, or hidden coordination costs limits the scale at which both new and existing technologies can be productively deployed, reducing economy-wide returns on innovation investment [7].

From a productivity perspective, diffusion is therefore the binding constraint. Improving the reliability, interoperability, and predictability of enabling infrastructure is one of the most direct ways to increase the realised productivity impact of innovation already present in the economy.

4. Digital infrastructure as core productivity infrastructure

Digital infrastructure should be treated as core economic infrastructure, comparable in importance to transport, energy, and water systems. In modern economies it acts as enablement infrastructure: it determines how efficiently labour and capital can be coordinated, how quickly inefficiencies are detected, and how reliably services can be delivered at scale.

In this submission, “digital infrastructure” is used in a broader sense than connectivity alone. It includes the measurement and control layers that make systems governable in practice: sensing, metering, real-time data flows, automation, and the operational capability and governance that turn data into timely action. Across sectors, these capabilities function like an upgrade from analogue to digital control: they reduce uncertainty, shorten feedback loops, and allow higher utilisation of existing assets.

From a productivity perspective, the central issue is not peak capability, but variance and latency. Where infrastructure performance is variable, organisations rationally build buffers into schedules, rostering, logistics, and system design. Where feedback is delayed, waste and faults persist longer than they should, increasing rework and exception handling. These are not edge cases; they become normal operating costs that accumulate across the economy.

The case studies that follow apply this logic across different domains:

- broadband infrastructure illustrates how performance variability and reliability shape what digital workflows are feasible at scale;
- digital water metering illustrates how measurement latency and delayed feedback create avoidable waste and operational overhead;
- smart traffic signals and rail signalling illustrate how real-time control and coordination reduce delay variance and increase the usable output of existing networks; and
- accessible public transport illustrates how whole-of-journey reliability determines who can participate consistently in the workforce and services, and how much hidden coordination cost households and employers must absorb.

The submission begins with national broadband infrastructure because it provides a clear, widely understood example of how enabling infrastructure quality - particularly reliability and performance consistency - determines whether technology adoption translates into realised productivity gains.

5. Case study 1: National broadband infrastructure as a productivity constraint

5.1. NBN strategy: evolution toward higher-capability access

This case study examines how national broadband infrastructure choices influence productivity outcomes, using the National Broadband Network (NBN) as a practical example. This case study establishes a core productivity principle used throughout this submission: that productivity depends not on peak capability, but on reliability, variance, and the ability of infrastructure to support predictable, scalable use.

The NBN is being progressively upgraded in response to changing work patterns, technology demand, and increasing reliance on digital services across the economy. Recent Government and NBN Co decisions - including the retirement of Fibre To The Node (FTTN) and Fibre To The Curb (FTTC), upgrades to Fixed Wireless services, and the selection of Low Earth Orbit (LEO) satellite solutions - reflect a policy direction toward higher-capability, more reliable access technologies.

This direction aligns with international evidence indicating that both the availability and quality of fixed broadband are associated with improved economic performance, and that connectivity quality matters for productivity outcomes, not merely access alone [1][2]. From a productivity perspective, this evolution reflects a shift toward treating broadband as foundational economic infrastructure rather than a minimum coverage utility.

5.2. Technology mix: progress on upgrades, with Hybrid Fibre-Coaxial remaining economically significant

Australia's fixed broadband access mix includes Fibre To The Premises (FTTP), Hybrid Fibre-Coaxial (HFC), Fixed Wireless, satellite services, and remaining legacy technologies undergoing upgrade.

Material progress has been made in improving non-fibre segments of the network. Fixed Wireless upgrades have been justified on the basis of congestion relief, improved consistency, and support for contemporary digital use cases [3]. Similarly, the transition from legacy satellite services toward LEO solutions reflects recognition that structural limitations - particularly latency and service variability - constrain participation in modern digital workflows [4].

Despite this progress, HFC remains a substantial component of the fixed network footprint in economically active urban and suburban areas. As such, its structural characteristics continue to influence productivity outcomes in the medium term, even as other access technologies are actively transitioned.

5.3. Quality, not just headline speed: productivity friction and invisible workarounds

A productivity-focused assessment of broadband infrastructure must consider not only peak download speeds, but the consistency and reliability with which connectivity supports real-world work and service delivery.

Empirical research indicates that broadband quality is associated with economic outcomes. Cross-country studies have found that increases in broadband speed and quality correlate with higher levels of economic output, although the magnitude of impact varies by context [5]. In practice, connectivity limitations often manifest not as outright service failure, but as invisible workarounds: reduced feature use, deferred synchronisation, manual processes, duplicated effort, and conservative system design.

These adaptations suppress productivity even when services are technically “available”, creating hidden efficiency losses that are difficult to observe through aggregate performance metrics alone.

Regulatory measurement of broadband performance in Australia consistently indicates that fibre-based services deliver more reliable and consistent performance during peak demand periods than shared-medium technologies, which exhibit greater performance variability under load [6]. As reliance on cloud services, real-time collaboration, and remote access increases, performance consistency becomes a more important determinant of productivity than peak speed alone.

While HFC represents a more capable platform than copper-based technologies, several of the same transition drivers that justify retiring FTTN and FTTC - including performance variance and operational complexity - may also apply in high-demand environments.

5.4. Connectivity constraints and lowest-common-denominator productivity effects

Connectivity limitations can impose hard productivity ceilings on organisations regardless of workforce capability, intent, or digital maturity.

In my professional experience working in critical infrastructure operations, some sites operate with extremely constrained connectivity due to the absence of fixed broadband coverage and poor mobile reception. In practice, systems must be designed around minimal bandwidth assumptions - in some cases measured in tens of kilobits per second. Under these conditions, routine activities such as remote management, monitoring, secure access, collaboration, and software updates become difficult or impractical, not because tools are unavailable, but because infrastructure cannot support them.

While alternative connectivity solutions may exist, they often introduce additional cost and operational complexity that would not arise if appropriate baseline infrastructure were available. From a productivity perspective, this represents a structural constraint: capability is limited by connectivity, not by skills or demand.

Where organisations operate across multiple locations with varying connectivity quality - including a mix of FTTP, HFC, Fixed Wireless, satellite, or no fixed service - systems and workflows are routinely designed to accommodate the least capable or least reliable connection. This lowest-common-denominator effect suppresses productivity across the entire organisation, even in locations with high-quality connectivity, and limits the realised benefit of digital investment [7].

In this context, adaptation is not a neutral response. Designing around infrastructure constraints is itself a productivity loss, embedding lower performance ceilings, higher operating costs, and reduced ambition into everyday practice.

5.5. Infrastructure reliability as a productivity requirement

For broadband infrastructure to function as a productivity enabler, it must operate reliably under foreseeable, non-exceptional conditions, including power interruptions, extreme weather, and peak demand.

Australian experience demonstrates that telecommunications disruptions during such conditions are not rare. Analysis following the 2019–20 bushfire season identified power loss - rather than direct physical damage - as a dominant cause of service disruption across telecommunications networks [8]. NBN Co guidance also acknowledges that during power outages, customer-side power alone may not be sufficient to restore service where upstream network elements are without power, particularly for HFC services [9].

From a productivity perspective, reliability is not a secondary attribute or resilience add-on. Where connectivity reliability is uncertain, organisations rationally adapt by delaying digital adoption, designing workflows conservatively, duplicating systems, or relying on manual processes. These behaviours suppress productivity even when services are operational most of the time. Infrastructure that performs well only under ideal conditions does not provide the stable input required for modern work, service delivery, and economic participation.

5.6. Policy consistency: applying existing upgrade logic across the network

Recent NBN upgrade decisions establish a clear policy precedent: infrastructure transition has been justified not only when services fail outright, but when structural characteristics constrain modern use cases and productivity outcomes.

Fixed Wireless upgrades and the shift toward LEO satellite services were justified on the basis of reducing structural limitations and enabling contemporary digital activity [3][4]. Applying the same productivity-based analytical framework to HFC is therefore a matter of policy consistency rather than exceptional treatment.

From a productivity perspective, the question is not whether HFC services function, but whether they meet the same productivity-enabling criteria already used to justify upgrades elsewhere in the network.

5.7. Infrastructure consistency, investment confidence, and productivity outcomes

Uneven access to high-capability broadband infrastructure can distort economic decision-making and suppress productivity.

Where full fibre connectivity is available in some locations but not others, households and businesses may factor connectivity into location and investment decisions, reinforcing two-tier outcomes. At the same time, uncertainty about long-term infrastructure capability discourages investment in productivity-enhancing digital transformation and encourages conservative system design.

International policy analysis highlights that clear upgrade pathways and consistent infrastructure capability are important for investment confidence and productivity realisation [7][24].

6. Case study 2: Digital water metering as productivity-enabling infrastructure

6.1. Context

Water supply and distribution systems are foundational economic infrastructure. Unlike electricity networks - where digital meters are now standard - much of Australia's water metering infrastructure remains analogue, providing low-frequency, manually collected consumption data.

From a productivity perspective, analogue water meters function as low-resolution measurement instruments in systems that increasingly depend on timely data to support automation, optimisation, and early intervention. This case study introduces a second foundational productivity mechanism: measurement latency and delayed feedback as a structural source of waste.

6.2. Productivity implications of analogue water metering

Analogue water meters introduce several structural constraints:

- **Delayed feedback loops:** Leaks and abnormal usage may persist for weeks or months before detection, increasing waste and repair costs. Australian utilities have noted that historically there was no practical way to identify customer-side leaks until a quarterly bill revealed abnormal usage [10].
- **Manual operational overhead:** Manual meter reading is labour-intensive and introduces estimation, billing disputes, and rework, diverting effort from higher-value activities.
- **Limited visibility for users and operators:** Without interval data, customers cannot easily identify inefficiencies, and utilities lack granular insight into localised demand or emerging faults.

These constraints result in time, labour, and capital being spent correcting problems late rather than preventing them early.

6.3. Demonstrated benefits of digital water metering

Where digital water meters have been deployed, documented benefits include:

- **Early leak detection and intervention:** South East Water reports alerting more than 14,000 customers to leaks, saving over 1.25 billion litres of water and reducing customer bills [11]. Barwon Water's trials similarly identified leaks that would otherwise have persisted undetected, delivering measurable water and cost savings [12].
- **Operational efficiency gains:** Digital meters reduce manual reading requirements and enable targeted maintenance, lowering operational costs [11][13].

- **Improved demand management and capital efficiency:** High-frequency data enables better use of existing assets and can defer costly supply augmentation. Cost–benefit analysis for South East Water estimated $1.37 in benefits for every $1 invested in digital metering [14].

International experience mirrors these outcomes. Singapore's Public Utilities Board has deployed smart water meters to support operational efficiency and demand management, with pilots identifying leaks in approximately 10% of households and delivering measurable consumption reductions [15][16]. Experimental evidence from California shows that the majority of water savings from advanced metering arise from early leak detection, with rapid payback in affected households [17].

6.4. Uneven access and the absence of consumer pathways

While digital water metering programs are being rolled out by several Victorian water utilities, access remains uneven and largely determined by utility-led prioritisation rather than consumer demand or productivity value.

In my local area, Yarra Valley Water has announced plans to roll out digital water meters to selected suburbs. However, my suburb is not included in the current rollout, and there is no mechanism for households to request a digital meter, express willingness to participate, or opt in where capacity allows.

From a productivity perspective, this highlights a structural access problem: even where customers understand the benefits of digital metering and are willing to adopt it, there is no pathway to do so unless and until the utility's rollout schedule reaches their location. This suppresses potential productivity gains at the household and small-business level and limits the speed at which system-wide benefits can be realised.

The absence of consumer or demand-side pathways also reduces the feedback available to utilities and policymakers about where digital metering could deliver the greatest marginal benefit, reinforcing rollout decisions based primarily on internal operational considerations rather than broader productivity outcomes.

6.5. Investment misalignment and productivity policy relevance

Despite system-wide benefits, digital water meter rollout is often treated as a utility-specific capital decision. This creates a structural misalignment:

- costs are concentrated with individual utilities; and
- benefits accrue broadly - to customers, governments (through deferred infrastructure investment and improved resilience), and the wider economy.

From a productivity policy perspective, this represents a positive externality problem. Investments that are economically efficient at the system level may be under-provided when assessed solely on enterprise-level returns.

Digital water meters should therefore be understood not merely as billing upgrades, but as measurement and automation infrastructure that enables productivity gains through reduced waste, improved feedback loops, and more efficient use of labour and capital.

6.6. Trust, data governance, and security-by-design

Digital metering creates a new category of operational data: fine-grained, time-series consumption information. This data is valuable for leak detection, demand management, and operational optimisation, but its usefulness depends on public trust and robust governance.

To avoid slowing adoption through privacy concerns or perceived surveillance, digital metering programs should be paired with clear commitments on:

- **Data minimisation and purpose limitation:** collect and retain only what is needed to deliver defined operational and customer outcomes.
- **Transparent access and use:** clear descriptions of who can access meter data, for what purposes, and under what controls.
- **Security-by-design:** strong authentication, encryption, monitoring, and lifecycle management for meters, networks, and data platforms, recognising that metering becomes part of critical operational technology.

From a productivity perspective, weak governance creates rollout friction and delays diffusion. Strong governance accelerates adoption by reducing dispute, resistance, and remediation overhead.

6.7. Productivity levers beyond the meter: interoperability and implementation pathways

The productivity impact of digital metering depends not only on device deployment, but on the ability to convert data into timely action across households, small businesses, and utility operations. To maximise realised benefits, implementation should emphasise:

- **Interoperability and standardisation:** ensure meter and data platforms support consistent interfaces and avoid vendor lock-in that increases long-term costs.
- **Actionable customer pathways:** practical mechanisms for customers to receive alerts, confirm leaks, and access support quickly, so benefits are realised as reduced waste and avoided rework.
- **Targeted rollout and opt-in pilots:** mechanisms that allow willingness-to-adopt and expected marginal benefit (e.g., leak risk, small business usage, constrained supply areas) to inform sequencing, alongside utility operational priorities.

These design choices matter because the productivity gain is primarily realised through reduced exception handling (e.g., billing disputes, late leak discovery, reactive maintenance) and faster feedback loops that turn information into action.

6.8. Equity, resilience, and small-business productivity impacts

Digital water metering delivers productivity and efficiency benefits that are not evenly distributed across the population, but are often most valuable in contexts where visibility and responsiveness are otherwise limited.

For renters, strata residents, and multi-occupancy dwellings, analogue metering and infrequent billing can obscure responsibility for leaks and delay intervention, leading to higher costs, disputes, and avoidable waste. Digital metering improves transparency and accountability, reducing administrative effort and conflict while enabling earlier resolution of issues.

From a resilience and drought-management perspective, high-frequency consumption data enables earlier identification of system stress, targeted demand management, and more efficient use of existing water resources. This supports productivity by deferring or reducing the need for costly supply augmentation and by improving system reliability during periods of constraint.

For small businesses, water is often a direct production input rather than a passive utility. Unexpected leaks or billing shocks impose administrative overhead, disrupt cash flow, and divert time away from core activities. Digital metering reduces these disruptions by providing earlier warning, clearer attribution, and more predictable operating conditions, enabling small businesses to plan and operate more efficiently.

Together, these considerations reinforce the case for treating digital water metering as productivity-enabling infrastructure with broad public benefits, rather than as a narrow billing or utility modernisation initiative.

7. Case study 3: Smart traffic signals as productivity-enabling infrastructure

7.1. Context

Road congestion is often treated as a transport problem. In practice, it is also a productivity problem: time lost to unreliable travel times, stop–start conditions, and intersection delay is time and fuel not spent on productive activity.

A large share of urban delay is concentrated at intersections. Traditional fixed-time signals (and many "time of day" plans) behave like analogue control systems: they rely on historical assumptions, change slowly, and respond poorly to atypical demand patterns, incidents, school peaks, events, or weather. The result is avoidable variance - not only in travel time, but in predictability.

In contrast, "smart" traffic signals are a family of approaches that use better sensing and control to reduce delay and variability:

- adaptive signal control adjusts phase splits, cycle lengths, and offsets in response to real-time traffic conditions;
- traffic management integration coordinates corridors ("green waves"), manages incidents, and updates timing plans dynamically; and
- connected vehicle integration uses signal phase and timing data (for example, Signal Phase and Timing, (SPaT)) to support applications such as Green Light Optimal Speed Advisory (GLOSA), signal priority for buses, and freight or incident management.

These approaches aim to improve travel time reliability and reduce stop–start inefficiency, with flow-on productivity and emissions benefits [22][23].

From a productivity perspective, this is measurement and control infrastructure for the road network - the same class of productivity input illustrated earlier in digital networks and water systems.

7.2. Productivity implications of analogue or non-adaptive traffic signals

Where signal timing is fixed, outdated, or poorly coordinated, the productivity impacts show up as:

- **Unreliable travel times (variance):** Businesses and households build buffers into schedules, deliveries, and rostering. Those buffers represent real economic cost.
- **Stop–start inefficiency:** Increased idling and repeated acceleration raise fuel use and vehicle wear and contribute to local emissions - costs borne privately and socially.
- **Coordination overhead:** Logistics operators, service businesses, and critical infrastructure field teams lose time synchronising to uncertain travel conditions (missed slots, rework, rescheduling).

- **Safety and compliance friction:** Where user behaviour is poorly supported (for example, unclear pedestrian phase timing), compliance and conflict costs rise. Peer-reviewed evidence suggests pedestrian countdown displays can influence behaviour and compliance, with downstream impacts on flow and safety at crossings [20].

In effect, poorly managed signals impose a hidden tax in the form of time lost, buffer planning, and degraded reliability - even when roads are technically functional.

7.3. Demonstrated benefits of smarter signal control and information

Evidence from adaptive signal control deployments indicates measurable operational improvements, including reduced delay and improved travel time reliability.

In the United States, the Federal Highway Administration describes Adaptive Signal Control Technology (ASCT) as adjusting signal timing in response to demand, with the intent of reducing delay and improving travel time reliability compared to static plans [18].

Empirical evaluation work has reported reductions in peak-hour travel time and improvements in corridor performance following implementation of adaptive control, although results vary by corridor characteristics, sensor coverage, and calibration quality [18].

A second tier of benefit comes from making signal information available to vehicles and operators. Connected eco-driving systems that use SPaT information can reduce stops and idling by advising optimal approach speeds, reducing delay and fuel consumption in both simulation and field contexts [22].

The productivity link is direct: fewer stops, less time lost, and more predictable movement improve both economic throughput and daily time efficiency.

7.4. Comparable global examples and “what good looks like”

Australia is not starting from zero. Adaptive control has a long lineage; systems such as SCATS originated in Australia and are deployed internationally [19]. Internationally, the direction of travel is clear:

- **United States and Europe:** Adaptive signal control and connected vehicle applications are increasingly framed as part of broader Intelligent Transport Systems programs, emphasising reliability, emissions reduction, and network efficiency.
- **Singapore:** Smart mobility programs include signal optimisation and integrated traffic management approaches, with emphasis on operational governance and reliable movement in dense urban conditions [23].
- **China:** Multiple cities have deployed advanced intersection optimisation approaches and “green wave” corridor concepts using richer sensing and algorithmic control. Peer-reviewed studies report measurable reductions in peak congestion indicators following deployment, though results are context-dependent and sensitive to implementation quality [21].

Australia also shows current policy momentum toward modernisation:

- **Victoria (baseline platform):** The Victorian transport portfolio notes that traffic signals are managed using SCATS, positioning it as a sophisticated and dynamic intelligent transport system. This establishes a clear baseline capability and an existing platform to modernise around, rather than starting from scratch [25].
- **Victoria (advanced research deployment):** Melbourne hosts the AIMES Intelligent Corridor on Nicholson Street, delivered in partnership with the University of Melbourne and industry. The corridor integrates real-time sensing, artificial intelligence, and predictive modelling to dynamically optimise signal operation and corridor performance, demonstrating how adaptive, data-driven control can reduce congestion and improve reliability in dense urban environments [27].
- **New South Wales:** Transport for NSW's Intelligent Traffic Light Program is framed as a trial to improve intersection efficiency and safety where pedestrian volumes are large and variable. It also provides an opportunity to explicitly evaluate productivity outcomes - including delay variance, corridor reliability, and freight or service travel-time predictability - alongside safety outcomes [26].

Across jurisdictions, the common best-practice thread is not a particular vendor or algorithm, but the combination of:

a) better sensing;
b) adaptive control;
c) corridor coordination; and
d) operational governance that treats signals as a managed system rather than a set-and-forget asset.

7.5. Implementation considerations: governance, interoperability, and security-by-design

Signal modernisation is also a systems-engineering and governance task. Productivity gains are realised only if deployment avoids creating brittle, vendor-locked, or cyber-fragile environments. Key considerations include:

- **Interoperability and standards:** Prioritise open interfaces and data standards (for example, the ability to publish SPaT or MAP data where appropriate) so cities are not locked into single-supplier ecosystems.
- **Operational capability:** Adaptive systems require ongoing tuning, monitoring, and performance management. Benefits decay if treated as a one-off capital project rather than a continuously managed capability.
- **Security-by-design:** Connected signal infrastructure expands the attack surface of operational technology. Security controls should cover identity, patching, segmentation, monitoring, and supplier assurance, consistent with critical infrastructure risk-management expectations.

From a productivity perspective, these are implementation prerequisites. Without them, trust and operational reliability degrade, slowing adoption and increasing remediation overhead.

8. Case Study 4: Rail interoperability and dual-use mobility as productivity infrastructure

8.1. Context

Rail infrastructure is often assessed as a transport asset, evaluated through corridor-specific freight efficiency, passenger service outcomes, or jurisdiction-level investment decisions. From a productivity perspective, however, rail functions as a coordination and mobility system, whose value depends on interoperability, predictability, and the ability to redeploy capacity across the network.

Australia's rail system retains a significant structural constraint: multiple track gauges across states, together with associated physical, operational, and technical discontinuities. While this configuration reflects historical development, its productivity effects are ongoing rather than historical. Breaks-of-gauge and related interoperability barriers impose coordination costs, suppress redeployment and optionality, and embed variance into freight and passenger movement in ways that act as a persistent drag on productivity [28][29].

8.2. Interoperability failure as a source of productivity variance

Breaks-of-gauge represent the most visible form of rail interoperability failure, but they are rarely the only one. In practice, gauge discontinuities interact with other constraints - including axle load limits, train length restrictions, signalling compatibility, and operating rules - to fragment national rail operations.

Where gauge discontinuities exist, movements across state or corridor boundaries require additional handling steps, including transshipment, bogie exchange, rerouting, or mode substitution. Each interface introduces delay, labour, and planning overhead. The direct costs of these adaptations are visible in duplicated rolling stock fleets, specialised maintenance capability, and interface infrastructure at break points [28].

The larger productivity cost is less visible. Interoperability barriers introduce variance into travel time, scheduling, and capacity planning. To manage this uncertainty, operators and customers build buffers into logistics chains, design services conservatively, and reduce reliance on rail for time-sensitive or flexible movements. These adaptations are rational responses to infrastructure constraints, but they embed inefficiency permanently into operating practice.

8.3. Infrastructure sets the ceiling: lost optionality and national optimisation

The most significant productivity impact of rail fragmentation is not that trains cannot cross jurisdictional boundaries at all, but that seamless national redeployment is excluded from system design.

In interoperable systems, freight can be rerouted dynamically in response to disruption, rolling stock can be redeployed where demand is highest, and investment decisions can assume national rather than jurisdiction-limited markets. Where interoperability is constrained, optimisation occurs locally rather than nationally, suppressing scale economies and reducing the resilience of the system as a whole.

Australia's experience following the standardisation of the Melbourne–Adelaide corridor illustrates this effect. Removal of a major break-of-gauge enabled longer trains, higher utilisation, and more than a doubling of the rail freight task between those cities - demonstrating that interoperability reform can materially change feasible operating models, not merely reduce interface costs [28].

8.4. Dual-use mobility as a productivity multiplier

Rail interoperability also illustrates the productivity value of dual-use infrastructure. Infrastructure designed to support everyday commercial freight and passenger movement, while also enabling credible surge mobility during disruption, delivers higher utilisation in peacetime and lower coordination costs under stress.

Internationally, interoperable rail corridors are increasingly justified on civil economic grounds, with resilience and security benefits treated as multipliers rather than primary drivers. This reflects recognition that the same characteristics that support emergency or defence mobility - interoperability, load capacity, predictable routing, and rapid redeployment - also reduce everyday logistics friction and improve productivity outcomes [30][31].

From a productivity perspective, dual-use capability does not depend on the occurrence of rare events. Benefits accrue continuously through reduced fragility, faster recovery from disruption, and lower planning overhead across both public and private operations.

8.5. Avoiding a new "digital break-of-gauge"

As Australia modernises its rail network, there is a parallel risk of entrenching a digital break-of-gauge. Independent state-level upgrades to train control, signalling, and operational technology - if pursued without harmonised standards and interoperability requirements - risk reproducing fragmentation in digital form.

Such fragmentation would impose similar productivity costs: duplicated systems, constrained redeployment of rolling stock, higher training and compliance overhead, and reduced diffusion of operational innovation. International experience indicates that preventing this outcome requires deliberate governance and standardisation early in the upgrade cycle, rather than attempting retrospective integration after systems have diverged [29][30].

9. Case Study 5: High-capacity rail signalling as productivity-enabling infrastructure (metro and non-metro)

9.1. Context

Rail congestion is often treated as a transport problem. In practice, it is also a productivity problem: time lost to unreliable travel times, uneven service intervals, and slow disruption recovery is time not spent on productive activity. The economic burden is not driven solely by average delay, but by variance - the uncertainty that forces households and organisations to build buffers into commuting, rostering, service delivery, and supply-chain scheduling.

A large share of rail performance is determined not by how much track exists, but by how the network is measured, controlled, and coordinated. Traditional fixed-block signalling behaves like an analogue control system: it enforces conservative separation rules, relies on coarse state information, and responds slowly to atypical demand patterns, incidents, or degraded running. The result is avoidable variance - not only in travel time, but in predictability and recovery.

In contrast, high-capacity signalling and modern digital train control are a family of approaches that use richer sensing, continuous train location and speed supervision, and stronger network regulation to reduce delay and variability. These include moving-block and CBTC-style systems that allow trains to run closer together while maintaining safe separation, as well as in-cab digital train control such as European Train Control System (ETCS) Level 2, which replaces reliance on line-side signals with continuous movement authority and supervision.

From a productivity perspective, this is measurement and control infrastructure for the rail network - analogous to the shift from analogue to digital control in utilities and industrial systems. The objective is not technology for its own sake, but reduced variance, improved recovery, and higher utilisation of existing assets.

9.2. Productivity implications of legacy or fragmented signalling

Where signalling and train control remain fixed, inconsistent across corridors, or treated as a set-and-forget asset, the productivity impacts are predictable:

- **Unreliable travel times (variance):** When services run unevenly and recover slowly from disruption, passengers and employers build buffers into start times, meetings, and rostering. Those buffers represent real economic cost - time that could otherwise be used for work, coordination, or output [29][32].
- **Capacity suppression and underutilisation:** Conservative separation rules reduce the number of usable train paths, even where track and rolling stock capacity exists. This suppresses the productive output of existing infrastructure and increases pressure for higher-cost interventions such as track duplication [28][35].

- **Coordination and rescheduling overhead:** Delay propagates across interconnected services and junctions, increasing planning and rescheduling effort for operators and creating friction for customers who must continually re-plan around uncertainty. Programs that pair digital train control with traffic management capability explicitly recognise the importance of network-level regulation and recovery [30][32].
- **Interoperability penalties ("digital break-of-gauge"):** If digital signalling upgrades are delivered as disconnected, state-based solutions, Australia risks embedding new forms of fragmentation - incompatible interfaces, duplicated training and assurance regimes, and constrained fleet flexibility. The National Transport Commission has identified interoperability as a prerequisite for realising the productivity value of digital train control at scale [38].

In effect, poorly coordinated signalling imposes a hidden productivity tax through time lost, degraded reliability, and suppressed utilisation - even when track infrastructure is technically available.

9.3. Demonstrated benefits and current Australian direction

Australia is not starting from zero. High-capacity signalling and ETCS-based train control are already being deployed across multiple jurisdictions, providing a practical foundation for treating signalling as productivity-enabling infrastructure, rather than as project-by-project rail modernisation.

In Victoria, High-Capacity Signalling is being introduced through the Metro Tunnel program to enable trains to run more frequently by dynamically maintaining safe separation, supporting higher throughput and improved reliability on constrained Central Business District (CBD) approaches [28][29].

In New South Wales, the Digital Systems Program includes ETCS Level 2, automation components, and a Traffic Management System, explicitly framing signalling modernisation as an uplift in how the network is operated and recovered during disruption. This recognises that capacity and reliability depend on both train control and operational coordination, not signalling technology alone [30][32]. The Rail Service Improvement Program further reinforces a policy direction toward measurable service performance improvements [31].

In Queensland, ETCS is being rolled out through Cross River Rail and the broader South East Queensland network as a staged, long-term network uplift, embedding digital train control into future capacity and reliability planning rather than treating it as a metro-only feature [33][34].

In Western Australia, the Public Transport Authority's High-Capacity Signalling program replaces fixed-block constraints with moving-block capability to lift capacity and reliability across the Perth network. Infrastructure Australia's assessment of METRONET's High-Capacity Signalling further grounds this investment class as productivity-relevant infrastructure [35][36][37].

Across jurisdictions, the direction of travel is consistent: rail networks are moving from analogue signalling as a static asset to digital train control as a managed system.

9.4. Comparable global practice and "what good looks like"

Internationally, high-capacity signalling and digital train control are now standard practice on busy and constrained rail corridors, framed explicitly as tools for increasing usable capacity, improving reliability, and deferring more capital-intensive expansion.

In Europe, deployment of the ETCS, particularly Level 2, has been driven by the need to increase throughput and improve recovery on constrained mainlines without extensive new civil works. European rail policy positions digital signalling as a means of extracting more productive capacity from existing infrastructure, improving operational resilience, and reducing lifecycle cost through standardisation and interoperability [39][40].

In the United Kingdom, the Digital Railway program led by Network Rail frames modern signalling and traffic management as system-level capacity and reliability infrastructure. On heavily used corridors, digital signalling has been used to increase trains per hour, reduce delay propagation, and improve recovery performance, with the explicit intent of deferring or reducing the scale of additional track investment [41].

In high-density Asian systems such as Japan and Singapore, advanced automatic train control and moving-block-style supervision underpin extremely reliable, high-frequency services. In these contexts, signalling is treated as economic coordination infrastructure - the mechanism by which dense labour markets, service industries, and just-in-time urban economies function predictably. Singapore's Land Transport Authority explicitly frames high-capacity signalling as essential to maintaining reliability and recoverability in a constrained city-state environment [42][43].

Across these jurisdictions, the common thread is not a particular technology or vendor, but the consistent treatment of signalling as system-level measurement and control infrastructure - enabling higher utilisation, faster recovery, and lower variance on constrained networks. Australia's current signalling programs align with this established global direction.

9.5. Implementation considerations: governance, interoperability, and security-by-design

Signalling modernisation is fundamentally a systems engineering and governance task. Productivity gains are realised only if deployment avoids creating brittle, vendor-locked, or cyber-fragile environments that undermine reliability over time.

Key considerations include:

- **Interoperability and standards:** Signalling programs should be designed to converge over time, with explicit expectations for interfaces, upgrade pathways, and operational compatibility. National alignment is critical if productivity benefits are to scale beyond individual corridors or projects [38].

- **Operational capability:** Digital signalling systems require ongoing tuning, monitoring, and network-level performance management. Productivity benefits decay if signalling is treated as a one-off capital replacement rather than as a continuously managed operational capability [30][32].
- **Security-by-design:** Modern signalling and connected control centres expand the attack surface of rail operational technology. Security controls - including identity management, network segmentation, patching, monitoring, and supplier assurance - must be integrated from the outset to preserve reliability, safety, and public trust.

From a productivity perspective, these are not secondary considerations. Without strong governance, interoperability, and security foundations, reliability degrades, adoption slows, and remediation overhead increases - eroding the very productivity gains these investments are intended to deliver.

10. Case study 6: Accessible public transport as productivity-enabling infrastructure

10.1. Context

Accessible public transport is commonly framed as an equity or compliance obligation. It is also a productivity input: it determines who can reliably participate in the workforce, how consistently people can reach work, education, and services, and how much hidden coordination overhead organisations and households must absorb to manage mobility risk.

Globally, disability is not a niche condition. The World Health Organization estimates that around 1.3 billion people experience significant disability - approximately one in six people worldwide. As populations age, the share of people with mobility, sensory, and cognitive access needs increases rather than decreases [44]. From a productivity perspective, this matters because accessibility constraints suppress labour participation and increase friction costs across the economy, particularly in service-heavy sectors where on-time arrival, shift coverage, and reliable customer access are material inputs.

Accessibility should therefore be treated as whole-of-journey productivity infrastructure, not as a collection of isolated compliance works. A trip is only usable if the end-to-end chain functions reliably: step-free paths, platform–train interfaces, boarding and alighting, accessible stops, information provision, and consistent operating patterns. When any link fails, the system behaves like a network with intermittent outages - usable sometimes, but not reliably enough to support work and daily economic participation.

10.2. The productivity implications of inaccessible or partially accessible networks

When access is partial, inconsistent, or uncertain, the productivity impacts appear as repeatable friction patterns rather than isolated failures:

- **Labour participation and job-matching losses:** People who cannot rely on transport access face narrower job choices - fewer viable workplaces, fewer shift types, and fewer usable routes. This reduces job-matching efficiency, constrains effective labour supply, and increases underemployment. These outcomes represent a structural productivity loss rather than a personal inconvenience. Organisation for Economic Co-operation and Development (OECD) work on disability and inclusion highlights persistent labour market disadvantage for people with disability, including substantially higher unemployment risk compared to people without disability [45].
- **Reliability penalties and buffer costs:** Where accessibility depends on the chance arrival of a low-floor tram at a level-access stop, or on a station lift being operational, people must build buffers into every trip. Those buffers translate directly into lost time, reduced usable working hours, and higher coordination overhead for employers and service providers.

- **Higher service delivery costs and "parallel transport" dependence:** When mainstream networks are not reliably accessible, demand shifts to costlier alternatives - specialised transport services, taxis, ride share, or informal arrangements such as carers driving. While often essential, these options are typically higher-cost per trip than accessible mass transit and scale poorly, creating an avoidable operational cost burden for households and governments.
- **Economic exclusion concentrated in dense service precincts:** Inaccessible tram corridors, stations, or interchange points reduce access to employment clusters, health services, education, and retail precincts, suppressing both workforce participation and customer access in areas where economic activity is otherwise concentrated.

In productivity terms, these effects operate like a hidden tax: time lost to planning and detours, reduced workforce participation, and increased reliance on higher-cost mobility substitutes.

10.3. Evidence of the problem and why incremental progress can still be structurally insufficient

The Australian policy direction is clear: accessibility is intended to be progressively achieved under national standards and associated review processes. The statutory review of the Disability Standards for Accessible Public Transport 2002 (final report published in 2024) documents persistent barriers and the lived experience of users, based on input from over 1,000 respondents, including more than 600 people with disability [47].

At a network level, the Victorian Auditor-General's Accessibility of Tram Services: Follow-up (2025) provides a concrete example of how partial improvements can still leave the system structurally inaccessible. The report found only modest improvement since the earlier audit: by 2023–24, only 18% of tram services were accessible (defined as a low-floor tram stopping at a level-access stop), up from just 15% in 2018–19 [48][49].

Public reporting on the audit highlights that users with mobility restrictions can face significant additional waiting time due to this mismatch between accessible stops and accessible trams. It also identifies governance gaps, including the absence of clear targets or directed funding pathways to materially improve accessibility outcomes [49][50].

This is the central productivity point: a network that is accessible "sometimes" is not accessible enough to support reliable workforce participation and daily economic activity. Incremental gains matter, but if they do not close the reliability gap - whole-of-journey usability - the productivity dividend remains unrealised.

10.4. Global comparators and "what good looks like"

Internationally, leading transport systems increasingly treat accessibility as a managed, measurable network performance program, rather than as a collection of isolated compliance works.

For example, Transport for London reports system-level accessibility outcomes alongside traditional service metrics. It has stated that additional journey times for users requiring accessible routes have been reduced by approximately 40% since 2016, and it publishes network-wide counts of step-free stations across modes [54]. While London's scale, density, and funding context differ from Australian cities, the transferable lesson is governance maturity: accessibility is treated as an operational performance objective with defined measures, staged delivery, and public accountability - not as a series of localised upgrades delivered in isolation.

More broadly, international evidence increasingly frames accessibility improvements as economically productive investments, rather than purely distributive or compliance-driven expenditure. Work by the International Transport Forum (ITF/OECD) highlights that accessibility upgrades generate economic benefits through increased labour participation, improved job matching, and reduced reliance on higher-cost mobility substitutes [46].

In the United Kingdom, parliamentary material referencing research commissioned by the Department for Transport has cited positive benefit–cost ratios for step-free access investments (as conveyed via public parliamentary Q&A) [55]. While such ratios cannot be directly transferred to Australian projects without careful context-specific appraisal, they demonstrate that mature transport evaluation frameworks can explicitly recognise accessibility as value-creating infrastructure, rather than as a residual social obligation.

From a productivity perspective, the common thread across these examples is not a particular design standard or funding model, but treatment of accessibility as system-level infrastructure: planned, measured, and delivered with an explicit focus on reducing variability, improving reliability, and enabling consistent participation.

10.5. Implementation considerations: the "whole-of-journey" test, prioritisation, and measurable outcomes

Accessibility programs deliver productivity gains when they are designed as a system:

- **Whole-of-journey prioritisation:** Prioritise corridors and precincts where accessibility unlocks workforce participation and essential service access (major employment clusters, hospitals, education precincts, interchanges, and high-frequency routes). The goal is not isolated accessible assets; it is *end-to-end usable journeys*.
- **Reliability and usability metrics, not just asset counts:** Move beyond "number of upgraded stops" as the headline measure. Track outcomes such as: percentage of services that are accessible end-to-end; additional travel time imposed on users who require accessible journeys; accessibility-related service failures (lifts outages, boarding interface failures); and corridor-level accessible throughput.
- **Integrated capital and operations planning:** Accessibility is often undermined by operational fragility (lift outages, inconsistent deployment, unclear information). Programs should explicitly fund the operational reliability of accessibility infrastructure, not only the initial retrofit.

- **Transparent sequencing and targets:** Productivity-relevant accessibility requires certainty. Where targets and funding pathways are missing or vague, the network continues to impose hidden mobility risk costs on users and employers.

10.6. Why this is a productivity case study, not only an accessibility case study

The productivity claim in this case study is direct and structural. Accessibility upgrades expand the effective labour pool, improve job matching, reduce travel-risk buffers, and reduce reliance on higher-cost mobility substitutes. These effects are economy-wide and cumulative, rather than confined to individual users or isolated journeys.

Treating accessibility as productivity-enabling infrastructure aligns it with the same enablement logic applied elsewhere in this submission - including digital networks, signalling, and traffic management. In each case, the mechanism is the same: reducing variance, removing friction, and increasing the usable capacity of existing systems. In this case, the system is the capacity of people to participate reliably in work, education, and daily economic activity.

11. Recommendations

The case studies presented in this submission demonstrate a common productivity mechanism across multiple sectors: productivity outcomes are shaped less by access to technology alone than by the quality of the infrastructure that enables it. Specifically reliability, consistency, feedback speed, and the ability to operate effectively under normal, non-exceptional conditions [1][2][7].

Across digital connectivity, measurement systems, and transport control infrastructure, the same pattern emerges. Where infrastructure introduces high variance, delayed feedback, or operational complexity, organisations rationally adapt by adding buffers, workarounds, and conservative design choices. These adaptations are individually sensible, but cumulatively impose a persistent drag on productivity that is rarely visible in headline performance metrics.

The recommendations below focus on reducing these structural frictions by treating enabling infrastructure explicitly as a productivity input, and by applying consistent, productivity-based criteria to infrastructure investment, upgrade, and governance decisions.

11.1. Recommendations from Case Study 1: National broadband infrastructure

Recommendation 1 - Treat high-capability digital connectivity as core productivity infrastructure

- **Type:** Strategic policy recognition and planning guidance
- **Recommendation aim: To** ensure that national productivity policy recognises digital connectivity as foundational economic infrastructure, with reliability, consistency, and scalability treated as productivity inputs rather than secondary telecommunications attributes.
- **Recommendation:** Explicitly recognise high-capability digital connectivity - particularly fibre-based broadband - as core productivity-enabling infrastructure within national productivity, infrastructure, and digital economy frameworks. Assessment of broadband investment and upgrade priorities should explicitly consider productivity-relevant characteristics such as reliability, performance consistency under load, symmetry, and long-term scalability, rather than relying primarily on minimum service availability or headline speed metrics.
- **Justification:** Modern productivity increasingly depends on stable, low-variance digital infrastructure that supports cloud services, remote and hybrid work, digital service delivery, and real-time collaboration. Where connectivity performance is inconsistent or constrained, organisations rationally adapt by limiting system design, deferring digital adoption, and embedding workarounds that suppress productivity. Treating high-capability connectivity as discretionary or “premium” infrastructure therefore risks underinvestment in a foundational input to economy-wide productivity growth.

Recommendation 2 - Develop a time-bound pathway to progressively retire Hybrid Fibre-Coaxial (HFC) infrastructure

- **Type:** National infrastructure transition planning guidance
- **Recommendation aim:** To reduce structural digital friction and productivity losses arising from infrastructure variance, operational complexity, and performance inconsistency in economically active areas.
- **Recommendation:** Develop and publish a time-bound national plan to progressively retire Hybrid Fibre-Coaxial (HFC) infrastructure and transition affected premises to full-fibre connections. The plan should prioritise areas with high business density, service-sector activity, and uptake of remote or hybrid work, and should articulate indicative sequencing horizons, productivity-based prioritisation criteria, and a transparent transition pathway to provide certainty for households and businesses.
- **Justification:** This recommendation is not driven by preference for a particular access technology, but by the consistent application of productivity-based performance criteria already used to justify upgrades elsewhere in the network [3][4]. While HFC services may meet minimum performance benchmarks, their shared-medium characteristics introduce variability and reliability constraints that impose hidden productivity costs, particularly as reliance on cloud services and real-time collaboration increases [5][6]. A planned and progressive transition reduces long-term technical debt, improves investment confidence, and supports more effective diffusion of productivity-enhancing digital technologies across the economy [7].

Recommendation 3 - Incorporate infrastructure reliability and variance into productivity assessment

- **Type:** Measurement and evaluation framework guidance
- **Recommendation aim:** To improve the measurement and understanding of how infrastructure quality affects real-world productivity outcomes.
- **Recommendation:** Average speeds and availability metrics can mask productivity-suppressing constraints caused by inconsistent performance, latency, and degradation under load [5][6]. Many of these characteristics are already measured by regulators, network operators, and infrastructure owners, but are not treated as productivity indicators. Incorporating reliability and variance into productivity assessment provides a more accurate representation of how infrastructure enables or constrains real-world economic activity, particularly in service-based and digitally intensive sectors [7].
- **Justification:** Average speeds and availability metrics can mask productivity-suppressing constraints caused by inconsistent performance.

Incorporating variance and reliability provides a more accurate representation of how infrastructure enables or constrains economic activity, particularly in service-based and digitally intensive sectors.

11.2. Recommendations from Case Study 2: Digital water metering

Recommendation 4 - Recognise and support digital water metering as productivity-enabling infrastructure

- **Type:** Investment alignment and incentive design guidance
- **Recommendation aim:** To accelerate the rollout of digital water metering by aligning investment incentives with the system-wide productivity, efficiency, and capital-deferral benefits these meters deliver.
- **Recommendation:** Explicitly recognise digital water metering as productivity-enabling infrastructure within national productivity, infrastructure, and water policy frameworks. Where digital metering delivers benefits beyond individual water utility balance sheets - including reduced non-revenue water, deferred supply augmentation, improved system resilience, and lower system-wide operating costs - governments should support rollout through appropriately targeted mechanisms. These may include co-funding, concessional finance, regulatory allowances, productivity-linked infrastructure programs, and demand-side pathways that allow informed consumers or small businesses to signal willingness to adopt or opt in where capacity permits.

  Support mechanisms should be calibrated to the share of benefits that accrue to the public and the broader economy, while preserving incentives for utilities to implement, operate, and maintain digital metering efficiently.
- **Justification:** Digital water meters generate productivity gains that extend beyond individual utilities and customers. In the absence of policy mechanisms that align costs with benefits, economically efficient investments risk being delayed or under-scaled. Treating digital water metering as productivity-enabling infrastructure enables measurement, automation, and waste-reduction capabilities to be deployed at a pace consistent with their economy-wide value.

Recommendation 5 - Enable demand-side adoption pathways and interoperability for digital water metering

- **Type:** Implementation and diffusion enablement guidance
- **Recommendation aim:** To accelerate realised productivity benefits from digital water metering by reducing adoption friction, improving interoperability, and enabling faster translation of data into action.

- **Recommendation:** Digital water metering programs should include mechanisms that enable demand-side participation and interoperability, alongside utility-led rollout. This includes clear opt-in or expression-of-interest pathways for households and small businesses where capacity permits, and the use of open data interfaces and standards that allow meter data to integrate with customer tools, utility systems, and third-party services in a secure and governed manner.

  These measures support faster diffusion of productivity benefits by reducing adoption delays, improving feedback speed, and ensuring that metering data can be readily converted into timely intervention and behavioural change.

- **Justification:** Evidence from Australian and international deployments indicates that the productivity gains from digital water metering arise primarily from early leak detection, rapid feedback, and reduced exception handling. Where adoption pathways are opaque or data is siloed, these benefits are delayed or under-realised. Enabling demand-side participation and interoperability reduces rollout friction, improves utilisation, and increases the realised return on metering investment without requiring additional infrastructure build.

11.3. Recommendations from Case Study 3: Smart traffic signals

Recommendation 6 - Treat traffic signal modernisation as productivity-enabling infrastructure and fund it accordingly

- **Type:** Targeted modernisation and operations capability guidance
- **Recommendation aim:** To reduce travel time variance and intersection delay - and thereby lift productivity - by modernising traffic signals through adaptive control, corridor coordination, and stronger operational governance.
- **Recommendation:** Treat traffic signal modernisation - including adaptive signal control, corridor coordination, and the publication of signal information for integrated transport applications where appropriate - as productivity-enabling infrastructure. Funding and governance arrangements should support:
  - prioritisation based on productivity-relevant criteria (including high-throughput corridors, freight routes, and major service precincts);
  - sustained operational capability, including monitoring, tuning, and performance management, rather than treating modernisation solely as a one-off capital upgrade; and
  - interoperability and security-by-design requirements to avoid brittle, vendor-locked, or cyber-fragile deployments.
- **Justification:** A material share of urban delay is intersection-driven. Adaptive and better-governed signal systems reduce avoidable stop–start conditions, improve reliability, and reduce the planning buffers organisations must build into logistics, service delivery, and workforce scheduling [18][22][23]. The resulting productivity

gains are realised through time saved, reduced rework, and improved predictability across the economy.

Recommendation 7 - Measure and report productivity-relevant performance of traffic signal systems

- **Type:** Performance measurement and evaluation guidance
- **Recommendation aim:** To ensure that the productivity benefits of traffic signal modernisation are visible, measurable, and inform future investment decisions.
- **Recommendation:** Traffic signal programs should incorporate productivity-relevant performance measures alongside traditional safety and throughput metrics. These should include indicators such as travel time variance, corridor-level reliability, stop–start frequency, and delay predictability during normal operating conditions. Where available, data from adaptive signal systems and traffic management platforms should be used to support consistent reporting at corridor and network levels.

  Embedding these measures into evaluation frameworks would allow signal modernisation investments to be assessed on their actual productivity contribution, rather than being treated solely as traffic management or safety interventions.
- **Justification:** The primary productivity gains from smarter traffic signals arise from reduced variability, fewer stops, and improved predictability, rather than large reductions in average travel time. Where these effects are not measured or reported, the productivity value of signal modernisation remains under-recognised, leading to underinvestment and fragmented delivery. Aligning measurement with productivity mechanisms improves investment discipline and supports more effective prioritisation of future upgrades.

11.4. Recommendations from Case Study 4: Rail interoperability as a productivity reform

Recommendation 8 - Treat rail interoperability as productivity-enabling infrastructure and govern it nationally

- **Type:** National interoperability and productivity governance reform
- **Recommendation aim:** To lift freight efficiency, reduce logistics variance, and improve national mobility by treating rail interoperability - physical and digital - as a core productivity input rather than a jurisdiction-specific transport consideration.
- **Recommendation:** Treat rail interoperability, encompassing both physical compatibility (including gauge, axle load, and train length) and digital interoperability (including train control, signalling, and operational rules), as productivity-enabling infrastructure. Establish a nationally coordinated governance and funding framework that supports:

- prioritisation of interoperability improvements on nationally significant freight and passenger corridors, rather than state-only optimisation;
- alignment of jurisdiction-level investment decisions with national productivity objectives; and
- progressive convergence of standards over time to reduce fragmentation, rather than entrenching it through uncoordinated upgrades.

- **Justification:** Rail fragmentation embeds coordination costs, suppresses network effects, and constrains national-scale optimisation. Treating interoperability as a productivity issue aligns incentives across jurisdictions and ensures that future investments reduce variance, improve utilisation, and unlock scale economies, rather than hard-coding inefficiency into the network [28][29].

Recommendation 9 - Prevent a “digital break-of-gauge” in rail modernisation through nationally coordinated digital standards

- **Type:** Digital infrastructure standardisation and assurance
- **Recommendation aim:** To avoid embedding long-term productivity costs through incompatible digital rail systems as signalling and train control technologies are modernised.
- **Recommendation:** Require nationally coordinated standards, assurance frameworks, and implementation pathways for digital train control and signalling upgrades, so that modernisation does not harden into incompatible state-based systems. This should include:
    - early agreement on core interoperability requirements for digital signalling and train control systems;
    - consistency in safety, security, certification, and assurance expectations across jurisdictions; and
    - governance mechanisms that ensure interoperability is addressed before deployment, rather than relying on costly and complex retrospective integration.

  These requirements should apply irrespective of vendor or deployment sequence, and should be embedded early in program design and procurement processes.
- **Justification:** International and Australian experience demonstrates that digital fragmentation can replicate the productivity impacts of physical infrastructure incompatibility, leading to duplicated systems, higher operating and training costs, constrained redeployment of rolling stock, and reduced diffusion of operational innovation. Early coordination of digital standards and assurance is materially lower (and more predictable) in cost than attempting to integrate incompatible systems

after deployment, while delivering substantially higher long-term productivity benefits [29][30].

Recommendation 10 - Use targeted corridor-level interoperability upgrades to unlock measurable productivity gains

- **Type:** Targeted infrastructure investment and optimisation
- **Recommendation aim:** To deliver measurable productivity uplift by selectively removing the highest-value rail interoperability bottlenecks, without requiring wholesale network reconstruction.
- **Recommendation:** Apply a corridor-level approach to rail interoperability investment, prioritising the removal of high-impact physical and operational bottlenecks where credible gains in freight task, asset utilisation, reliability, and service economics can be demonstrated. Investment decisions should explicitly consider how interoperability changes enable new or improved operating models, rather than focusing solely on reductions in interface or transfer costs.
- **Justification:** Australia's experience following the standardisation of the Melbourne–Adelaide corridor demonstrates that removing major interoperability constraints can materially change feasible rail operating models, enabling longer trains, higher utilisation, and a more than doubling of the rail freight task. This illustrates that targeted, corridor-level interoperability reform can deliver durable productivity gains without requiring full network standardisation [28].

Recommendation 11 - Require interoperability impact statements for major rail investments

- **Type:** Investment assurance and productivity safeguard
- **Recommendation aim:** To prevent new rail investments from embedding avoidable long-term productivity costs through incremental physical or digital fragmentation.
- **Recommendation:** Introduce an interoperability impact statement requirement for major rail investments, including digital signalling and train control upgrades. Proponents should be required to demonstrate that proposed investments:
  - improve physical, digital, or operational interoperability; or
  - do not create new incompatibilities whose future removal would impose avoidable cost, disruption, or productivity loss.

  Interoperability impact statements should be considered alongside business cases and funding decisions, particularly where investments affect nationally significant corridors or fleet redeployment.

- **Justification:** Rail fragmentation often arises through well-intentioned local optimisation rather than explicit decisions to diverge. Requiring interoperability impacts to be assessed and documented at the investment decision stage makes long-term consequences visible, reduces the accumulation of technical and operational debt, and improves capital efficiency. This approach aligns rail investment decisions with national productivity objectives rather than short-term project optimisation [29][30].

Recommendation 12 - Measure and publish national rail interoperability productivity indicators

- **Type:** Measurement, transparency, and accountability
- **Recommendation aim:** To make the productivity impacts of rail fragmentation visible, measurable, and governable at a national level.
- **Recommendation:** Publish a small, nationally consistent set of rail interoperability productivity indicators, such as:
    - the proportion of nationally significant freight and passenger paths operable end-to-end without system change (physical or digital);
    - delays and reliability impacts attributable to interoperability constraints (including breaks-of-gauge, signalling incompatibility, or operational rule changes); and
    - duplication of rolling stock, operator systems, training, or compliance requirements driven by fragmentation.

  These indicators should be reported at a national level and used to inform prioritisation of interoperability investments and reforms.
- **Justification:** Interoperability costs are often diffuse, embedded in operating practice, and therefore invisible in conventional project-by-project assessments. Publishing high-level, nationally consistent indicators would surface hidden productivity losses, support evidence-based investment prioritisation, and reinforce accountability for progressively reducing fragmentation over time. Measurement is a prerequisite for treating interoperability as a managed productivity input rather than an incidental technical issue [29][30].

11.5. Recommendations arising from Case Study 5: High-capacity rail signalling

Recommendation 13 - Treat high-capacity rail signalling as core productivity infrastructure

- **Type:** Strategic infrastructure recognition and investment guidance
- **Recommendation aim:** To ensure that national productivity policy recognises rail signalling and train control as foundational productivity infrastructure, with capacity,

reliability, and recovery performance treated as economic inputs rather than operational rail features.

- **Recommendation:** Explicitly recognise high-capacity signalling and modern digital train control - including moving-block systems, ETCS Level 2, integrated traffic management systems, and modern control centres - as productivity-enabling infrastructure within national productivity, infrastructure, and transport policy frameworks. This recognition should inform:
    - Commonwealth infrastructure funding priorities and co-funding conditions;
    - appraisal guidance for rail investments; and
    - assessment of projects with cross-jurisdiction or network-wide productivity impacts.

  Business cases for signalling and train control investments should explicitly assess and report productivity-relevant performance characteristics, including:
    - delay variability and reliability;
    - disruption recovery time;
    - corridor utilisation under stress conditions; and
    - network-level performance and recoverability,

  alongside traditional capacity metrics such as peak trains per hour.

  This approach aligns with established international practice, where digital signalling is treated explicitly as a capacity, reliability, and recovery lever on constrained rail networks [39][41][42].

- **Justification:** Signalling and train control determine practical corridor capacity, service reliability, and recovery performance - and therefore the level of variance that households, employers, and service operators must buffer. Treating modern train control as secondary or purely technical infrastructure risks underinvestment in a high-leverage productivity input. Properly governed signalling upgrades can unlock additional usable capacity, reduce delay variance, and defer or reduce the need for more capital-intensive expansion such as track duplication [28][29][35][36][37].

Recommendation 14 - Require nationally coordinated interoperability in signalling modernisation

- **Type:** National interoperability and standards guidance
- **Recommendation aim:** To reduce long-term productivity losses arising from fragmented, bespoke signalling systems and incompatible digital train control deployments.

- **Recommendation:** Require rail signalling modernisation programs - particularly those receiving Commonwealth funding - to demonstrate alignment with nationally coordinated interoperability expectations. This should include:
    - agreed interface specifications;
    - clear upgrade and migration pathways;
    - operational compatibility across jurisdictions; and
    - explicit long-term convergence planning to avoid entrenched fragmentation.

  Interoperability requirements should be established at program inception and treated as a productivity safeguard, not deferred to later integration stages.
- **Justification:** Uncoordinated signalling deployment risks creating a new "digital break-of-gauge" that increases lifecycle cost, constrains fleet flexibility, complicates operations, and suppresses network-wide productivity gains. International experience demonstrates that interoperability is a prerequisite for realising the full productivity benefits of digital signalling at scale, rather than a secondary technical consideration [38][39][41].

Recommendation 15 - Direct signalling investment to corridors with the highest productivity return

- **Type:** Targeted productivity uplift, prioritisation, and sequencing guidance
- **Recommendation aim:** To ensure signalling investment is directed first to corridors where variance reduction and recovery capability deliver the greatest productivity benefit.
- **Recommendation:** Apply digital train control and modern signalling investment to corridors where signalling constraints materially suppress reliability, recovery performance, or usable capacity - including both metro and non-metro contexts.

  Nationally consistent prioritisation and sequencing criteria should be developed and published, based on productivity impact rather than jurisdictional readiness alone. Criteria should explicitly consider:
    - corridor demand intensity and throughput;
    - network interdependency (including junctions, CBD approaches, and shared sections);
    - disruption spillover and recovery effects; and
    - mixed passenger–freight interface constraints.

This approach should explicitly support application beyond metro networks, including shared passenger–freight approaches to major cities and fast-growing regional corridors where disruption propagates widely.

- **Justification:** Signalling upgrades deliver the greatest productivity benefits where delay propagates across networks and where improvements materially reduce economic buffers across labour markets and supply chains. International and Australian experience demonstrates that digital train control is not solely a metro feature, but a scalable mechanism for improving corridor performance where reliability and recovery are binding constraints [33][34][36][38][41].

Recommendation 16 - Fund the operating model, not only capital replacement

- **Type:** Operations capability and performance management guidance
- **Recommendation aim:** To ensure signalling modernisation translates into sustained productivity improvement rather than one-off technology installation.
- **Recommendation:** Require signalling modernisation programs to include funded, ongoing operational capability alongside capital delivery. This should encompass:
    - continuous performance monitoring and reporting;
    - tuning and optimisation of signalling and traffic management systems;
    - network regulation and recovery tools;
    - workforce capability and competency development; and
    - post-deployment performance management tied to reliability and recovery outcomes.
- **Justification:** Operational capability is the mechanism through which signalling investment produces real-world productivity outcomes. Where signalling is treated as a static asset rather than a continuously managed system, benefits decay over time - particularly during disruption and recovery phases - eroding reliability, increasing variance, and reintroducing hidden productivity costs [30][32].

11.6. Recommendations from Case Study 6: Accessible public transport infrastructure

Recommendation 17 - Treat accessible transport as productivity-enabling infrastructure with explicit whole-of-journey targets

- **Type:** Strategic policy recognition and performance target setting
- **Recommendation aim:** To lift productivity by increasing reliable workforce participation and reducing mobility-related time loss and coordination overhead, by making accessibility a measurable network performance outcome.

- **Recommendation:** Explicitly recognise accessible public transport as productivity-enabling infrastructure within national productivity and infrastructure policy. Establish whole-of-journey accessibility targets (not just asset-upgrade counts), including service-level measures such as the percentage of accessible services and the additional travel time imposed on passengers who require accessible journeys, and require transparent reporting against these measures. [47][49]
- **Justification:** A network that is accessible only intermittently does not support reliable workforce participation. Whole-of-journey targets and reporting shift accessibility from ad hoc compliance works to a system performance outcome, enabling prioritisation of investments that remove real economic friction [49][50].

Recommendation 18 - Prioritise accessibility upgrades where they unlock workforce participation and essential service access

- **Type:** Targeted modernisation and corridor/precinct prioritisation guidance
- **Recommendation aim:** To maximise productivity returns by focusing investment on locations where accessibility removes the largest participation and coordination barriers: employment centres, health services, education precincts, and high-frequency interchanges.
- **Recommendation:** Adopt a prioritisation framework that weights accessibility upgrades by productivity-relevant criteria, including proximity to major employment and services, interchange criticality, frequency of services, and the scale of end-to-end journey completion achieved (e.g., “accessible corridor” outcomes rather than isolated stops) [46][54].
- **Justification:** Accessibility investments create the largest economic benefits when they convert whole journeys from “unreliable” to “reliably usable”, expanding the effective labour pool and reducing buffer time, cancellations, and reliance on higher-cost alternatives [45][46].

Recommendation 19 - Fund accessibility as a combined capital and operational reliability program

- **Type:** Program design and operational capability guidance
- **Recommendation aim: To** ensure accessibility improvements persist in real-world operation by funding the maintenance, monitoring, and reliability of accessibility assets (e.g., lifts, ramps, platform interfaces) alongside capital upgrades.
- **Recommendation:** Require accessibility programs to include sustained operational funding and performance management for accessibility-critical assets and information, including outage tracking, restoration time targets, and journey-planning visibility when assets are unavailable.

- **Justification:** Accessibility is undermined when operational fragility turns "accessible infrastructure" into unreliable infrastructure. Reliability is the mechanism that converts upgrades into participation and productivity gains [49][54].

Recommendation 20 - Use global comparators to normalise appraisal of accessibility as economic value, not only compliance cost

- **Type:** Measurement and appraisal methodology guidance
- **Recommendation aim:** To strengthen investment justification by ensuring project appraisal captures participation, reliability, and avoided "parallel transport" costs.
- **Recommendation:** Incorporate appraisal approaches that explicitly value participation gains and reduced accessibility-related journey penalties, drawing on international accessibility economic framing and comparator programs (e.g., ITF/OECD accessibility benefits work and large network programs such as TfL's step-free initiative), while calibrating assumptions to Australian conditions [46][54][55].
- **Justification:** Accessibility investments can produce measurable economic benefits through increased participation and reduced friction, and global comparators help demonstrate that this is an accepted infrastructure investment logic rather than a novel claim [46][55].

12. Conclusion

Australia's productivity challenge cannot be addressed through labour or innovation policy alone. It requires sustained attention to the infrastructure that enables technology, data, and coordination to function effectively at scale.

The case studies in this submission - national broadband infrastructure, digital water metering, smart traffic signals, rail interoperability, high-capacity signalling, and accessible public transport - demonstrate a common productivity mechanism. In each case, outcomes are shaped less by access to technology than by the quality of the enabling infrastructure: reliability, consistency, feedback speed, and the ability to operate predictably under normal, non-exceptional conditions.

Where infrastructure introduces high variance, delayed feedback, or operational fragility, organisations respond rationally by adding buffers, workarounds, and conservative design choices. These adaptations compound across sectors and locations, creating persistent productivity drag that is rarely visible in headline metrics but materially constrains economic performance.

Reducing variance, accelerating the emphasize detection of inefficiency, and treating enabling infrastructure as a long-term productivity asset represent practical, high-impact opportunities to lift economy-wide productivity. Fragmented pilots, one-off upgrades, or performance measured only at commissioning risk eroding these gains. Sustained productivity improvement depends on consistent capability, coordinated governance, and long-term operational focus across the infrastructure that underpins everyday economic activity.

13. References

[1]. World Bank (2009) Information and Communications for Development 2009: Extending Reach and Increasing Impact (IC4D 2009). Available at: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/645821468337815208.

[2]. World Bank (2016) World Development Report 2016: Digital Dividends. Available at: https://documents1.worldbank.org/curated/en/896971468194972881/pdf/102725-PUB-Replacement-PUBLIC.pdf.

[3]. NBN Co (2025) nbn Fixed Wireless upgrade program completed for 800k homes and businesses. Available at: https://www.nbnco.com.au/corporate-information/media-centre/media-statements/nbn-fixed-wireless-upgrade-program-completed.

[4]. NBN Co (2024) NBN Co selects Amazon's Project Kuiper. Available at: https://www.nbnco.com.au/corporate-information/media-centre/media-statements/nbn-co-selects-amazons-project-kuiper.

[5]. Czernich et al (2011) (2011). Broadband Infrastructure and Economic Growth. Available at: https://doi.org/10.1111/j.1468-0297.2011.02420.x.

[6]. ACCC (n.d.) Measuring Broadband Australia. Available at: https://www.accc.gov.au/by-industry/telecommunications-and-internet/telecommunications-monitoring/measuring-broadband-australia-program.

[7]. OECD (2019) Going Digital: Shaping Policies, Improving Lives. Available at: https://www.oecd.org/en/publications/2019/03/going-digital-shaping-policies-improving-lives_g1g9f091.html.

[8]. ACMA (2020) Impacts of the 2019–20 bushfires on the telecommunications network. Available at: https://www.acma.gov.au/publications/2020-04/report/impacts-2019-20-bushfires-telecommunications-network.

[9]. NBN Co (n.d.) What happens during a power blackout?. Available at: https://www.nbnco.com.au/learn/what-happens-in-a-power-blackout.

[10]. Barwon Water (n.d.) Digital meters program. Available at: https://www.yoursay.barwonwater.vic.gov.au/digital-meters.

[11]. South East Water (2024) Digital meters saving millions on water bills. Available at: https://southeastwater.com.au/about-us/news/digital-meters-saving-millions-on-water-bills/.

[12]. Barwon Water (2025) Marengo digital meter trial successfully saves water. Available at: https://www.yoursay.barwonwater.vic.gov.au/apollo-bay-hub/marengo-digital-meter-trial-successfully-saves-water.

[13]. Central Highlands Water (n.d.) Digital metering project. Available at: https://www.chw.net.au/home-business/digital-metering-project.

[14]. Frontier Economics (2024) The case for digital water meters – South East Water. Available at: https://www.frontier-economics.com.au/the-case-for-digital-water-meters-south-east-water/.

[15]. PUB Singapore (n.d.) Smart Water Meter Programme. Available at: https://www.pub.gov.sg/Public/KeyInitiatives/Smart-Water-Meter.

[16]. PUB Singapore (n.d.) How Smart Water Meter Works. Available at: https://www.pub.gov.sg/-/media/PUB/PDF/swm/How_Smart_Water_Meter_Works.pdf.

[17]. Rupiper & Wichman (2024) Smart water meters. PLOS Water. Available at: https://journals.plos.org/water/article?id=10.1371/journal.pwat.0000186.

[18]. FHWA (n.d.) Adaptive Signal Control Technology. Available at: https://ops.fhwa.dot.gov/arterial_mgmt/asct.htm.

[19]. Transport for NSW (n.d.) SCATS. Available at: https://www.scats.nsw.gov.au/.

[20]. Lipovac et al (2013) (2013). Pedestrian countdown displays. Available at: https://doi.org/10.1016/j.trf.2013.07.005.

[21]. Nguyen et al (2025) (2025). Intelligent traffic signal control. Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC11868367/.

[22]. NYSDOT (2019) Connected Eco-driving Technologies. Available at: https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/C-15-15%20Final%20Report.pdf.

[23]. LTA Singapore (n.d.) Intelligent Transport Systems. Available at: https://www.lta.gov.sg/content/ltagov/en/getting_around/driving_in_singapore/intelligent_transport_systems.html.

[24]. OECD (n.d.) Bridging the Digital Divide. Available at: https://www.oecd.org/en/topics/sub-issues/digital-divide.html.

[25]. Victorian Dept of Transport (n.d.) SCATS traffic signal management. Available at: https://transport.vic.gov.au/road-and-active-transport/business/road-and-traffic-management/traffic-lights/signal-coordination-and-automation/scats.

[26]. Transport for NSW (2025) Intelligent Traffic Light Program. Available at: https://www.transport.nsw.gov.au/projects/current-projects/intelligent-traffic-light-program.

[27]. University of Melbourne (2022) World’s smartest traffic management system launches in Melbourne. Available at: https://www.unimelb.edu.au/newsroom/news/2022/march/worlds-smartest-traffic-management-system-launches-in-melbourne.

[28]. Victoria’s Big Build (n.d.) High Capacity Signalling. Available at: https://bigbuild.vic.gov.au/projects/metro-tunnel/about/high-capacity-signalling.

[29]. Victoria’s Big Build (n.d.) Metro Tunnel - High Capacity Signalling Fact Sheet. Available at: https://bigbuild.vic.gov.au/__data/assets/pdf_file/0003/784083/MT-High-Capacity-Signalling-fact-sheet.pdf.

[30]. Transport for NSW (n.d.) Digital Systems Program. Available at: https://www.transport.nsw.gov.au/projects/current-projects/digital-systems-program.

[31]. Transport for NSW (n.d.) Rail Service Improvement Program. Available at: https://www.transport.nsw.gov.au/projects/current-projects/rail-service-improvement-program.

[32]. Transport for NSW / RTSA (n.d.) Digital Systems: Transforming Rail Transport in Sydney (ETCS L2, TMS & ATO). Available at: https://rtsa.com.au/wp-

content/uploads/2018/09/RTSA-Presentation-Transforming-Rail-Transport-in-Sydney-Simon-Lemon.pdf.

[33]. Queensland Department of Transport and Main Roads (n.d.) European Train Control System Program. Available at: https://www.tmr.qld.gov.au/projects/programs/european-train-control-system-program.

[34]. Cross River Rail Delivery Authority (n.d.) Rail Network Improvements. Available at: https://crossriverrail.qld.gov.au/about/rail-network-improvements/.

[35]. Public Transport Authority (WA) (n.d.) High Capacity Signalling. Available at: https://www.pta.wa.gov.au/projects/current-projects/high-capacity-signalling.

[36]. Infrastructure Australia (n.d.) METRONET - High Capacity Signalling. Available at: https://www.infrastructureaustralia.gov.au/ipl/metronet-high-capacity-signalling.

[37]. Infrastructure Australia (n.d.) METRONET: High Capacity Signalling System - Business Case Summary. Available at: https://www.infrastructureaustralia.gov.au/sites/default/files/2023-01/IA_METRONET_High_Capacity_Signalling_System.pdf.

[38]. National Transport Commission (n.d.) Digital Train Control Technology - Interoperability Requirements Assessment. Available at: https://www.ntc.gov.au/sites/default/files/assets/files/Digital-train-control-technology-interoperability-requirements-assessment.pdf.

[39]. European Union Agency for Railways (ERA) (n.d.) ERTMS / ETCS - Increasing capacity and interoperability. Available at: https://www.era.europa.eu/domains/ertms_en.

[40]. European Commission (n.d.) ERTMS Deployment Action Plan. Available at: https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/ertms_en.

[41]. Network Rail (UK) (n.d.) Digital Railway Programme. Available at: https://www.networkrail.co.uk/running-the-railway/railway-upgrade-plan/digital-railway/.

[42]. Land Transport Authority (Singapore) (n.d.) Communications-Based Train Control (CBTC) signalling systems. Available at: https://www.lta.gov.sg/content/ltagov/en/getting_around/public_transport/rail_network.html.

[43]. International Union of Railways (UIC) (n.d.) High-capacity signalling and automatic train operation in dense rail networks. Available at: https://uic.org/rail-system/rail-system-digitalisation.

[44]. World Health Organization (WHO) - Disability and health (factsheet) (n.d.) . Available at: https://www.who.int/news-room/fact-sheets/detail/disability-and-health.

[45]. OECD - Disability, Work and Inclusion (2022) . Available at: https://www.oecd.org/en/publications/disability-work-and-inclusion_1eaa5e9c-en.html.

[46]. International Transport Forum (ITF/OECD) - Economic Benefits of Improving Transport Accessibility (2017) . Available at: https://www.itf-

oecd.org/sites/default/files/docs/economic-benefits-improved-accessibility-transport-systems.pdf.

[47]. Australian Government (Department of Infrastructure, Transport, Regional Development, Communications and the Arts) - 2022 Review of the Disability Standards for Accessible Public Transport 2002 (Final Report PDF) (n.d.) . Available at: https://www.infrastructure.gov.au/sites/default/files/documents/2022-review-of-the-disability-standards-for-accessible-public-transport.pdf.

[48]. Victorian Auditor-General's Office (VAGO) - Accessibility of Tram Services: Follow-up (2025) (PDF) . Available at: https://www.audit.vic.gov.au/sites/default/files/2025-11/20251119-Accessibility-of-Tram-Services.pdf.

[49]. Victorian Auditor-General's Office (VAGO) - Accessibility of Tram Services: Follow-up (overview page) (n.d.) . Available at: https://www.audit.vic.gov.au/report/accessibility-tram-services-follow/.

[50]. ABC News - Melbourne's tram network falls short of accessibility standards (19 Nov 2025) (n.d.) . Available at: https://www.abc.net.au/news/2025-11-19/melbourne-tram-network-falls-short-accessibility-standards/106027512.

[51]. Victorian Government (DTP) - Accessibility Action Plan 2025–2029: Towards Equitable Journeys and Communities (n.d.) . Available at: https://www.vic.gov.au/dtp-accessibility-action-plan-2025-2029.

[52]. Victorian Government (DTP) - Outcomes from the Accessible Public Transport in Victoria Action Plan (2020–2024) (n.d.) . Available at: https://www.vic.gov.au/dtp-accessibility-action-plan-2025-2029/outcomes-accessible-public-transport-victoria-action-plan.

[53]. Transport for NSW - Safe Accessible Transport (SAT) program (n.d.) . Available at: https://www.transport.nsw.gov.au/projects/current-projects/safe-accessible-transport-program.

[54]. Transport for London (TfL) - Step-free access programme (n.d.) . Available at: https://tfl.gov.uk/travel-information/improvements-and-projects/step-free-access.

[55]. London Assembly (Mayor's Question Time) - Step-free access and London's economy (includes reference to DfT-commissioned benefit-cost ratio) (n.d.) . Available at: https://www.london.gov.uk/who-we-are/what-london-assembly-does/questions-mayor/find-an-answer/step-free-access-and-londons-economy.