

Managing transport system investment risk: Maximising Prioritisation of Infrastructure Investment Proposals in the Face of Uncertainty

Final Report

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Executive Summary

Background

In the last decade, interest in future mobility and transport (FMT) has seen consistent growth across the world. FMT is sought to address many transport problems, such as poor accessibility and growing congestion. However, FMT brings significant uncertainties, along with anticipated benefits. Also, many forms of FMT are expected to cause disruptions within the transport sector and potentially beyond. Therefore, infrastructure investment planning should consider the impacts of FMT. Investment decisions are usually made on the basis of general assumptions which presume that the existing infrastructure will continue to be used in the same way as they now. Also, much of the work that attempts to predict uptake and behaviours of FMT is still in development. Some literature suggests potential impacts of FMT, however, current models' ability to predict potential impacts in measurable and quantifiable terms is limited. A typical TIIA framework adopts a multi-criteria assessment (MCA) approach with a set of criteria. Infrastructure resilience against uncertainties is incorporated in some TIIA framework. However, the criteria typically used to assess infrastructure resilience are too broad and unspecific, which can leave room for subjectivity that would lead to inconsistent and unfair assessments, particularly when used across a variety of transport projects. This study explores ways to improve the capability of existing TIIA frameworks to account for the uncertainties of FMT. The improved TIIA framework would ensure that transport infrastructure planning is better prepared for the introduction of FMT and that the proposals with more future FMT potentials will be better placed within investment prioritisation.

Approach

This study explores literature to first determine a TIIA framework that is used typically in practice, and second to identify the impacts and uncertainties of FMT. It then proposes a methodology that can improve the TIIA framework. The proposed methodology is then applied to a real-life context using recent major transport projects. Through this, its limitations are identified and the conclusion is developed.

The literature review aims to provide sufficient knowledge of TIIA frameworks, particularly those that are used in practice, and the impacts and uncertainties of FMT. The scope of the review includes the literature that describes the TIIA frameworks that are used in Australian practice and the impacts and uncertainties of FMT. The implications for infrastructure investment assessment and prioritisation processes are explored by examining how the potential impacts can change the assessment outcomes.

Through reviewing existing TIIA frameworks, this study will explore appropriate ways to improve the framework to account for the uncertainties of FMT. The proposed additional tasks should not disrupt the existing process and/or require substantial additional resources. Therefore, this study needs to identify the TIIA tools currently used, the data required in the assessment and the tasks involved in the activities. Also, the appropriateness will be determined, while considering the impacts and uncertainties of FMT to ensure that the proposed methodology effectively assess them.

Once the proposed methodology is defined, it is applied in a real-life context by assessing existing transport investment proposals to test its applicability and practicality. This process can improve the methodology and identifies its limitations. Three recent major transport investment proposals from Australia are used. These are Brisbane Metro (QLD), METRONET: Yanchep Rail Extension (WA) and North East Link (VIC), which are all identified as high priority by Infrastructure Australia (Infrastructure Australia, 2020).

Literature Review

Transport Infrastructure Investment Assessment (TIIA) Frameworks

The TIIA frameworks used in Australia adopt a MCA approach. The MCA provides a systematic process to consider an investment proposal from various perspectives and the outcomes of various assessment tools. For instance, the Infrastructure Australia framework (Infrastructure Australia, 2018a) considers the “strategic fit” that assesses alignments between the project’s objectives and the government’s objectives; “deliverability” that assesses the project’s “readiness” such as maturity of planning and assessments; and the “economic, social and environmental value” that assesses the project’s value to society. A TIIA framework typically considers the following impacts using the set of criteria:

- Travel time and congestion;
- Vehicle operating costs including fuel costs;
- Environmental impacts such as air pollution;
- Health impacts; and
- Other social impacts.

Resilience against future uncertainties can be assessed within a TIIA by incorporating infrastructure resilience consideration. However, the TIIA frameworks that are currently used inadequately assess resilience against future uncertainties, including those associated with FMT. As a result, the infrastructure investment proposals that are resilient are not always prioritised.

Impacts and Implications on Infrastructure, Planning and Policy

The impact on transport demand and congestion will vary significantly depending on technology type. Also, there are claims that are potentially conflicting. This suggests that it is difficult to estimate the impacts and uncertainties of FMT in a quantified manner from the technical point of view at the moment. This means that numerical assessment tools, such as CBA, become pointless without reliable assumptions.

FMT can impact transport infrastructure, planning and maintenance in many ways through impacts on existing infrastructure and network, planning, and government’s strategic-level objectives. This suggests that improving the current infrastructure investment assessment framework is crucial to ensure that the framework accommodates these changes and as a result, the decisions maximise the benefits to society.

Exploring ways to Improve the TIIA Framework

We reviewed how resilience is generally assessed to identify a suitable method to assess the resilience against the uncertainties of FMT. First, various methods that are commonly used to assess resilience, in general, are identified, then, disruption due to FMT is closely examined.

Infrastructure Resilience

Infrastructure resilience is often associated with the resilience of critical infrastructure against disruption due to natural disasters. However, the concept of “resilience” is wider than natural disasters and covers the capacity to withstand disruption, absorb disturbance, and adapt to changing conditions (Hughes & Healy, 2014).

Infrastructure resilience can be measured using various methods. However, stochastic analysis based on probability distributions requires historic forecasting models that can predict the likelihood of disruptions and determine appropriate forms of distributions for modelling. Also, conducting simulations is extremely difficult to ensure that they produce reliable outcomes when simulating mixed vehicle environment with a lot of uncertainties with demand and supply. When

adopting MCA, the quality of analysis relies on the set of criteria used, thus, the criteria need to be specific and relevant in the context of FMT.

Disruption due to FMT

We explored the disruption due to FMT alongside with typically characterised disruption to determine a suitable method to assess the uncertainties of FMT. Here, we consider three types of disruptions:

- The disruption that causes negative impacts;
- The disruption that causes positive impacts; and
- The avoided disruption due to improvements in TIIA framework.

As shown, disruption due to FMT can increase or decrease utilisation. This suggests that the disruption due to FMT is more complex than the disruption due to natural disasters, which then suggests that a typical method/methodology to assess infrastructure resilience cannot fully assess the disruption due to FMT. To account for the complexity of FMT, we propose the “FMT uncertainty” criterion to be added within the existing TIIA framework, while noting that the suitable method still needs to be explored for a full assessment of the FMT uncertainty. The additional criterion would widen the scope, wider than “infrastructure resilience”, considering both increase and decrease of utilisation.

Exploring a Suitable Assessment Tool for the New Criterion

We explored various methods that can be used as the assessment tool for the “FMT uncertainty” criterion. This is necessary because examining the disruption due to FMT highlighted that a typical assessment tool for infrastructure resilience cannot fully assess the uncertainties of FMT.

Scenario testing is particularly useful when the future is uncertain and is often used in the context of FMT. It is also often used for prioritisation of transport investment proposals. Additionally, MCA is the most commonly used tool for TIIA as previously discussed, while CBA would be technically difficult as has been highlighted. Thus, we recommend the scenario testing using a MCA approach as the most suited tool for assessing the uncertainties of FMT due to technicality, practicality and applicability advantages.

Testing the Applicability and Practicality

For testing the applicability and practicality, the FMT uncertainty assessment is incorporated within the Infrastructure Australia framework (Infrastructure Australia, 2018a). Figure 12 and Table 2 (see Section 5.1) illustrates the assessment of FMT uncertainty.

Scenarios

For testing, this study incorporates the scenarios that are considered in the Transport Portfolio SAP 2019-20 document:

- a) Chasing Goliath: Provide integrated transport services that deliver efficient and safe solutions for a growing State;
- b) Uberlicious: Provide technology-enabled integrated transport solutions and services to support economic development and optimise the use of transport services;
- c) Safe and Sound: Redirect investment into maintenance projects and optimise resources in existing transport services to continue to deliver sustainable, safe and reliable journeys; and
- d) Tortoise and the Hare: Develop policy and create conditions to facilitate and enable the adoption of positive transformational transport options focused on network optimisation and influencing individual’s behaviour and travel choices.

Overall, the following scenario assumptions are found as the key factors that can influence the assessment outcome across the scenarios:

- Changes in demand for PT;
- Electric vehicle and AV uptake;
- Assumption relating to congestion and pollution;
- Strategic objectives/directions; and
- Assumptions relating to economic growth.

Assessment of the FMT Uncertainty

The FMT uncertainty assessment outcomes of the three projects showed that North East Link is likely to result positively, while Brisbane Metro and METRONET: Yanchep Rail Extension are likely to be exposed to considerable uncertainty. This suggests that investment decisions for the two projects need to be carefully considered, while North East Link should stay on the high priority list.

The testing found that the assessment outcome is considerably influenced by certain features of the project scope. These are:

- The nature of the work, whether the project is a road, PT or active travel project;
- Integration of technology features, such as better journey planning tools and more efficient operation management systems; and
- Being integrated within wider transport optimisation and service integrations, such as being part of the MaaS scheme.

The testing revealed that the uncertainties associated with social value were not fully captured. This can be due to the lack of comprehensiveness of the scenarios, leading to a shortage of assumptions relating to social value in the scenarios used in this study. This limits the assessment's ability to assess the uncertainties associated with social value. Similarly, across all scenarios, the changes in deliverability criterion also suffered from lacking related assumptions. Additionally, the assessment suffers from a key limitation of MCA, which is the risk of subjectivity.

Discussion

Through the testing, first, considerable demand uncertainties were evident, which can lead to uncertainty in all benefits and disbenefits. This emphasises that all resulting impacts due to changes in demand need to be exclusively assessed under the "changes in utilisation" criterion. It also suggests that the disruption of FMT needs to be fully understood when undertaking the assessment. Second, it found that the projects that are often inflexible in the way they can be used, are exposed to more uncertainties than others. Third, the comprehensiveness of the assessment depends on the comprehensiveness of the scenarios. Fourth, identifying "triggers" would be useful as it can flag potential loss of utilisations without any detailed analyses, which can be identified through the assessment of FMT uncertainty.

This study considered both an increase and decrease of utilisation. This is particularly important, given that the increase can offset the decrease, because overall network-wide impacts need to be considered in infrastructure planning, even when assessing at project-level.

Concluding Remarks

This study explored ways to improve the capability of existing TIIA frameworks to account for the uncertainties of FMT. The literature review determined a framework that is used typically for TIIA in practice and identified the impacts and uncertainties of FMT. This study then explored incorporating infrastructure resilience within the TIIA framework. However, an examination of the disruption of FMT revealed that a commonly used infrastructure resilience assessment tool cannot fully assess the uncertainties of FMT, without any improvements. This study, therefore, considered adopting scenarios and MCA and identified a set of criteria that can fully assess the FMT uncertainties. The applicability and practicality of the proposed assessment tool are tested using real-life transport projects, which also identified its key limitations.

To best deal with the uncertainties of FMT, regularly conducting detailed analyses of status quo and emerging trends based on recent historical data is crucial. Additionally, further work on analysing transport demand trends and forecasting that can feed into developing more comprehensive scenarios would improve the capability and comprehensiveness of the proposed methodology.

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1. Introduction

In the last decade, interest in future mobility and transport (FMT) has seen consistent growth across the world. FMT is sought to address many transport problems, such as poor accessibility and growing congestion. However, FMT brings significant uncertainties, along with anticipated benefits. Also, many forms of FMT are expected to cause disruptions within the transport sector and potentially beyond. Therefore, infrastructure investment planning should consider the impacts of FMT, such as autonomous vehicles (AV) (UK National Infrastructure Commission, 2018). However, incorporating uncertainties would test the capability and robustness of the transport infrastructure investment assessment (TIIA) frameworks used currently.

Investment decisions are usually made on the basis of general assumptions which presume that the existing infrastructure will continue to be used in the same way as they now. This means that the TIIA frameworks that are currently used inadequately assess uncertainties. Additionally, although improvements can be made to improve data collections, data quality and data analysis techniques almost infinitely, the ability to predict the future is always limited and any analysis is certainly exposed to some degree of uncertainty. Besides, much of the work that attempts to predict uptake and behaviours of FMT is still in development. Some literature suggests potential impacts of FMT, however, current models' ability to predict potential impacts in measurable and quantifiable terms is limited.

This study explores ways to improve the capability of existing TIIA frameworks to account for the uncertainties of FMT. A typical TIIA framework adopts a MCA approach with a set of criteria, such as deliverability strategic fit, and economic, environmental and social value (see Infrastructure Australia (2018a)). Infrastructure resilience against uncertainties is incorporated in some TIIA framework (such as Deloitte prioritisation matrix (Deloitte, 2012)). However, the criteria typically used to assess infrastructure resilience, such as exposure, vulnerability and coping capacity (Leviäkangas & Aapaoja, 2018), and adsorptive capacity, adaptive capacity and restorative capacity (Hosseini & Barker, 2016) are too broad and unspecific, which can leave a room for subjectivity that would lead to inconsistent and unfair assessments, particularly when used across a variety of transport projects. This study tackles this challenge by examining the impacts and uncertainties of FMT.

The improved TIIA framework would ensure that transport infrastructure planning is better prepared for the introduction of FMT and that the proposals with more future FMT potentials will be better placed within investment prioritisation.

2. Study Methodology

This study aims to improve the capability of existing TIIA frameworks to account for the uncertainties of FMT. Figure 1 illustrates the study methodology. This study explores literature to first determine a TIIA framework that is used typically in practice, and second to identify the impacts and uncertainties of FMT. It then proposes a methodology or method that can improve the TIIA framework. The proposed methodology is then applied to a real-life context using recent major transport projects. Through this, its limitations are identified and the conclusion is developed.

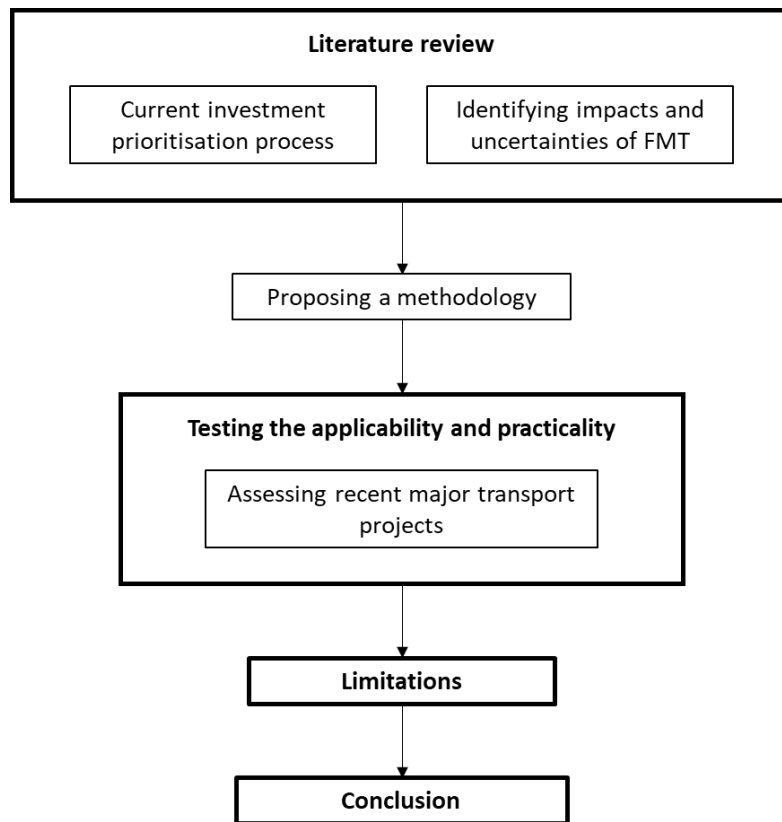


Figure 1 Study methodology

This study primarily focusses on proposals for new investments, seeking state and/or federal funding. Therefore, the proposals that are motivated by maintenance and rehabilitation work that is typically funded by a separate pocket of funding are beyond the scope. The rehabilitation work typically does not include major repurposing work that is generally proposed as a new substantial investment. Furthermore, this study focuses on physical infrastructure investments, as opposed to “soft” interventions such as travel behaviour change initiatives.

2.1. Literature Review

The literature review aims to provide sufficient knowledge in TIIA frameworks, particularly those that are used in practice, and the impacts and uncertainties of FMT. The review will ensure that what this study will propose would be practical and can be incorporated into an existing TIIA framework, while considering appropriateness for the context of FMT. To achieve these, the scope of the review includes the literature that describes the TIIA frameworks that are used in Australian practices, and the impacts and uncertainties of FMT. Also, it explores various FMT and a wide range of previous studies, in order to capture all relevant issues relating to the FMT. These include technology uptake rates, benefits of information sharing and mobility-as-a-service (MaaS). The implications for infrastructure investment assessment and prioritisation processes are explored by examining how the potential impacts can change the assessment outcomes. The literature

includes a wide range of literature types including academic studies, industry reports and government publications.

2.2. Exploring Ways to Account for the Uncertainties of FMT

Through reviewing existing TIIA frameworks, this study will explore appropriate ways to improve the framework to account for the uncertainties of FMT. What this study will propose is likely to introduce a new set of tasks, in addition to existing TIIA activities. The tasks should not disrupt the existing process and/or require substantial additional resources. Therefore, this study needs to identify the TIIA tools currently used, the data required in the assessment and the tasks involved in the activities. Also, the appropriateness will be determined, while considering the impacts and uncertainties of FMT to ensure that the proposed methodology effectively assess them.

2.3. Testing Applicability and Practicality of the Proposed Methodology

Once the proposed methodology is defined, it is applied in a real-life context by assessing existing transport investment proposals to test its applicability and practicality. This process can improve the methodology and identifies its limitations. Three recent major transport investment proposals from Australia are used. These are Brisbane Metro (QLD), METRONET: Yanchep Rail Extension (WA) and North East Link (VIC), which are all identified as high priority by Infrastructure Australia (Infrastructure Australia, 2020). See Table 6 in the Appendix for their detailed descriptions.

3. Literature Review

3.1. Transport Infrastructure Investment Assessment (TIIA) Frameworks

Australian TIIA frameworks adopt a MCA approach (Chi & Bunker, 2020). The MCA provides a systematic process to consider an investment proposal from various perspectives and the outcomes of various assessment tools. However, the Australian Transport Assessment and Planning (ATAP) guides advise against the use of an MCA approach for the purpose of transport infrastructure investment prioritisation due to criticisms regarding the use of the single weighted score approach (Australian Transport and Infrastructure Council, 2016). Nevertheless, MCA is currently included in government and multilateral project appraisal and selection practice in regions including the Pacific Island Countries and Argentina, as well as Chile, Ireland, and the UK (Marcelo, Mandri-Perrott, House, & Schwartz, 2016).

Many countries use comprehensive assessment frameworks that combine cost-benefit analysis (CBA) with other assessment tools to include both monetised and non-monetised impacts (Mackie, Worsley, & Eliasson, 2014). MCA allows both non-monetary and monetary attributes to be assessed within the same framework without rejecting CBA, and has considerable potential for application to mega infrastructure projects and complex urban projects as risk and opportunity registers, usefully complementing more traditional appraisal methods (Dimitriou, Ward, & Dean, 2016). A full assessment of all relevant impacts can be conducted by combining MCA with CBA (Beria, Maltese, & Mariotti, 2012a, 2012b). Other studies also confirm this claim. A case study that combined CBA and MCA to assess road projects (Gühnemann, Laird, & Pearman, 2012) concluded that MCA facilitates the inclusion of political objectives in the assessment that cannot be monetised. A study that reviewed cost-effectiveness analysis (CEA), planning balance sheet (PBS), goal achievement matrix (GAM), as well as CBA and MCA, for infrastructure investment prioritisation (Dimitriou et al., 2016), suggested that the MCA framework offers both informing and complementarity options to CBA. Another study that compared life-cycle assessment (LCA), social life-cycle assessment (SLCA) and rating systems, along with CBA and MCA as tools to assess proposed transport infrastructure investments (Bueno, Vassallo, & Cheung, 2015), recommended using MCA along with these various tools to support sustainability assessment.

Western Australia (WA) Transport Portfolio uses a comprehensive framework that adopts a MCA approach to assess and prioritise transport infrastructure investments in WA. The assessments and submission requirements of the agency-prioritised investments are prepared by each proponent agency. The assessments are combined as a long list and are scored against the Portfolio assessment criteria which consist of six criteria supported by criteria scoring guidance (WA Portfolio Investment Coordination, 2017). Then, multiple parties and subject experts review the scores to ensure consistent and fair scoring. Prioritisation is based on average MCA scores, along with investment costs and benefit-cost ratio (BCR). The non-prioritised proposals can be considered for the next round of assessment.

Table 7 (see Appendix) summarises the assessment criteria that various government departments and agencies currently use which often accommodate a wide range of issues. For instance, the Infrastructure Australia framework (Infrastructure Australia, 2018a) considers the “strategic fit” that assesses alignments between the project’s objectives and the government’s objectives; “deliverability” that assesses the project’s “readiness” such as maturity of planning and assessments; and the “economic, social and environmental value” that assesses the project’s value to society. A TIIA framework typically considers the following impacts using the set of criteria:

- Travel time and congestion;
- Vehicle operating costs including fuel costs;
- Environmental impacts such as air pollution;
- Health impacts; and
- Other social impacts.

Scoring guidance is usually attached to the assessment criteria to ensure consistent scoring across investment proposals. Providing scoring guidance that fit all contexts can be challenging when assessing a wide range of investments. For instance, the Deloitte assessment criteria and scoring guidance (Deloitte, 2012) are intended to be used for infrastructure investment proposals across sectors. However, the criteria are only given generic definitions and may be inappropriate in some contexts. Furthermore, some assurance objectives such as project management and major risks do not address the impacts of the investment, and therefore the definitions provided are not suitable for these criteria. The World Bank infrastructure investment prioritisation framework uses a unique set of criteria and weightings for each investment proposal (Marcelo et al., 2016). This means that the level of comprehensiveness of the assessment relies only on the technical knowledge of the practitioners and government agencies. Additionally, comparing multiple investment proposals fairly would be difficult using different sets of criteria.

Unlike the World Bank framework (Marcelo et al., 2016) that requires a fixed budget amount, Australian TIIA frameworks prioritise investment proposals with respect to the timeframe as shown in the Deloitte prioritisation matrix (Deloitte, 2012) and the Infrastructure Priority List (Infrastructure Australia, 2020). Both frameworks place proposals on different timeframes, such as short or long term and near, medium or longer-term, based on MCA outcomes. The investment size is considered under some criteria but is not the only consideration in decision making. Instead, in the World Bank framework, the proposals are prioritised based on the investment size and available budget size at the time of decision making.

Additionally, a different set of criteria may be needed for proposals associated with smaller investments. The current set of criteria is designed for those with large investments and assumes that there are no funding issues to conduct detailed analyses such as CBA. However, small-scale projects and the proposals seeking funding to conduct the planning activities that also tend to have smaller costs will be disadvantaged using the current set of criteria. Also, the current framework requires substantial planning activities for the purpose of providing sufficient information for decision-making. This suggests that the time and resources spent on submission preparations would be wasted, if the proposals that are unlikely to receive funding progress through the planning process. Also important is the treatment of the proposals that are motivated by election commitments. These proposals should not be assessed alongside other proposals as it would hinder the assessment process by opening room for bias. Finally, the assessment of an investment program needs further consideration. When each project is assessed separately, they may not provide sufficient benefits, because the benefits may only be maximised when all proposed interventions are provided. In addition, the proposed interventions often inter-depend on each other. Specific guidance on the assessment of the investment program needs to be provided.

Many forms of FMT are expected to cause disruptions within the transport sector and potentially beyond. Infrastructure investment planning needs to consider the impacts of the FMT (UK National Infrastructure Commission, 2018). Resilience against future uncertainties can be assessed within a TIIA by incorporating infrastructure resilience considerations. Also, as resilient infrastructure supports a resilient economy (Hallegatte, Rentschler, & Rozenberg, 2019), effectively identifying and prioritising infrastructure investment proposals that are resilient is crucial. However, Australian governments often do not incorporate infrastructure resilience in assessment criteria, particularly for active and public transport modes (Infrastructure Australia, 2019b). Investment decisions are usually made on the basis of general assumptions which presume that the existing infrastructure will continue to be used the same way as they are used now. This is also evident in Table 7 as only the Deloitte framework (Deloitte, 2012) includes infrastructure resilience consideration. This means, and as suggested in a study (Hallegatte et al., 2019), the TIIA frameworks that are currently used inadequately assess resilience against future uncertainties, including those associated with

FMT. As a result, the infrastructure investment proposals that are resilient are not always prioritised.

3.2. Future Mobility and Transport (FMT)

Figure 2 summarises a variety of FMT that can influence the transport sector. Although numerous emerging technologies and industry trends can impact the transport sector, this study particularly focuses on the technologies that directly impact transport infrastructure and planning. These include autonomous vehicles (AV), mobility-as-a-service (MaaS), on-demand mobility, shared mobility and other technologies that are relevant in the freight sector, as well as those needed for the deployment of these services such as smart freeways.

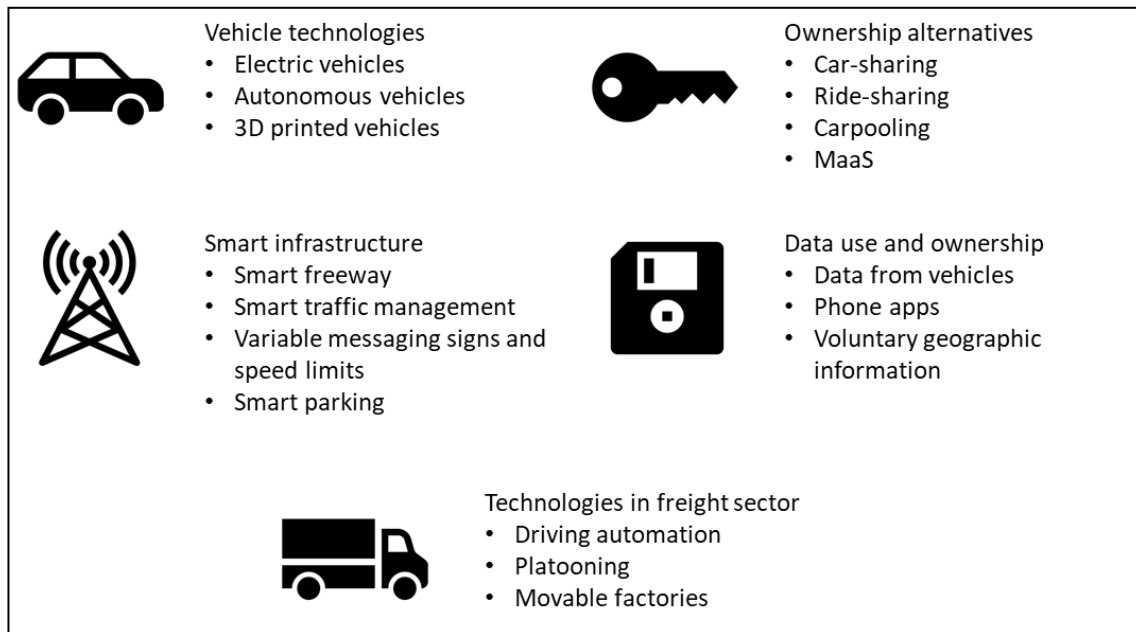


Figure 2 Summary of FMT that can impact the transport sector, adapted from Smith and Gladstone (2017)

Figure 3 illustrates a conceptual representation of FMT that are discussed in this study. Although service provision differs between different countries and locations, currently available travel options in most cities include public transport (PT), privately owned traditional vehicles, on-demand mobility and shared mobility. Currently, most cars are privately owned, petrol-fuelled and not autonomous. PT is typically provided as buses, trams, trains, ferries and taxis. On-demand mobility includes ride-sourcing services such as Uber. Shared mobility includes, but is not limited to, carpooling, car-sharing and ride-sharing services. While these services are offered or will be offered in the near future, vehicle technologies are advancing as well. These include electric, autonomous and connected vehicles. In many academic studies, connected vehicles are presumed as autonomous (CAV), and AV and CAV as both electric. Connections can be facilitated between vehicle-to-vehicle and vehicle-to-infrastructure. CAV is considered as a form of AV in this study for simplicity.

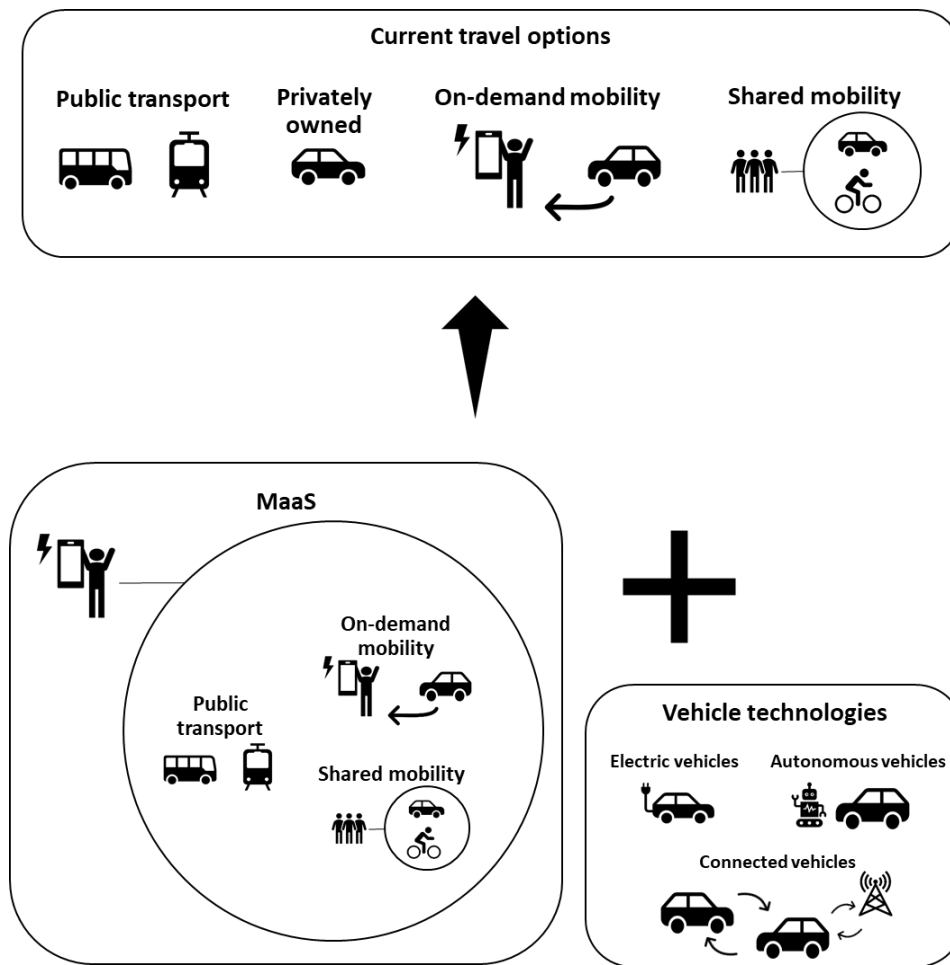


Figure 3 Conceptual representation of FMT

Table 8 (see Appendix) summarises the technology articles that are relevant to FMT and were published in 2019. The articles are summarised as follows:

1. AV (not-shared)
 - a. Businesses are developing partnerships through investments and acquisitions for AV development and on-demand AV services
 - b. Only a limited number of articles relating to on-demand AV service announcements were found
2. Shared AV services
 - a. Autonomous shuttle services are currently available to the public
 - b. Various autonomous shuttle services have been announced
 - c. Partnerships are established by various businesses for the development of autonomous shuttles
3. Autonomous trucks, delivery vehicles and drones
 - a. Autonomous vehicles are currently in use at the mining site and rail yard
 - b. Autonomous trucks and delivery vehicles are currently in use for freight hauling and delivery services
 - c. Drone delivery services have recently launched
 - d. There are more autonomous trucks and delivery services announced and launched
4. Vehicle productions
 - a. A number of AV factories are opening
 - b. A limited number of new AV manufacturers are entering the market

5. Technology testing and enhancement
 - a. A large number of tests and trials of various AV related technologies are taking place
 - b. There are tests and trials particularly for autonomous delivery vehicles, autonomous trucks, Blockchain and CAV
6. Infrastructure development
 - a. There has been an announcement on funding infrastructure development to cater for electric vehicles
7. Regulations and legal framework
 - a. A number of authorities are working on legalising AV and establishment of regulations for AV

As shown, the use of AV and drones are limited to the freight and delivery sectors. There are a number of drone delivery services recently being launched, while autonomous trucks are already in use for freight hauling. While most autonomous heavy vehicles are only utilised in non-public spaces (such as rail yards and mining sites), autonomous shuttle services are now available in many cities. To support these recent trends, a number of tests and trials are undertaken for AV related technologies such as sensors. Numerous published articles about acquisitions and investment announcements suggest that there will be more AV trials and deployment in the near future. While there are many existing car manufacturers building partnerships with AV and technology businesses, there are only a limited number of articles relating to new manufacturing businesses entering the market.

Regulations and the legal framework for AV readiness are still very much in the development phase. Current trends suggest that although the industry is ready to develop and use AV, much work is still required around regulations and legal frameworks to establish AV services, shared mobility and MaaS concept services before they can be made fully available to the public. In Australia, funding toward infrastructure development for electric vehicles has only recently been announced (see Infrastructure Magazine (2019)). FMT such as CAV needs to be supported by infrastructure, in order to accommodate their needs such as connectivity. This emphasises the importance of infrastructure planning. The following further summarises the insights.

- Current service provisions
 - Currently, no on-demand AV (single occupant) services are offered
 - Autonomous shuttles are offered to the public
 - Autonomous trucks, delivery vehicles and drones are currently used for various purposes
- Vehicle development
 - A number of AV factories are opening
 - A strong presence of existing car manufacturers in AV production
- Future potentials
 - Businesses are forming partnerships through investments and acquisitions
 - Many tests and trials are still undertaken particularly for autonomous delivery vehicles, autonomous trucks, Blockchain and CAV
 - New autonomous shuttle services, autonomous trucks and drone delivery services are recently being launched
- Setbacks
 - Infrastructure provisions to accommodate FMT are falling behind
 - Legal framework and regulations for AV are still under development

FMT is often seen as the solution to numerous transport problems currently faced, such as growing travel demand, and environmentally unsustainable vehicles and fuel options. For instance, Vanderschuren and Baufeldt (2018) claim that non-motorised vehicle modes and shared mobility are beneficial to society and that shared mobility addresses low-income households' social needs, and reduces high-income households' economic and environmental impacts. However, deployments of FMT can be challenging. For instance, people are particularly concerned about cybersecurity, legal issues and safety of the AV technology (Kyriakidis, Happee, & De Winter, 2015), and the security of the passengers of autonomous shared mobility services (Piao et al.,

2016). Additionally, the uptake of AV ahead of shared AV could reduce PT demand and increase zero-occupant vehicles (Ohnemus & Perl, 2016), which would adversely impact already congested roads.

Although a high level of supportive interest from academia and the public sector is apparent, FMT cannot solve all transport problems. As has been evident during the recent COVID-19 pandemic outbreak, changes in travel demand are difficult to predict due to the complex nature of people's needs and preferences. During the outbreak, the changes have drastically changed the way people travel. For instance, demand for PT has been significantly lower compared to post-COVID (Google, 2020). Whether the demand for PT will ever return to its original level is uncertain, due to reduced confidence in PT, is yet to be revealed. Peak time traffic has reduced compared to post-COVID because many employees who were once office-based are now working remotely, from home. Meanwhile, it has been evident during the outbreak that physical attendance for primary and secondary school education is crucial, in contrast to tertiary education which quickly switched to online teaching. These end-results are difficult to anticipate and therefore, predicting travel demand under uncertainties and/or disruptions such as the outbreak, is also difficult. Although this study does not focus on uncertainties due to pandemic outbreaks, it particularly focuses on the uncertainties of FMT, instead of focusing only on its benefits.

Conceptually, at a high level of integration (according to Sochor et al. (2018)'s MaaS topology), MaaS will significantly change current forms of vehicle ownership and mobility provision. As shown in Figure 3, MaaS can offer a variety of mobility options as a bundle that can provide on-demand, and "last-mile" or "door-to-door" future mobility solutions. MaaS blurs the boundaries between transport modes and between public and private operators (Karlsson, Sochor, & Strömberg, 2016), will improve the efficiency of current transport systems and promote a sharing economy (Rantasala, 2015). The key service attributes of MaaS are the "transportation smorgasbord" concept, simplicity, improved access and flexibility, convenience, and economy (Karlsson et al., 2016). Particularly, the flexible mobility's "pick up from home" services are a highly desirable feature (Frei, Hyland, & Mahmassani, 2017). Using MaaS bundle services, those who do not prefer using shared mobility would be willing to try the modes once subscribed that they previously did not use or prefer (Matyas & Kamargianni, 2018), which suggests that the MaaS bundled service can be used to encourage travellers to use the modes that best fit societal needs. It is important to note that MaaS can provide transport services with or without AV that may be shared. The impacts on the existing transport network and the market would be different when services and modes offered using MaaS are different.

Integrating different transport modes and services as one product can be complex (Kamargianni, Li, Matyas, & Schäfer, 2016). Although many current PT operators show a strong enthusiasm for offering packages of mobility services to their current users (Mulley, Nelson, & Wright, 2018), the support from a high level of governments is critical for achieving a sustainable solution for MaaS (Sochor, Strömberg, & Karlsson, 2017). The transport agencies need to consciously decide on the level and type of collaboration required to bring the various stakeholders to the table, and to ensure that broader mobility goals are achieved (Delplace et al., 2019).

Studies suggest that MaaS deployment should be led by the public sector (Sochor et al., 2017; Wong, Hensher, & Mulley, 2017), however, the mismatch between the benefits to society and commercial profit is evident (Sochor et al., 2017). For instance, maximising efficiency of the transport system may be better dealt with by the private sector, because the efficiency improvement directly contributes to maximising their profits. Additionally, a study (Cohen & Kietzmann, 2014) suggests that a pure reliance on the private sector may fail to optimise the service and to achieve the desired environmental impacts. Furthermore, replacing the existing PT service with private ride-sharing services can be challenging due to information sharing issues, the latent demand for the services, social equity and political/legal concerns over the introduction of the services, and usage of public funding to provide the services (Zhou, 2019). Meanwhile, the potential MaaS customers have no strong preference for public or private-led MaaS provider (Vij, Sampson, Swait, Lambides, & Hine, 2018). These findings suggest that the MaaS operator needs

to ensure that both market needs and private transport supplier's interests are addressed within its governance and business models.

Reliable estimations of users' willingness-to-pay for MaaS is crucial because the demand for MaaS significantly depends on its pricing and is thus the key to its successful deployment. Also, the adoption of equitable transport pricing models is required (Vij et al., 2018) particularly to minimise accessibility gaps. A recent study found that on average, Sydney travellers are willing to pay AU\$6.40 for an hour of access to car-sharing (with one-way car-sharing valued more than station-based car-sharing) and AU\$5.90 per day for unlimited use of PT (Ho, Hensher, Mulley, & Wong, 2018). These figures are much less than the actual prices of car-share services and PT services currently provided, which suggests the complexity of pricing, particularly when a new service is first introduced.

Many government transport agencies in Australia have investigated MaaS. Most recently, Austroads has commissioned a study to identify the risks and opportunities MaaS represents for the public sector (Delplace et al., 2019). Also, the transport agency in Queensland has commissioned a study (KPMG, 2018) which attempted to measure the impacts of FMT including MaaS. Also, ITS Australia has commissioned a study (Vij et al., 2018) that explored suitable MaaS deployment strategies in Australia. All of these agencies and industry bodies highly value MaaS and its potential benefits. For instance, the economic assessment of FMT concluded that MaaS would be beneficial to society (KPMG, 2018).

3.3. Impacts and Implications of FMT on Infrastructure Planning and Policy

FMT can impact transport planning and infrastructure in a number of ways. For instance, the value of time (VOT) for AV can become similar to the VOT for PT in-vehicle time (Steck, Kolarova, Bahamonde-Birke, Trommer, & Lenz, 2018). VOT is one of the key assumptions in traffic models and economic assessments, and therefore, changes in VOT would alter the outcomes of the models and assessments.

Table 9 (see Appendix) lists the potential impacts of FMT that have been identified in previous studies. The impacts are organised using three categories: impacts on demand and congestion; economic and financial impacts; and social impacts and impacts on land use. Uncertainties that are identified in the previous studies are also summarised in the table. For clarity of this report, Table 9 is then presented as an infographic in Figure 4 which better summarises the impacts by removing duplicates and overlaps in claims.

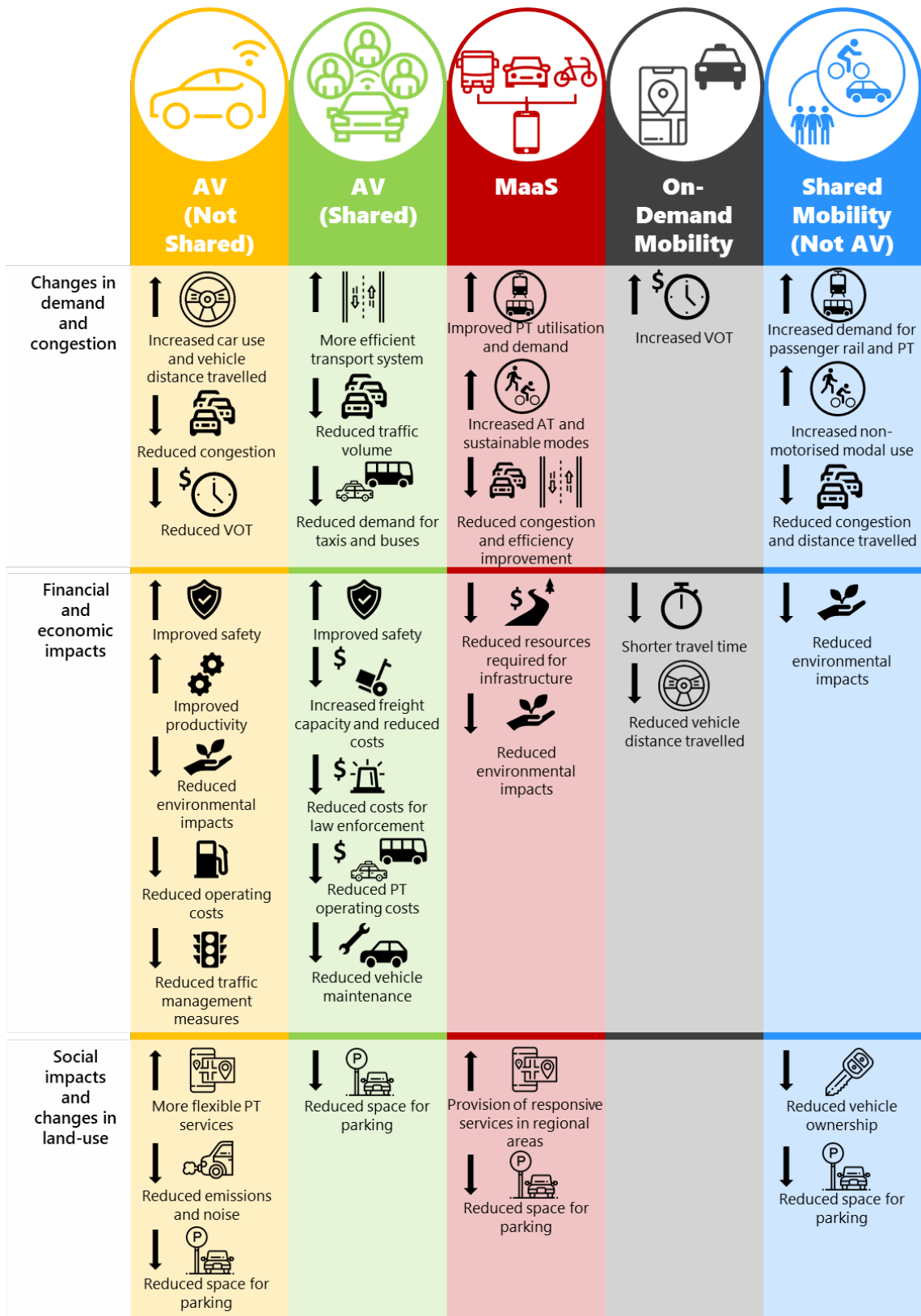


Figure 4 Illustration of the impacts of FMT

Table 9 and Figure 4 highlight how the impact on transport demand and congestion will vary significantly depending on technology type. For instance, AV technology would increase private car travel, while MaaS would reduce it. Also, there are claims that are potentially conflicting. For instance, Bahamonde-Birke et al. (2018) claim that AV will reduce congestion but will also increase

car use. This suggested that whether the increase of car use would outweigh the reduction congestion depends on the uptake of the AV technology and its deployment forms. Additionally, Clements and Kockelman (2017) claim that vehicle distance travelled for shared AV would increase, while Ohnemus and Perl (2016), and Mourad, Puchinger and Chu (2019) claim that it would be reduced. This illustrates a clear contradiction between the studies.

Also important to note is the wide variety of MaaS scenarios that have been observed in the literature. Vehicles are presumed to be electric, autonomous and shared in some studies; while other studies presumed that MaaS would be provided using existing public transport modes. This suggests that the overall impacts of MaaS are uncertain. Hence, estimating model parameters to cater for these technologies is complex. For instance, many studies suggest changes in VOT for AV, shared AV and on-demand mobility. The degree of changes would vary between the modes, therefore accurate predictions of a future modal share will be critical to estimate weighted average changes in VOT. VOT, in particular, is a crucial model input in both traffic modelling and economic assessment.

FMT can impact transport infrastructure, planning and maintenance in a number of ways. Figure 5 illustrates the impacts using three categories: impacts on existing infrastructure and network, planning, and government's strategic-level objectives. As previously discussed, FMT will impact existing infrastructure and network. Additional projects can be proposed to particularly address the need for FMT. In addition, FMT can impact early and later stages of planning, as well as previously approved projects. This suggests that improving the current infrastructure investment assessment framework is crucial to ensure that the framework accommodates these changes and as a result, the decisions maximise the benefits to society.

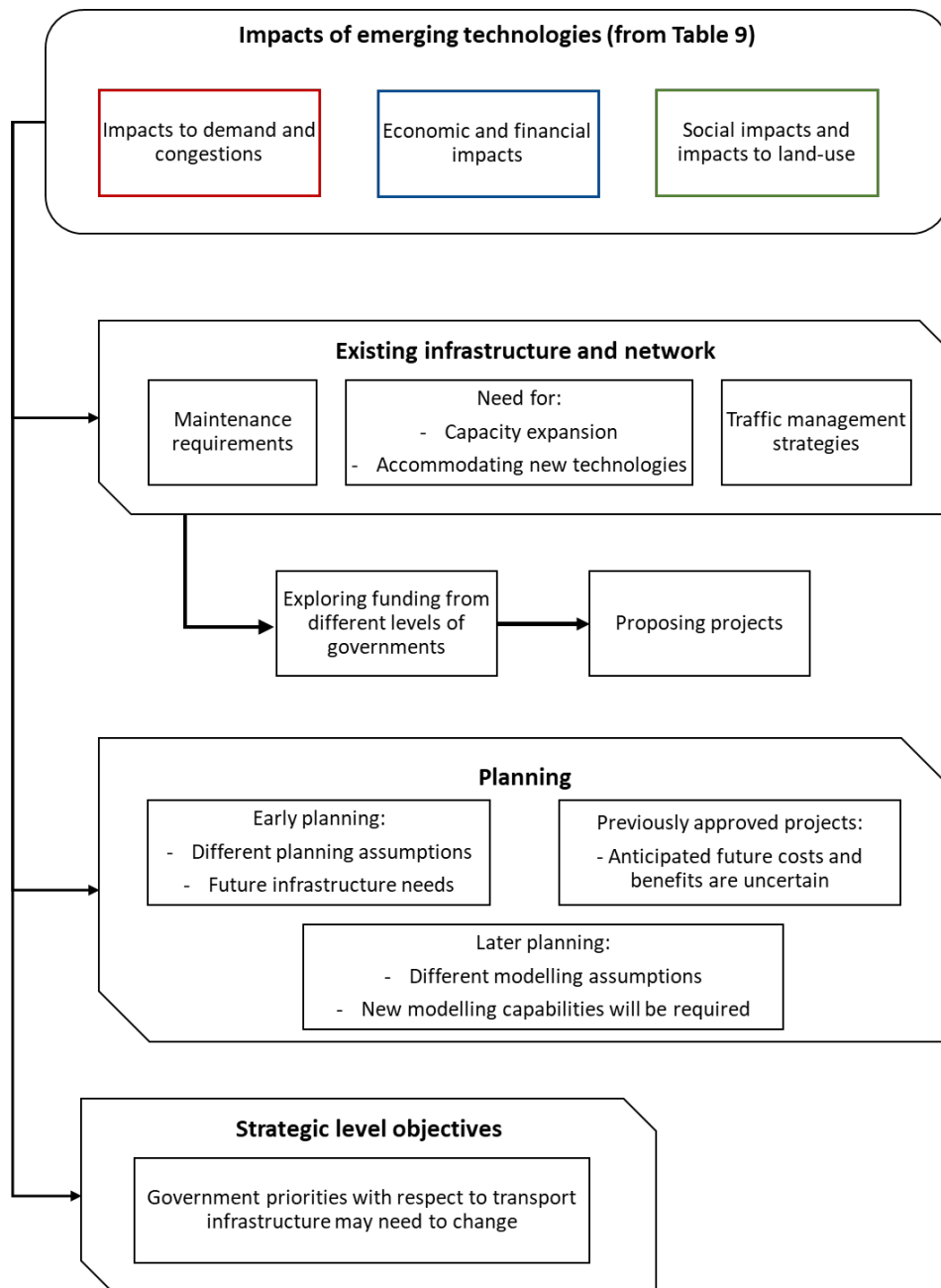


Figure 5 Conceptual illustration of impacts on infrastructure planning

The literature review highlighted that the overall impacts of FMT depend on current transport system configuration (OECD - International Transport Forum, 2015), types of the technologies and its deployment forms. In addition, the introduction of MaaS emphasises the interactions of land-use and transport planning due to increased PT demand as a result (Rantasila, 2015). This suggests that integrated land-use and transport planning is needed in order to best cater to future needs. Furthermore, OECD - International Transport Forum (2017) showed that future rail station designs need to incorporate requirements for integrating shared mobility services. This shows that infrastructure investment assessment needs to identify the investment proposals that consider FMT. However, it is difficult to estimate the impacts and uncertainties of FMT in a quantified manner from the technical point of view at the moment. This means that numerical assessment tools, such as CBA, become pointless without reliable assumptions. Thus, we rather suggest strengthening assessing the resilience against the uncertainties of FMT in a TIIA framework.

Figure 6 illustrates and summarises the impacts and uncertainties of FMT that are previously shown in Table 9. As summarised in the figure, many of the impacts and uncertainties influence multiple assessments that are considered in the decision-making around infrastructure investments. This suggests that the outcome of TIIA can be significantly influenced when the impacts and uncertainties of FMT are considered. Whether this would change the order of prioritisation require further investigation (investigated in Section 5).

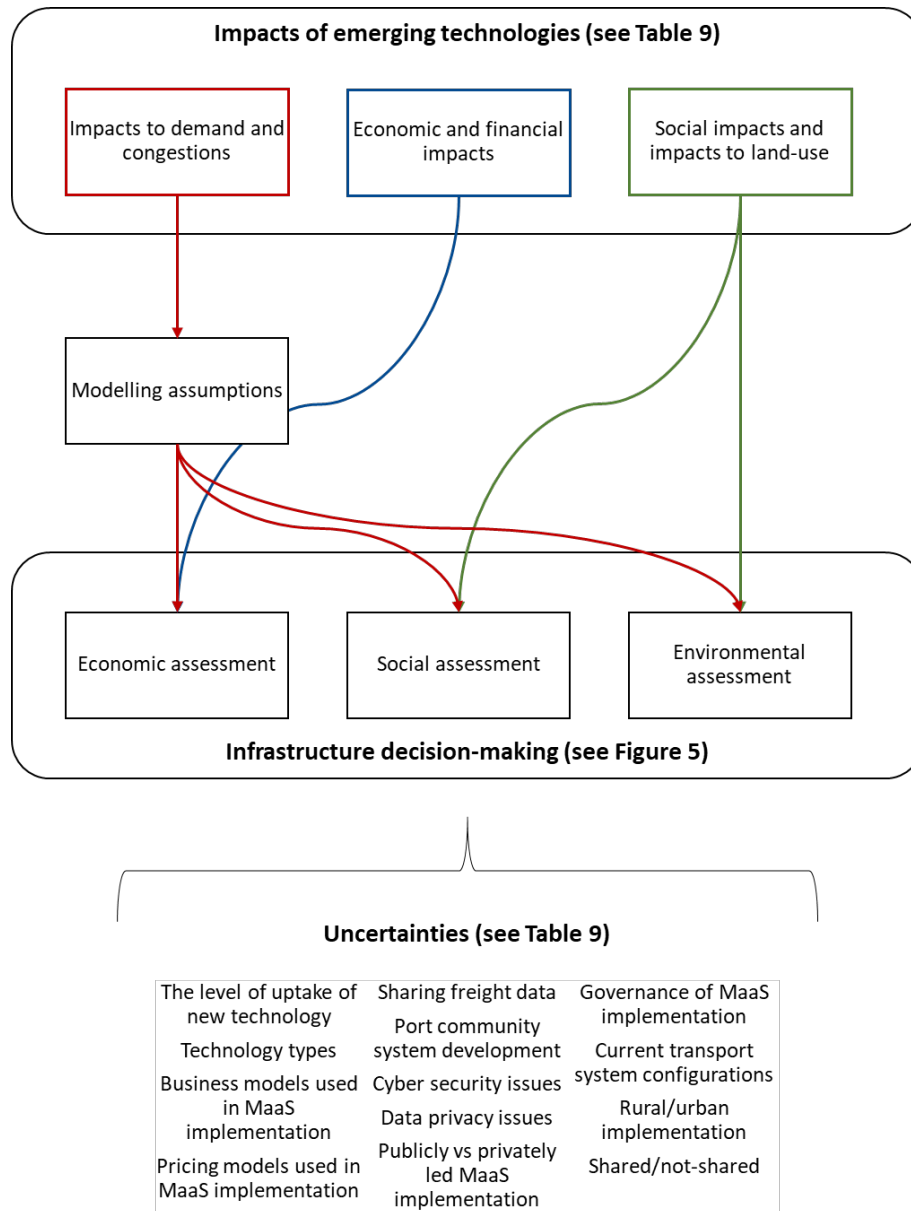


Figure 6 Conceptual illustration of impacts on infrastructure investment decision-making

4. Exploring ways to Improve the TIIA Framework

We argue that although improvements can be made to improve data collection, data quality and data analysis techniques almost infinitely, the ability to predict future demand is always limited and any analysis is certainly exposed to some degree of uncertainty. The current TIIA frameworks inadequately assess the uncertainties of FMT. Although assessing infrastructure resilience can potentially assess resilience against the uncertainties of FMT, as previously highlighted (see Section 3.1), many TIIA frameworks do not assess infrastructure resilience effectively, including those used commonly in Australia.

Here, we review how resilience is generally assessed to identify a suitable method to assess the resilience against the uncertainties of FMT. First, various methods that are commonly used to assess resilience, in general, are identified, then, disruption due to FMT is closely examined.

4.1. Infrastructure Resilience

Infrastructure resilience is often associated with the resilience of critical infrastructure against disruption due to natural disasters as seen in O'Donnell (2013). However, the concept of "resilience" is wider than natural disasters and covers the capacity to withstand disruption, absorb disturbance, and adapt to changing conditions (Hughes & Healy, 2014). Here, we explore the application of infrastructure resilience assessment in the context of FMT.

First, project-level resilience and system/network level resilience need to be distinguished (Marcelo, House, & Raina, 2018). For instance, project-level resilience (Marcelo et al., 2018), system-level resilience (Leviäkangas & Aapaoja, 2018) and network-level resilience (Twumasi-Boakye & Sobanjo, 2018) are typically assessed differently. This study focuses on project-level resilience because the proposed methodology is intended for transport infrastructure investment proposals which generally are undertaken at the project-level. This does not mean that indirect impacts are irrelevant. TIIA typically considers direct, indirect and sometimes wider economic benefits (WEBs). Assessing resilience at the project level means the resilience of other projects and existing infrastructure is not assessed. For instance, the resilience assessment of a road section would not consider the likelihood of road closures of other road sections, while diverted travel time through other roads would be considered. It is also important to note that operational resilience is beyond the scope.

Infrastructure resilience can be measured using various methods including an MCA approach (e.g. Hughes and Healy (2014)), methods based on probability distributions (e.g. Franchin and Cavalieri (2015), Hosseini and Barker (2016), Pant et al. (2014), and Shafieezadeh and Burden (2014)) and other methods based on numerical function (e.g. Marcelo, House and Raina (2018)). Stochastic analysis based on probability distributions requires historic forecasting models that can predict the likelihood of disruptions and determine appropriate forms of distributions for modelling. Also, conducting simulations is extremely difficult to ensure that they produce reliable outcomes when simulating mixed vehicle environment with a lot of uncertainties with demand and supply. This means that measuring resilience against the disruption where historic data is available (e.g. earthquakes, extreme weather events, etc.) can be modelled stochastically, while this would not be suitable for those without any historical data including disruptions due to FMT.

Additionally, existing TIIA frameworks adopt a MCA approach for investment decision making. Therefore, we argue that from the technical and applicability points, adding a new criterion within the existing TIIA framework would be suitable for assessing the resilience against the uncertainties of FMT.

When adopting MCA, the quality of analysis relies on the set of criteria used. The criteria such as exposure, vulnerability and coping capacity (Leviäkangas & Aapaoja, 2018), and adsorptive

capacity, adaptive capacity and restorative capacity (Hosseini & Barker, 2016) are commonly used to assess resilience. Yet, these are too broad and unspecific, which can leave a room for subjectivity that would lead to inconsistent and unfair assessments.

Additionally, the methodologies that are specifically designed for measuring disruptions from natural disasters are not suitable for assessing disruptions due to FMT. This is because the set of assessment criteria used would not be relevant and suitable in the context of FMT. For instance, the transport infrastructure resilience against natural disasters generally focuses on four dimensions of road functionality: travel time, road utilisation, access for lifesaving services and provision of relief (Marcelo et al., 2018). However, these are not all relevant and would be limited to capture all impacts of FMT.

The World Bank criteria (Hallegatte et al., 2019) sheds some light on overcoming these challenges. As shown in Figure 7, their criteria consider the costs and impacts that align with those considered in a typical TIIA framework (see Section 3.1).

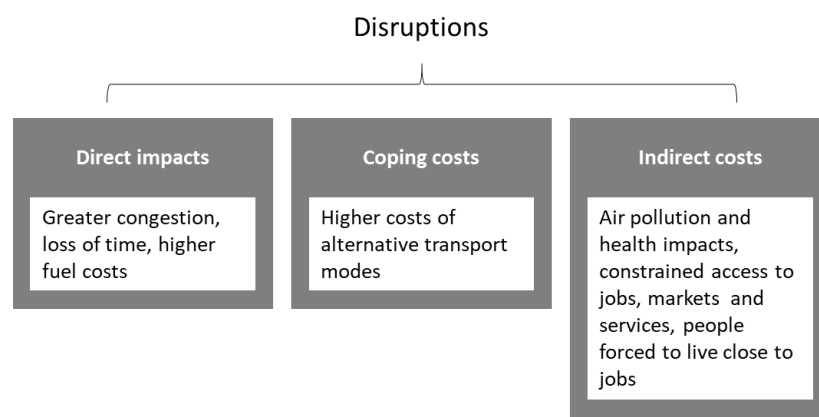


Figure 7 Disruptions in transport, adapted from (Hallegatte et al., 2019)

4.2. Disruption due to FMT

In this section, we explore the disruption due to FMT alongside typically characterised disruption to determine a suitable method to assess the uncertainties of FMT. Here, we consider three types of disruption:

- Disruption that causes negative impacts (Figure 9);
- Disruption that causes positive impacts (Figure 10); and
- Avoided disruption due to improvements in TIIA framework (Figure 11).

Typically, when a sudden disruption is considered, changes in functionality of a transport facility such as road is expressed as shown in Figure 8. Degree of impact, recovery time and recovery trajectory generally differ in reality (Elms, McCahon, & Dewhirst, 2019; Marcelo et al., 2018).

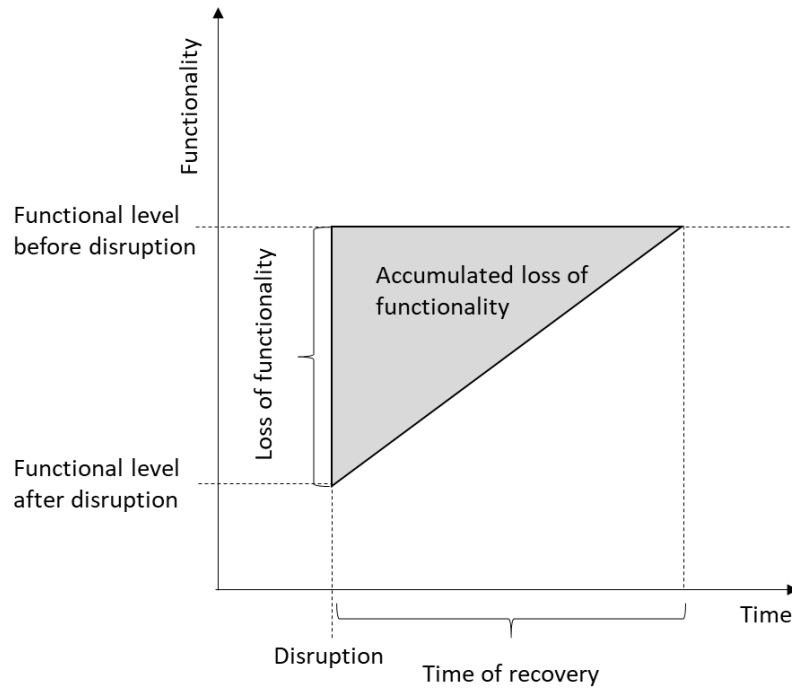


Figure 8 Disruption and functionality typically considered, adapted from Marcelo et al. (2018)

However, unlike natural disasters as illustrated in Figure 8, disruptions due to FMT do not occur overnight. We express and define the disruption due to FMT as shown in Figure 9. For instance, when FMT decreases the demand for PT, the demand decreases gradually over time as more people use the FMT. It is also important to note that we present “utilisation” of assets, facilities and services, instead of their “functionality”. We define the loss of utilisation as a reduction in utilisation of proposed investments and existing transport facilities and services. Accumulated changes of utilisation (ACU) accounts for the aggregated utilisation loss. The ACU relates to its capacity to accommodate the FMT and its impacts on the transport facilities and services.

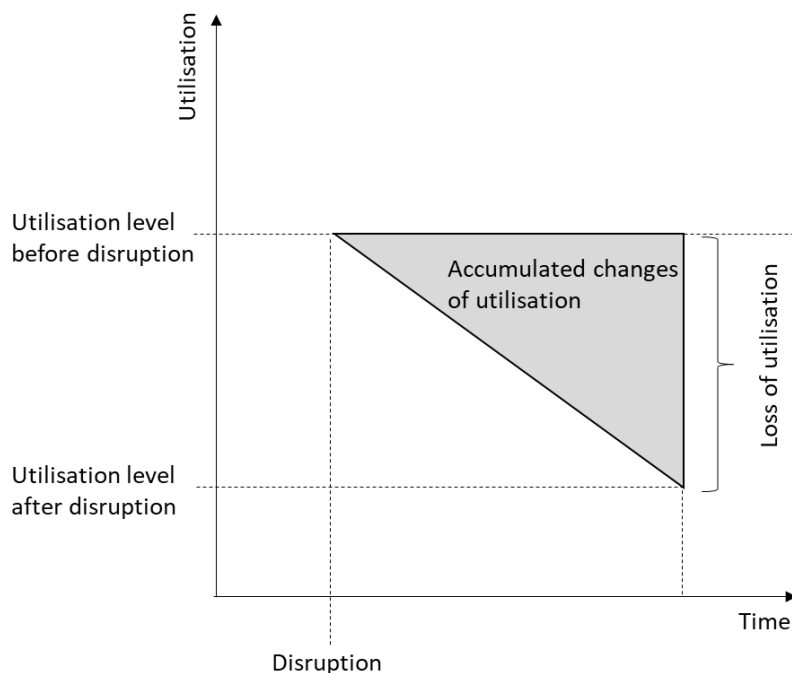


Figure 9 Disruptions due to FMT and functionality (when functionality is lost)

Figure 10 illustrates when the disruption causes an increase of utilisation. As seen in Section 3.2, the end of result of some FMT, such as AV, for instance, increases vehicle distance travelled and the utilisation of road infrastructure. In here, the ACU accounts for the increased and decreased utilisation due to the introductions of FMT.

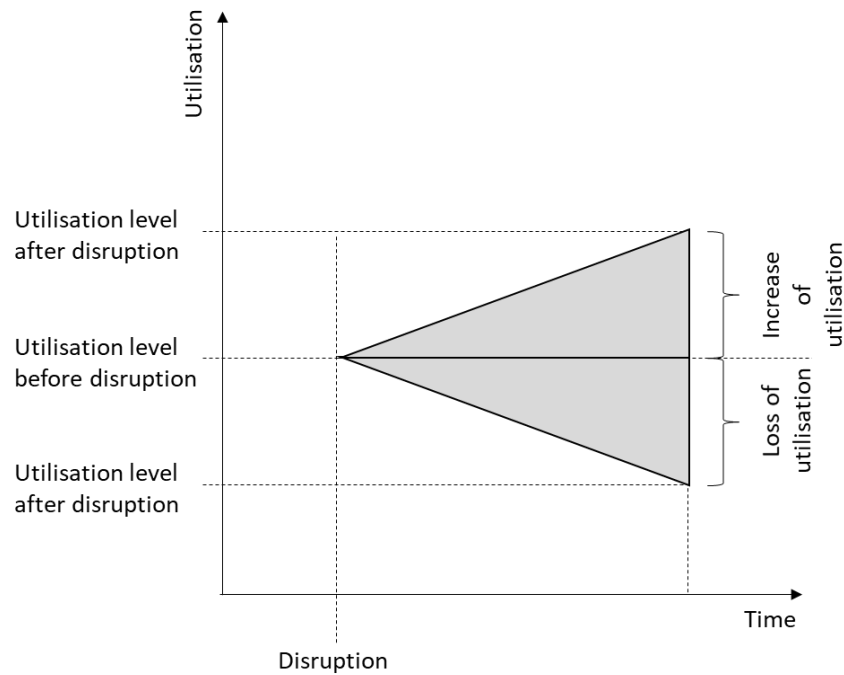


Figure 10 Changes of utilisation due to FMT disruptions

This study essentially aims to find a way to reduce the loss of utilisation as shown in Figure 11. When capacity and/or capability of the facility is improved as a result of improved TIIA, further loss of utilisation can be avoided. For instance, the improved TIIA will prioritise the road investments that will encourage full deployment of AV, which will ensure that the roads will continue to be used by AV and the loss of road utilisation will be somewhat avoided.

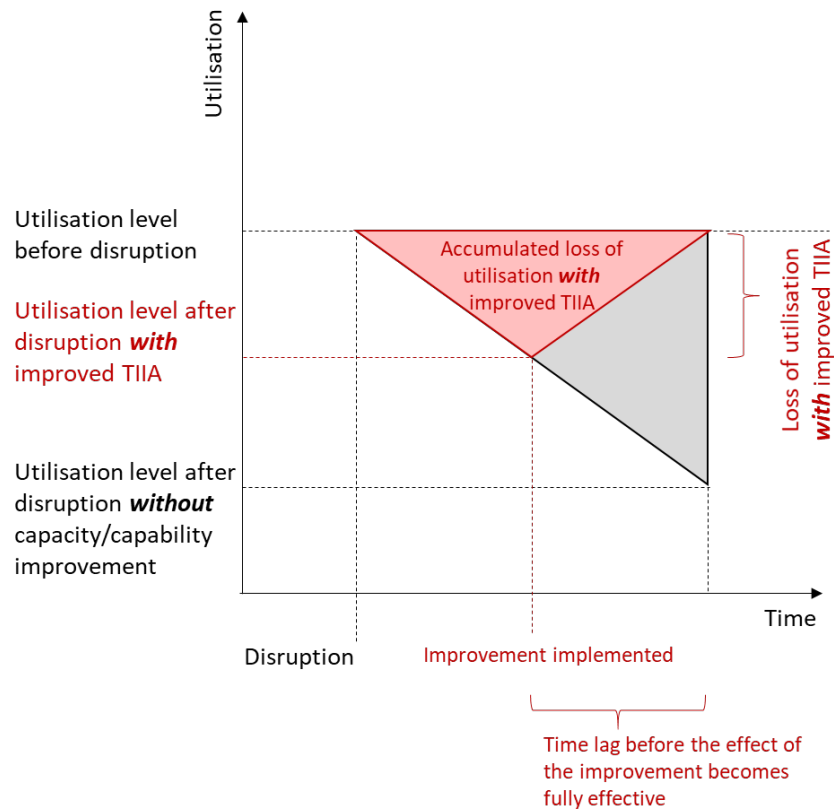


Figure 11 Avoided loss of utilisation through improved TIIA framework

As shown in Figure 10, disruption due to FMT can increase or decrease utilisation. The decrease of utilisation can also be avoided with the improved TIIA as shown in Figure 11. This suggests that the disruption due to FMT is more complex than the disruption due to natural disasters, which then suggests that a typical method/methodology to assess infrastructure resilience cannot fully assess the disruption due to FMT. To account for the complexity of FMT, we propose the “FMT uncertainty” criterion to be added within the existing TIIA framework, while noting that the suitable method still needs to be explored for a full assessment of the FMT uncertainty. The additional criterion would widen the scope, wider than “infrastructure resilience”, considering both increase and decrease of utilisation.

4.3. Exploring a Suitable Assessment Tool for the New Criterion

Here, we explore various methods that can be used as the assessment tool for the “FMT uncertainty” criterion. This is necessary because examining the disruption due to FMT highlighted that a typical assessment tool for infrastructure resilience cannot fully assess the uncertainties of FMT (see Section 4.2). Also, each of the criteria that are considered within a typical TIIA framework, has a suitable assessment tool. For instance, cost-benefit analysis (CBA) is generally used to assess the “economic value” criterion. Depending on how far the proposal is progressed through the planning process, rapid and detailed CBA are both used, yet, the overall methodology is the same. Similarly, the new criterion also needs an assessment tool that would effectively assess the uncertainties of FMT.

Table 1 summarises various methods commonly used to assess various types of uncertainties in the transport context, including advantages and disadvantages reviewed for each.

Table 1 Review of various methods that assess uncertainties within transport projects, initiatives, policies or models

Method/approach	Advantage	Disadvantage	Context	Reference
Stochastic analysis (or Monte Carlo simulation)	Comprehensive and uses quantitative measures	Data and resource-intensive	Uncertainties of analysis inputs or assumptions	(Asplund & Eliasson, 2016; de Palma, Picard, & Andrieu, 2012; D. Fagnant & Kockelman, 2012; Giudice, Passeri, Torrieri, & Paola, 2014; Lemp & Kockelman, 2009; Mishra, Khasnabis, & Swain, 2015; Salling & Leleur, 2006; Zhang, Bai, Labi, & Sinha, 2013)
			Crash risk analysis	(Sadeghi & Mohammadzadeh Moghaddam, 2016)
Scenario testing	Potential to be comprehensive, depending on the scenarios analysed	Requires well-designed scenarios or forecasting models	Urban transport and transport investments	(Chen & Yao, 2012; Espinet, Schweikert, & Chinowsky, 2017; Naughtin et al., 2018; Transport for New South Wales, 2016)
Real options analysis (ROA)	Can be used in various applications	Requires CBA model to be incorporated in the ROA when assessing uncertainties to the CBA outcomes. Also requires a set of scenarios and their probabilities.	Port investments	(Balliau, Meersman, Van de Voorde, & Vanelslander, 2018)
MCA and CBA	Widely used in TIIA	Comprehensiveness depends on the assessment criteria used.	Transport investments	(Shiau, 2014)

The key disadvantage of stochastic analysis and real options analysis (ROA) is the data requirement. Any type of stochastic analysis requires a form of a probability distribution, standard deviation and relative extreme boundaries (Giudice et al., 2014). Also, the ROA requires the sources and implications of uncertainty to be investigated and the probabilistic likelihood of each scenario (Balliau et al., 2018). Across all methods, technical knowledge of the analysis and models that are incorporated and/or interrelated is crucial. For instance, CBA is occasionally mistaken as a type of financial analysis, which uses an interest rate instead of a real discount rate as seen in (de Palma et al., 2012). These technical errors lead to inaccurate results.

Scenario testing is particularly useful when the future is uncertain and is often used in the context of FMT (as seen in Naughtin et al. (2018) and Transport for New South Wales (2016)). As shown in Table 1, scenario testing is also often used for prioritisation of transport investment proposals. Most recently, CSIRO has undertaken a scenario testing to determine the challenges, risks and opportunities of FMT in Queensland out to 2048 (Naughtin et al., 2018). Also, MCA is the most commonly used tool for TIIA as previously discussed (see Section 3.1), while CBA would be technically difficult as has been highlighted (see Section 3.3). Thus, we recommend the scenario testing using a MCA approach as the most suited tool for assessing the uncertainties of FMT due to technicality, practicality and applicability advantages.

4.4. Summary

Reviewing a typical TIIA framework suggested that infrastructure resilience is often insufficiently considered in investment decision making, although it can assess the resilience against the uncertainties of FMT. Therefore, we examined how resilience is assessed typically and found that a MCA approach, such as the World Bank framework (Hallegatte et al., 2019), can easily be incorporated into an existing TIIA framework. However, examining disruptions due to FMT revealed that infrastructure resilience typically focuses on natural disasters, thus cannot fully assess the uncertainties of FMT without any improvements. It then suggested the “FMT uncertainty” criterion be added within the TIIA framework to account for the complexity of the FMT disruption. Exploring various assessment tools concluded that a scenario testing using a MCA approach would be a suitable tool to assess the FMT uncertainty.

5. Testing the Applicability and Practicality

In this section, the applicability and practicality of the proposed criterion and the assessment tool (see Section 4.3) are tested through three recent major transport projects (see Table 6 for details), identifying the limitations of the proposed methodology and opportunities for improvement. The three projects: Brisbane Metro, METRONET: Yanchep Rail Extension and North East Link, are all being identified as a high priority in Australia (Infrastructure Australia, 2020).

5.1. Incorporating the New Criterion within the Infrastructure Australia Framework

For testing, the proposed criterion is incorporated within the Infrastructure Australia framework (Infrastructure Australia, 2018a), which is summarised in Figure 12.

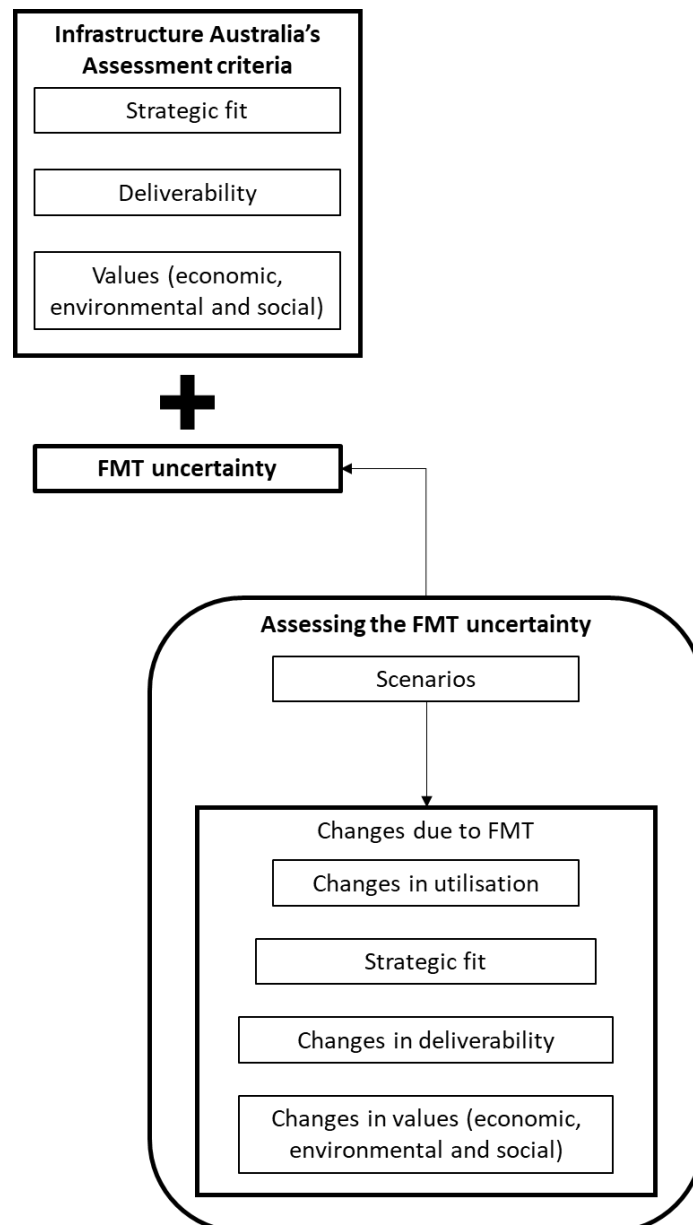


Figure 12 Assessing the FMT uncertainty within the Infrastructure Australia framework

Table 2 illustrates how FMT uncertainty is assessed through a MCA approach, which ensures that the assessment is conducted systematically. As shown, the criteria closely align with those considered in the Infrastructure Australia framework (Infrastructure Australia, 2018a). It is important to note that the changes in utilisation and the resulting changes are all captured under “changes in utilisation” to avoid double counting. For instance, reduction of congestion due to decreased utilisation (e.g. reduced traffic volume) should be captured in “changes in utilisation”, while reduction of congestion due to more efficient driving (e.g. through autonomous driving) should be captured in other criteria.

Table 2 Assessing the FMT uncertainty

Scenario testing criteria	Chasing Goliath	Uberlicious	Safe and Sound	Tortoise and the Hare
Changes in utilisation				
Strategic fit				
Changes in deliverability				
Changes in economic value				
Changes in environmental value				
Changes in social value				

5.2. Scenarios

5.2.1. Descriptions of the Scenarios

For testing, this study incorporates the scenarios that are considered in the Transport Portfolio SAP 2019-20 document (WA Portfolio Investment Coordination, 2019). The scenarios are described as follows:

- a) Chasing Goliath: Provide integrated transport services that deliver efficient and safe solutions for a growing State
 - No growth in mode shift for active, on-demand or public transport;
 - More congestion, pollution and increased travel times; and
 - Increased network maintenance costs.

- b) Uberlicious: Provide technology-enabled integrated transport solutions and services to support economic development and optimise the use of transport services
 - Increase in population and land use density levels;
 - Increase in economic growth;
 - High electronic vehicle and AV uptake; and
 - Strong demand for on-demand transport (MaaS).

- c) Safe and Sound: Redirect investment into maintenance projects and optimise resources in existing transport services to continue to deliver sustainable, safe and reliable journeys
 - Public transport demand drops;
 - Maintenance demand can be stretched (i.e. continue to sweat the asset); and
 - Lower than 2.5 per cent economic growth.

- d) Tortoise and the Hare: Develop policy and create conditions to facilitate and enable the adoption of positive transformational transport options focused on network optimisation and influencing individual's behaviour and travel choices
- Increase in electric vehicle and AV registrations and adoption;
 - Increase in the number of public transport trips, active transport and on-demand transport;
 - Increase in MaaS development; and
 - Increased investment in on-demand and public transport.

5.2.2. Uncertainty due to the Scenarios

The assumptions of the Chasing Goliath scenario add uncertainties to the projects that anticipate growth in PT demand and are designed to combat congestion, pollution and increased travel time problems. These assumptions influence the identified problem of the base case and anticipated future benefits, which can affect estimated economic and environmental values.

The Uberlicious scenario assumes an increase in population and land use density levels, which can impact the social values of the projects, as it affects liveability and the quality of life. Increase in economic growth can directly translate into growth of economic and social values. However, it can also suggest higher environmental impacts, such as increased emissions associated with increased economic activities, which can be offset by high uptake of electric vehicles. Also, the demand for on-demand mobility and MaaS can bring significant uncertainties to all PT projects.

Most PT projects will be exposed to significant uncertainties under the Safe and Sound scenario, as poor growth of PT demand will significantly limit the future benefits of the project.

Adopting policies to encourage uptake and deployment of electric vehicles and AV (Tortoise and the Hare scenario) can highly influence the utilisation of all projects. Yet, the scenario also contains increased demand for PT.

Overall, the following scenario assumptions are found as the key factors that can influence the assessment outcome across the scenarios:

- Changes in demand for PT;
- Electric vehicle and AV uptake;
- Assumption relating to congestion and pollution;
- Strategic objectives/directions; and
- Assumptions relating to economic growth.

5.3. Assessment of the FMT Uncertainty

5.3.1. Brisbane Metro

The assumptions relating to PT demand influenced the changes in utilisation. Also, under the scenarios that provide a more integrated transport system, such as Tortoise and the Hare, the utilisation can increase further. As Brisbane Metro evolves to resolve increasing congestion, pollution and travel time, its economic and environmental benefits can be higher under the Chasing Goliath scenario, although shifting to PT to maximise its benefit may be challenging. It can also contribute to providing a more efficient and optimised PT system. Therefore, its uncertainties under the Uberlicious scenario are high. Under the Safe and Sound scenario, the overall benefits of Brisbane Metro project will be lower than estimated. The assessment result of Brisbane Metro is summarised in Table 3. It suggests that Brisbane Metro is likely to result in positive outcome under the Chasing Goliath and Tortoise and the Hare scenarios, while it is likely to result in negative or uncertain outcome under Uberlicious and Safe and Sound scenario.

Table 3 Assessment for Brisbane Metro

Scenario testing criteria	Chasing Goliath	Uberlicious	Safe and Sound	Tortoise and the Hare
Changes in utilisation	Minimal impact	Decrease	Decrease	Increase
Strategic fit	Minimal impact	Aligns	Does not align	Aligns
Changes in deliverability	Lacking assumptions	Lacking assumptions	Lacking assumptions	Lacking assumptions
Changes in economic value	Positive	Positive	Negative	Positive
Changes in environmental value	Positive	Lacking assumptions	Lacking assumptions	Positive
Changes in social value	Lacking assumptions	Lacking assumptions	Lacking assumptions	Lacking assumptions

5.3.2. METRONET: Yanchep Rail Extension

As METRONET: Yanchep Rail Extension targets low-density areas, the impacts of increased congestion would not be as high as metropolitan areas under the Chasing Goliath scenario. Rail services are difficult to be operated as the on-demand basis, therefore, its utilisation can decrease under the Uberlicious scenario. The utilisation can also decrease significantly due to reduced PT demand under the Safe and Sound scenario. Additionally, depending on how the project is incorporated in potential MaaS development and how on-demand mobility is incorporated into existing PT system, its benefits can potentially be maximised under the Tortoise and the Hare scenario. The assessment result is summarised in Table 4. It suggests that METRONET: Yanchep Rail Extension is likely to result in positive outcome under the Chasing Goliath and Tortoise and the Hare scenarios, while it is likely to result in negative or uncertain outcome under Uberlicious and Safe and Sound scenario.

Table 4 Assessment for METRONET: Yanchep Rail Extension

Scenario testing criteria	Chasing Goliath	Uberlicious	Safe and Sound	Tortoise and the Hare
Changes in utilisation	Minimal impact	Decrease	Decrease	Increase
Strategic fit	Does not align	Lacking assumptions	Does not align	Lacking assumptions
Changes in deliverability	Lacking assumptions	Lacking assumptions	Lacking assumptions	Lacking assumptions
Changes in economic value	Positive	Positive	Negative	Lacking assumptions
Changes in environmental value	Positive	Lacking assumptions	Lacking assumptions	Positive
Changes in social value	Lacking assumptions	Lacking assumptions	Lacking assumptions	Lacking assumptions

5.3.3. North East Link

As North East Link combats existing road congestion, its benefits under the Chasing Goliath scenario would be maximised. Similarly, high electronic vehicle and AV uptake can significantly impact traffic modelling and CBA outcomes, and maximise the benefits as a result, under the Uberlicious scenario. Additionally, investing into North East Link would be contradictory under Safe and Sound scenario. Similar to Uberlicious scenario, adopting policies to encourage electric vehicle and AV registrations and adoption can positively impact the project under the Tortoise and the Hare scenario. The assessment result is summarised in Table 5, which suggest that North East Link is likely to result in positive outcome under the FMT uncertainty, as most criteria resulted positively across all scenarios.

Table 5 Assessment for North East Link

Scenario testing criteria	Chasing Goliath	Uberlicious	Safe and Sound	Tortoise and the Hare
Changes in utilisation	Increase	Increase	Increase	Increase
Strategic fit	Aligns	Aligns	Does not align	Minimal impact
Changes in deliverability	Lacking assumptions	Lacking assumptions	Lacking assumptions	Lacking assumptions
Changes in economic value	Positive	Positive	Negative	Lacking assumptions
Changes in environmental value	Positive	Positive	Lacking assumptions	Positive
Changes in social value	Lacking assumptions	Lacking assumptions	Lacking assumptions	Lacking assumptions

5.4. Summary of Key Findings and Identifying Limitations of the Tool

The FMT uncertainty assessment outcomes of the three projects showed that North East Link is likely to result positively, while Brisbane Metro and METRONET: Yanchep Rail Extension are likely to be exposed to considerable uncertainty. This suggests that investment decisions for the two projects need to be carefully considered, while North East Link should stay on the high priority list.

The testing found that the assessment outcome is considerably influenced by certain features of the project scope. These are:

- The nature of the work, whether the project is a road, PT or active travel project;
- Integration of technology features, such as better journey planning tools and more efficient operation management systems; and
- Being integrated within wider transport optimisation and service integrations, such as being part of the MaaS scheme.

The nature of the work considerably changed the “changes in utilisation” results. As shown, the two PT projects resulted in the same outcome, while North East Link resulted in a different outcome. Also, the projects that are assessed in this study do not offer a lot of technology-enabled features. Thus, the assessment was partially incomplete, under the scenarios with assumptions relating to the use of technology (shown as “lacking assumptions”). Similarly, the projects also do not offer service and transport system integration features. Thus, the assessment was partially incomplete, under the scenarios with assumptions relating to service and transport system integrations.

The testing revealed that the uncertainties associated with social value were not fully captured. This can be due to the lack of comprehensiveness of the scenarios, leading to a shortage of assumptions relating to social value in the scenarios used in this study. This limits the assessment's ability to assess the uncertainties associated with social value. The scenarios need to improve to include the assumptions relating to changes in car ownership, the availability and demand for flexible transport systems and changes in land use, such as required space for parking. Similarly, across all scenarios, the changes in deliverability criterion also suffered from lacking related assumptions.

The assessment suffers from a key limitation of MCA, which is the risk of subjectivity. Any qualitative assessments, including MCA, leave a room for subjectivity. However, as has been highlighted (see Section 3.3), it is difficult to estimate the impacts and uncertainties of FMT in a quantified manner at the moment. Also, it does not provide clear-cut indicators (such as BCR) due to the subjectivity.

6. Discussion

Through the testing, considerable demand uncertainties were evident, which also lead to uncertainty in all benefits and disbenefits. This emphasises that all resulting impacts due to changes in demand need to be exclusively assessed under the “changes in utilisation” criterion, which suggest that the disruption of FMT (as examined in Section 4.2) needs to be fully understood when undertaking the assessment.

This study highlighted that the projects that are often inflexible in the way they can be used, are exposed to more uncertainties than others. For instance, a passenger rail extension project can only accommodate trains, while a road project can accommodate a variety of modes such as cars, trucks, pedestrians and cyclists. The rail project would be exposed to more uncertainties particularly when PT demand is uncertain. While, the road project can still be utilised under many scenarios considered, and the uncertainties associated with it would be fewer.

Also highlighted is that the comprehensiveness of the assessment depends on the comprehensiveness of the scenarios. For more comprehensive assessments, mid-term and long-term scenarios can be developed to consider more relevant FMT. For instance, full deployment of AV would be more relevant in long-term scenarios, at least in Australia. Therefore, uncertainties associated with the deployment of AV would be more relevant for those projects with a longer planning horizon.

To best deal with the uncertainties of FMT, regularly conducting detailed analyses of status quo and emerging trends based on recent historical data is crucial. This ensures that the decision is made to the best of knowledge at the time while considering the uncertainties of FMT. Additionally, identifying “triggers” would be useful as it can flag potential loss of utilisations without any detailed analyses, which can be identified through the assessment of FMT uncertainty (see Section 5.3). For instance, assume 50% private AV (not-shared) uptake is found to be the key trigger to reduce investments in PT improvement, once the uptake of 50% is observed, it can trigger the consideration of reducing PT investments.

This study considered both an increase and decrease of utilisation. This is particularly important, given that the increase can offset the decrease, because overall network-wide impacts need to be considered in infrastructure planning, even when assessing at project-level. Also, the uncertainties of FMT are best to be considered at a strategic-level or early stage of planning as FMT can have an impact on the whole network. In the Infrastructure Australia framework (Infrastructure Australia, 2018a), this would be Stage 2: Initiative Identification and Options Development. However, although MCA is conducted to compare options in Stage 2, the set of criteria generally used varies between proposals, because each proponent develops their own set of criteria. This would hinder mandating the “FMT uncertainty” criterion to be considered in all proposals in Stage 2. Although MCA is also conducted in Stage 4: Business Case Assessment, planning may be progressed too far in Stage 4 to consider the uncertainties of FMT.

Additionally, careful consideration needs to be given to those projects with lower BCR. For instance, the BCR of the North East Link is 1.3. Given the flexibility of the highway project to accommodate FMT, such as AV in the future, although there are uncertainties within the estimated economic, environmental and social values for the project, the project should stay on the high priority list due to its flexibility to accommodate a wide variety of modes. For instance, for the North East Link, as discussed, given its potential to accommodate AV, its risk of having considerably lower BCR is likely to be relatively lower. However, there would be projects with lower BCR that will not be given priority due to their uncertainties, but otherwise would be.

7. Conclusion

This study explored ways to improve the capability of existing TIIA frameworks to account for the uncertainties of FMT. The literature review determined a framework that is used typically for TIIA in practice and identified the impacts and uncertainties of FMT. This study then explored incorporating infrastructure resilience within the TIIA framework. However, an examination of the disruption of FMT revealed that a commonly used infrastructure resilience assessment tool cannot fully assess the uncertainties of FMT, without any improvements. This study, therefore, considered adopting scenarios and MCA and identified a set of criteria that can fully assess the FMT uncertainties. The applicability and practicality of the proposed assessment tool are tested using real-life transport projects, which also identified its key limitations.

This study highlighted that certain projects are exposed to more uncertainties than the other, which tend to be inflexible the way they can be used. The flexibility provides the potential to avoid the loss of utilisation. This finding highlighted that the disruption of FMT (as examined in Section 4.2) is fully understood when undertaking the assessment.

Also highlighted was that the comprehensiveness of assessments depends on the comprehensiveness of the scenarios. Additionally, the proposed methodology suffers from limitations due to its subjectivity to assess uncertainties and does not provide clear-cut indicators, such as BCR.

To best deal with the uncertainties of FMT, regularly conducting detailed analyses of status quo and emerging trends based on recent historical data is crucial. Additionally, the use of triggers is recommended, which would be useful to flag potential loss of utilisations without the detailed analyses of emerging trends. Further work on analysing transport demand trends and forecasting that can feed into developing more comprehensive scenarios would improve the capability and comprehensiveness of the proposed methodology.

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Appendix A

Table 6 Recent major transport projects

Project	Type	Description
Brisbane Metro (Infrastructure Australia, 2018b)	Public transport – bus network improvement	<p>Brisbane Metro would improve frequencies of bus services between Eight Mile Plains and Roma Street busway station (Metro 1) and between the Royal Brisbane and Women’s Hospital and the University of Queensland Lakes (Metro 2). The scope of the project includes:</p> <ul style="list-style-type: none"> • Vehicle changes – the introduction of 60 metro vehicles (bi-articulated buses) with a capacity of 150 people each • Service changes – high-frequency trunk services (every three minutes in peak periods) and truncation of some existing services, with interchange onto the high-frequency trunk services • Infrastructure changes – a new underground station at the Cultural Centre, a new Adelaide Street tunnel, changes to North Quay, existing busway station upgrades, and changes to remove cars from Victoria Bridge • Management and information system changes – to manage vehicles at stations and to provide information to customers about platforms and arrival times • Policy and operations changes – the introduction of pre-paid zones for all metro stations, multi-door entry and exit through up to four doors per metro vehicle.
METRONET: Yanchep Rail Extension (Infrastructure Australia, 2018c)	Public transport – passenger rail network extension	<p>The project would extend the Joondalup Line from Butler Station approximately 14.5 kilometres north to Yanchep, with new stations at Alkimos and Eglinton, and terminating at the Yanchep Strategic Metropolitan Centre.</p> <p>The scope of the project includes:</p> <ul style="list-style-type: none"> • A 14.5-kilometre rail extension from Butler to Yanchep • New stations at Yanchep, Alkimos and Eglinton, with up to 1,000 parking bays at each station for park-and-ride. Initially, 400 parking bays would be provided at Eglinton station and 600 at Alkimos station • Grade separations and over-bridges at key road crossings • Changing the Joondalup Line rail operating plan to provide six train services per hour between Yanchep and Mandurah in the AM peak. A further six train services per hour would operate between Whitfords and the CBD

North East Link
(Infrastructure
Australia, 2018d)

Road and
freeway
upgrades, bus
lane provision
and tunnels

- Changing the bus network to provide feeder services to Yanchep town centre, Eglinton Station and Alkimos Station. The revised bus network would require 26 new buses in 2021 and an additional 32 buses in 2031
- Expanding the existing bus interchange at Butler
- A travel demand management program to encourage uptake of the new public transport services.

The project would create a Managed Motorway connection from the M80 Metropolitan Ring Road in the north to the M3 Eastern Freeway in the south through:

- A new 11-kilometre roadway between the M80 at Greensborough and the M3 at Bulleen
- Approximately 2.3 kilometres of upgrades to the M80 between Greensborough and Plenty Road
- Three-lane twin tunnels (5 kilometres) travelling from Lower Plenty Road to the south of the Veneto Club in Bulleen
- Five interchanges at the M80, Grimshaw Street, Lower Plenty Road, Manningham Road, and the M3
- Upgrades to the Eastern Freeway between Springvale Road and Chandler Highway with up to eight new lanes
- Around 10.6 kilometres of bus lanes between Doncaster and Hoddle Street (“the Doncaster Busway”).

The project also includes new walking and cycling paths, upgraded and new noise barriers along the Eastern Freeway, and a Freeway Control Centre for controlling traffic and managing operations.

The project includes the systems and infrastructure to enable tolling, operation as a Managed Motorway, and integration with connecting roads. Modernisation of the Eastern Freeway is a core element of the project to ensure the freeway integrates effectively with the North East Link and keeps pace with increasing traffic volumes and changing travel demands. The proponent has stated that the North East Link will be tolled.

Table 7 Summary of assessment criteria for used infrastructure investment assessment in Australia

Scope	Government/statutory body	Assessment criteria
Nationally significant investments	Infrastructure Australia (2019a)	<ul style="list-style-type: none"> • Strategic fit • Deliverability • Economic, social and environmental value <ul style="list-style-type: none"> ○ Economic impact: This includes limiting productive capacity; reducing productivity; constraining economic capability; constraining global competitiveness; safety impacts. ○ Social impact: Including problems which result in, maintain or exacerbate major issues of social exclusion and/or quality of life, such as access to services and employment and safety ○ Environmental impact: Including issues such as greenhouse gas emissions, waste creation, noise pollution, visual intrusion, heritage impacts and more
Western Australia (WA)	WA Portfolio Investment Coordination (2017)	<ul style="list-style-type: none"> • Strategic alignment <ul style="list-style-type: none"> ○ To what extent does the proposal contribute to government policy and transport service delivery objectives? • Criticality and urgency <ul style="list-style-type: none"> ○ How critical are the consequences of delaying the investments to government services? • Economic outcomes <ul style="list-style-type: none"> ○ How valuable are the economic benefits to the government and does the investment demonstrate value for money? • Social outcomes <ul style="list-style-type: none"> ○ What is the scale and extent of the social benefits of the investment? • Achievability <ul style="list-style-type: none"> ○ Is the investment proposal likely to be supported by key stakeholders or face significant opposition? • Maturity and deliverability <ul style="list-style-type: none"> ○ How well developed is the preferred solution and how mature is the investment proposal?
New South Wales (NSW)	Deloitte (2012)	<p data-bbox="707 1464 959 1494">Strategic objectives</p> <ul style="list-style-type: none"> • Infrastructure flexibility <ul style="list-style-type: none"> ○ Can assets be used in a way that demand or supply can become more scalable? • Reliability <ul style="list-style-type: none"> ○ Will quality, availability and compliance with standards improve with the investment? • Capacity <ul style="list-style-type: none"> ○ Will investment allow current and future demand to be met or promote economic development? • Legibility <ul style="list-style-type: none"> ○ Will the asset or system be easier and more convenient to use? • Cost of living and doing business <ul style="list-style-type: none"> ○ Will investment save time or reduce the cost of living or doing business? • Amenity and liveability

- Will the investment improve comfort, happiness, social cohesion and the environment?
- Economic efficiency
 - Are economic benefits likely to exceed economic costs?

Infrastructure NSW project assurance objectives

- Strategic alignment
 - Is there a clear alignment with key government and departmental policies and strategies?
- CBA
 - How robust is the CBA?
- Level of planning
 - How advanced is planning, design and technical feasibility?
- Complements and alternatives
 - Have other alternatives been considered? Does the project enable benefits for other projects?
- Social, economic and environmental impacts
 - Are there significant non-monetary social, economic and environmental impacts?
- Project management
 - Is there a project team/agency with appropriate skill and experience to manage/monitor/deliver?
- Major risks
 - Have all major risks been identified? If so, is there a strategy to mitigate major risks?
- Stakeholder support
 - Have issues raised by stakeholders been considered with common agreement achieved?

Queensland Queensland Treasury (2017)

- The benefit realisation plan is documented
- Strategic alignment, deliverability
- Statutory and procedural requirements are met
- The procurement strategy is agreed
- Stakeholder support, implementation and risk management plan are agreed
- Availability of expertise and resources to manage the supplier relationship
- Draft contracts and service level agreements are agreed

Queensland Building Queensland (2013)

- Service need
- The validity of options assessment
- Strategic alignment
- Legal and regulatory requirements
- Design and deliverability
- Public interests
- Environment
- Economic benefits

Victoria State of Victoria (2017)

- Economic
- Environment
- Social
- Innovation

Table 8 Technology news in 2019 (as of 27 September 2019)

Technology	Context	Headline	Reference
AV (not-shared)			
AV	Partnership	Ford and VW Discuss Autonomous Car Team-Up at a \$4 Billion Valuation	Bloomberg (2019a)
	Partnership	Yandex inks deal with Hyundai to build self-driving car tech for its Mobis OEM division	Tech Crunch (2019a)
	Partnership	GMV Spearheading Development of Positioning Technology for Autonomous Vehicles	Inside Unmanned Systems (2019b)
	Investment	Amazon Dives Into Self-Driving Cars With A Bet On Aurora	WIRED (2019)
	Investment	GM Cruise autonomous vehicle unit valued at \$19 billion	Smart Highways (2019a)
	Investment	Ford will spend almost \$1 billion to tool up Detroit plants for EVs and autonomous vehicles	Red Green and Blue (2019)
On-demand AV	Acquisition	Uber buys AI firm to advance push on autonomous cars	Phys.org (2019)
	Launching service	Chinese ride-hailing giant Didi plans to launch a robotaxi service in Shanghai	CNBC (2019b)
Shared AV			
Shared AV services	Partnership	Sony and Yamaha Create Autonomous Vehicle For Theme Parks	Techthelead (2019)
	Partnership	Texas A&M University signs up for remote control of autonomous shuttles	Smart Cities World (2019c)
	Service announced	Toyota teases its plans for the Olympics in Tokyo	Automotive News (2019)
	Service launched	Perrone Robotics Launches Public Autonomous Shuttle Service in Virginia	Robotics Business Review (2019b)
	Service provided	Denver's First Autonomous Shuttle Hits the Streets	Inside Unmanned Systems (2019a)
	Service provided	World's First All-Weather Autonomous Bus Rolls Out in Finland	Geek.com (2019b)
Autonomous trucks, delivery vehicles and drones			
Autonomous delivery vehicles	Acquisition	San Francisco food delivery firm DoorDash acquires autonomous vehicle specialist Scotty Labs	Automotive IT (2019)
	Investment	Driverless delivery startup Nuro raises almost \$1 billion	Ars Technica (2019)

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	Service launched	Providing autonomous pizza delivery in the Houston area later this year	Robotics Business Review (2019a)
	Service provided	Amazon delivery robots are officially on the streets of California	ZDNet (2019b)
	Service provided	Starship Self-Driving Robots Complete Milestone Of 50,000 Deliveries	Clean Technica (2019)
Autonomous trucks	Investment	Driverless truck startup TuSimple raises \$95 million at \$1 billion valuation	Venture Beat (2019a)
	Partnership	RoboSense and Airdrivers partner to deliver autonomous solutions for industrial transportation	Green Car Congress (2019)
	Trial starting	Walmart begins delivering with driverless vehicles	Logistics and Materials Handling (2019)
	Service announced	Peloton outlines plan for platoons with driverless following truck	Fleet Owner (2019)
	Service launched	Driverless electric truck starts deliveries on Swedish public road	Reuters (2019)
	Service launched	COAST Autonomous to deploy first self-driving vehicles at rail yard	The Robot Report (2019)
	Service provided	Fortescue autonomous fleet achieves major milestone	Safe to Work (2019)
	Service provided	Amazon is hauling cargo in self-driving trucks developed by Embark	CNBC (2019a)
Drone delivery	Service launched	DHL launches its first regular urban drone delivery service	Smart Cities World (2019a)
	Service launched	Google's drone delivery service launches in Canberra after being given green light to take to the skies	ABC News (ABC News, 2019)
Vehicle productions			
AV	Approval given to build an AV factory	Waymo will build self-driving cars in Michigan	Engadget (2019a)
	Opening a facility	Kyocera to open autonomous driving facility in Japan	ITS International (2019b)
	A new AV manufacturer entering the market	Yandex's Self-Driving Car Is a High-Tech Ride	Geek.com (2019a)
Technology testing and enhancement			
AV	Acquisition	Porsche invests in 'low visibility' sensor startup TriEye	Tech Crunch (2019b)
	Development	Jaguar's "pod projection" tech signals driverless cars' intentions	New Atlas (2019)

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	Development	TomTom Maps Out Revamp With Bet on Self-Driving Cars	Bloomberg (2019b)
	Trial funded	\$7.5 million awarded to Michigan to test self-driving cars	Smart Highways (2019b)
	Starting trial	Volvo's self-driving car venture gets approval to test on Swedish roads	Automotive News Europe (2019)
	Starting trial	Swedish state and industry back autonomous vehicle testing facility	Computer Weekly.com (2019)
	Starting trial	Verizon and Sprint are ramping up their presence in AV technology development	Business Insider (2019)
	Testing	Apple's Self Driving Car Spotted Testing With A New And Improved Sensor Arrangement	India Times (2019)
	Testing	Toyota experiment uses cameras to create city maps for self-driving cars	Engadget (2019b)
	Testing	Ford to deploy up to 100 autonomous cars by the end of 2019, expand testing to third city	Venture Beat (2019b)
Autonomous delivery vehicles	Trial starting	Robot delivery startup Udelv partners with Walmart and Baidu	The Verge (2019)
Autonomous trucks	Development	Einride T-pod is a driverless truck you can control remotely via 5G	Pocket-lint (2019)
Blockchain technology for AV	Development	University of Nevada, Reno, develops driverless vehicle Blockchain tech with IoT firm	Cointelegraph (2019)
CAV	Starting trial	London announces real-world testing for driverless cars	Smart Cities World (2019b)
	Starting trial	Spark and Ohmio trial 5G-connected driverless car in New Zealand	ITS International (2019a)
	Trial ended	LG Uplus and Hanyang successfully trial 5G autonomous car in Seoul	ZDNet (2019a)
	Trial ended	UK's ground-breaking CAV project demonstrates a connected transport future	Traffic Technology Today (2019)
Infrastructure development			
Electric vehicles	Funded	Massive EV highway charging network receives \$15 million in funding	Infrastructure Magazine (2019)
Regulations and legal framework			
	Legalising	Florida establishes a legal framework for self-driving vehicles	Venture Beat (2019c)
	Permit given	Self Driving Car Manufacturer Zoox Gets First Permit In California To Transport People	The Richest (2019)

Table 9 Impacts and uncertainties of FMT

Study focus	Finding/claim	Reference
Changes in demand and congestion		
AV	Increased car users	Bahamonde-Birke et al. (2018)
	Increased vehicle distance travelled for the populations of age 19 and over	Harper, Hendrickson, Mangones and Samaras (2016)
	Reduced congestion	Bahamonde-Birke et al. (2018), and Kim, Pourrahmani and Fagnant (2016)
	Reduced VOT (not limited to commuting)	De Loeff, Correia, van Cranenburgh, Snelder and van Arem (2017)
	Reduced VOT for commuting	Steck et al. (2018)
MaaS	Improved PT attractiveness and utilisation	Rantasila (2015)
	Improve the efficiency of transport systems in urban areas	Rantasila (2015)
	Increased active travel (AT)	Strömberg, Karlsson and Sochor (2018)
	Increased PT demand	Strömberg et al. (2018)
	Increased sustainable transport modes	Utriainen and Pöllänen (2018)
	Reduced congestion	Rantasila (2015)
	Reduced private car users	Rantasila (2015), Strömberg et al. (2018), and Utriainen and Pöllänen (2018)
On-demand mobility	Increased VOT: VOT for flexible mobility is US\$21.1 per hour (while US\$16.3 per hour for cars)	Frei et al. (2017)
On-demand shared AV	Reduced traffic volume	Mourad et al. (2019)
Shared AV	Increased vehicle distance travelled	Clements and Kockelman (2017) and, Fagnant and Kockelman (2014)
	Increased car travels	OECD - International Transport Forum (2015)
	Reduced demand for taxis and buses	Clements and Kockelman (2017)
	More efficient transport system	OECD - International Transport Forum (2015)
	Reduced traffic volume	Fagnant and Kockelman (2014) and OECD - International Transport Forum (2015)
	Reduced vehicle distance travelled	Mourad et al. (2019) and Ohnemus and Perl (2016)

Shared mobility	Increased non-motorised modal use	Martin and Shaheen (2011)
	Increased passenger rail demand	OECD - International Transport Forum (2017)
	Increased PT demand	Martin and Shaheen (2011)
	Reduced congestion	OECD - International Transport Forum (2017)
	Reduced vehicle distance travelled	OECD - International Transport Forum (2017)
	Reduced VOT for commuting	Kolarova, Steck and Bahamonde-birke (2019)
Economic and financial impacts		
AV	Improved safety	Kim et al. (2016) and Stead and Vaddadi (2019)
	Increased productivity	Stead and Vaddadi (2019)
	Reduced environmental impacts resulted from efficient driving	Bahamonde-Birke et al. (2018)
	Reduced operating costs resulted from unmanned and efficient driving	Bahamonde-Birke et al. (2018)
	Reduced traffic management measures	Stead and Vaddadi (2019)
	Reduced VOT (not limited to commuting)	De Loeff et al. (2017)
	Reduced VOT for commuting	Steck et al. (2018)
MaaS	Reduced resources required for development and maintenance of transport infrastructure facilities	Rantasila (2015)
	Reduced environmental impacts resulted from more efficient transport system	Rantasila (2015)
On-demand mobility	Increased VOT: VOT for flexible mobility is US\$21.1 per hour (while US\$16.3 per hour for cars)	Frei et al. (2017)
On-demand shared AV	Shorter travel time	Mourad et al. (2019)
	Reduced vehicle distance travelled	Mourad et al. (2019)
Shared AV	Increased freight capacity	Clements and Kockelman (2017)
	Improved road safety	OECD - International Transport Forum (2015)
	Increased labour productivity	Abe (2019)
	Increased productivity of in-vehicle time	Clements and Kockelman (2017)
	Reduced costs for law enforcement on the road	Clements and Kockelman (2017)
	Reduced freight costs	Clements and Kockelman (2017)
	Reduced medical expenses	Clements and Kockelman (2017)

	Reduced operating costs of taxis, trains and buses	Abe (2019)
	Reduced vehicle maintenance	Clements and Kockelman (2017)
	Reduced VOT for commuting	Kolarova et al. (2019)
Shared mobility	Reduced environmental impacts resulted from reduced vehicle distance travelled	OECD - International Transport Forum (2017)
Social impacts and changes in land-use		
AV	Provision of more flexible and personalised PT services	Bahamonde-Birke et al. (2018)
	Reduced emissions and noise	Stead and Vaddadi (2019)
	Reduced required space for parking	Stead and Vaddadi (2019)
MaaS	Promotes investing in new technologies	Rantasila (2015)
	Provision of more responsive transport services in regional areas	Rantasila (2015)
	Reduced required space for parking	Rantasila (2015)
Shared AV	Reduced required space for parking	Clements and Kockelman (2017), OECD - International Transport Forum (2015) and Ohnemus and Perl (2016)
	Reduced required space for vehicle storing	Ohnemus and Perl (2016)
Shared mobility	Lack of access for low-income populations to some shared mobility services	Shaheen and Chan (2016)
	Provision of ad-hoc transport services to low-income households	Vanderschuren and Baufeldt (2018)
	Reduced car ownership	Vanderschuren and Baufeldt (2018)
	Reduced required space for parking	Mounce and Nelson (2019)
Uncertainties		
MaaS	The views of MaaS actors on impacts to PT services differ	G. Smith, Sochor and Karlsson (2018)
	Non-car owners realised that they do not need cars when MaaS is provided	Strömberg et al. (2018)
On-demand mobility	Environmental impacts such as energy consumption and greenhouse gas emissions of on-demand mobility have not been thoroughly studied	Jin, Kong, Wu and Sui (2018)
	Raises concerns, such as whether sharing economy platforms would exploit producers and/or consumers, whether ride-sourcing drivers are reasonably compensated and their working rights are protected	Jin et al. (2018)
	Raises the issues of digital divide, discrimination, and data privacy and security	Jin et al. (2018)
Shared AV	Environmental impacts depend on vehicle technologies	OECD - International Transport Forum (2015)

	Managing the transition would be challenging	OECD - International Transport Forum (2015)
	The availability of PT influences the required vehicle size to service autonomous shared mobility	OECD - International Transport Forum (2015)
	The impacts on congestion depend on system configurations	OECD - International Transport Forum (2015)
	In the places where last-mile mobility is mainly served by cars, the impacts of AV depend on its market adoption	Ohnemus and Perl (2016)
	Whether AVs are shared or not changes the future trajectory of mobility in suburban areas	Ohnemus and Perl (2016)
Shared mobility	A large potential to act as PT feeder services and can increase the use of high capacity PT services	OECD - International Transport Forum (2017)
	Future rail station designs need to incorporate requirements for integrating shared mobility services such as pick-up and drop-off areas	OECD - International Transport Forum (2017)
	Raises concerns in terms of the type of employment the drivers should be employed with	Shaheen and Chan (2016)
