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Identifying MaaS schemes that maximise economic benefits through an economic appraisal

Dr Sae Chi[1]
Planning and Transport Research Centre (PATREC), the University of Western Australia, Perth, Australia.

Sam Mazzer[2]
Hadron Group, Sydney, Australia.

Mobility-as-a-Service (MaaS) is a new concept of transport mobility where various mobility services such as public transport, taxi and sometimes rideshare services are offered as a bundle with subscription payment. Many government transport agencies, industry bodies and academia have shown interest in MaaS, evidenced by the release of policy papers, trials and academic studies. The trials and studies to date presume that MaaS will benefit society, however, there is a lack of economic justification within the literature on the impacts on users, governments and communities. This paper explores multiple MaaS options through an economic appraisal framework and quantifies the economic benefits of MaaS. The economic appraisal framework monetised the MaaS impacts that were identified in past literature and compared the net benefits to society of several MaaS options developed for this paper. The appraisal demonstrated that the MaaS option that promotes public and active travel generates the largest economic benefits compared to other options that were considered. This paper demonstrates that transport policy can be developed based on the net impacts MaaS can provide to society. It also contributes to the discussion on policy issues surrounding MaaS which is important as government transport agencies and industry partners explore the justification for investment and implementation requirements.

Keywords: *Economic appraisal; transport economics; mobility-as-a-service; maas; economic impacts*

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[1] Planning and Transport Research Centre (PATREC), the University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia, sae.chi@uwa.edu.au.
[2] Hadron Group, Level 3, 223 Liverpool Street, Sydney, NSW 2000, Australia, sam@hadrongroup.com.au

1. Introduction

Mobility-as-a-Service (MaaS) is a new concept of transport mobility where several services such as public transport (PT), taxi and sometimes rideshare services are offered as a bundle with subscription-based payments, including monthly and weekly. MaaS incorporates a range of mobility modes and providers and can make multi-modal travel more convenient and efficient for end-users (Pangbourne, Mladenović, Stead, & Milakis, 2020), provide better accessibility (Eckhardt, Lauhkonen, & Aapaoja, 2020) and improve the service quality of PT (Liljamo, Liimatainen, Pöllänen, & Viri, 2021).

MaaS has received high interest from industry, governments and academia globally. For instance, many government transport agencies and industry bodies in Australia have investigated MaaS, including a study that identified the risks and opportunities MaaS represents for the public sector (Delplace et al., 2019); a study that attempted to measure the impacts of MaaS and other future mobility and transport (KPMG, 2018); and study that explored suitable MaaS deployment strategies in Australia (Vij, Sampson, Swait, Lambides, & Hine, 2018). These government transport agencies and industry bodies highly value MaaS and its potential network benefits. The interest from academia is also reflected in a large number of published studies, particularly in the last couple of years.

The investments in research and development presume that MaaS will benefit society. As evident in even early literature (Sochor, Karlsson, & Strömberg, 2016), MaaS is assumed to provide favourable outcomes that address societal objectives such as emission reduction (Becker, Balac, Ciari, & Axhausen, 2020). While the studies and trials to date have explored important operational aspects of MaaS, there is limited analysis of the economic justification for investment and bundles that may provide net benefits to society.

This paper explores multiple MaaS options from the economic perspective to identify and inform the implementation of the bundles that most benefit society. The economic appraisal framework applied by this paper is a widely accepted approach that is used by transport agencies to assess and prioritise investments.

This paper will address the research question, "how the benefits of MaaS can be maximised and whether the benefits substantiate government subsidy". It will quantify and monetise those MaaS impacts that are identified in other studies (see Sections 2.5 to 2.9) and the net impacts of MaaS will be considered in the appraisal which provides a holistic view of the MaaS impacts which have not been undertaken.

As a result, this paper will contribute to the discussion of long-term impacts and policy issues by providing an economic appraisal of the MaaS options and by exploring policy implications. This is an important outcome for government transport agencies and industry stakeholders as they aim to understand the merits of MaaS and implement schemes that maximise benefits to society.

This paper provides a background (Sections 2.1 to 2.4) and comprehensively reviews the literature to identify the potential impacts of MaaS (Sections 2.5 to 2.8). A summary of the literature review findings is provided in Section 2.9. Using the Cost-Benefit Analysis (CBA) theory, this paper then quantifies the identified impacts that can be monetised (Sections 3 and 4). It considers multiple options of MaaS and evaluates them based on each of their overall societal benefits, to determine the most beneficial option from the economic perspective. The implications of the results and policy considerations are developed in Section 5.

2. Literature review

2.1 Mobility-as-a-Service

MaaS combines various transport modes, encourages the access-based mobility perspective, and provides individually tailored and on-demand mobility solutions (Lopez-Carreiro, Monzon, Lopez, & Lopez-Lambas, 2020). Studies suggest that MaaS deployment should be led by the public sector (Sochor, Strömberg, & Karlsson, 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 the efficiency of the transport system may be better dealt with by the private sector, because the efficiency improvement directly contributes to maximising their profits. However, pure reliance on the private sector may fail to optimise the service and achieve the desired environmental impacts (Cohen & Kietzmann, 2014).

While this paper does not intend to conduct a systematic review of MaaS, a search on the Web of Science Core Collection (Clarivate, 2021) database identified 85 articles that study MaaS as the main focus. Of those, 26 articles studied the uptake, preferences and Willingness to Pay (WTP) of MaaS (e.g. Lopez-Carreiro et al., 2020; Matyas & Kamargianni, 2021; Zijlstra, Durand, Hoogendoorn-Lanser, & Harms, 2020) and 28 articles studied business models, governance and other implementation issues of MaaS (e.g. Hirschhorn, Paulsson, Sørensen, & Veeneman, 2019; Karlsson et al., 2020; Surakka, Härri, Haahtela, Horila, & Michl, 2018). Only two articles modelled MaaS (see Djavadian & Chow, 2017; Pantelidis, Chow, & Rasulkhani, 2020) while eight articles studied existing MaaS and trials (see Arias-Molinares & Carlos García-Palomares, 2020; Chang, Chen, & Chen, 2019; Esztergár-Kiss, Kerényi, Mátrai, & Aba, 2020; Ho, Hensher, & Reck, 2021; Singh, 2020; Smith, Sochor, & Sarasini, 2018; Sochor et al., 2016; Strömberg, Karlsson, & Sochor, 2018).

The feasibility and benefits of various business models, governance and implementation of MaaS are assessed based on the operational perspective, and expert opinions of transport policymakers and mobility providers. These are generally assessed qualitatively, and the societal benefits and costs of MaaS have not been quantified in these studies.

2.2 Levels of Mobility-as-a-Service integration

There are varying levels at which MaaS can integrate with the existing transport networks, service providers and external platforms. The level of integration not only has implications for users, businesses and technology, but the ability for MaaS to progress toward societal goals including reducing vehicle emissions and congestion, encouraging active travel that provides health benefits, and providing a safe and efficient way to travel.

There are four widely referenced levels of MaaS integration (Sochor et al., 2017). The levels of integration include:

- Level 0 – No intervention with single separate services. This may include current public service providers.
- Level 1 – Integration of information to support travel planning and pricing information. This may include Google and third party smartphone apps such as Next There.
- Level 2 – Integration of travel planning, bookings and payments. This may include ridesharing providers such as Uber which allow bookings for their vehicles and public transport.
- Level 3 – Integration of a service offering including contracts and responsibilities. This may include car-sharing platforms such as Go Get and Car Next Door.
- Level 4 – Integration of the societal goals. To date, this has been explored by (Hensher et al., 2021) and (iMOVE CRC, 2021) through trials in Sydney and Brisbane, respectively.

Other authors have explored five, six and 10 levels of MaaS integration (see Lyons et al., 2019; Traffic Technology, 2018; Bandeira et al., 2021; Kamarginanni et al., 2016). These studies focused on various attributes of MaaS including functionalities that appeal to users, responsibilities for businesses, data policy, Internet of Things (IoT) integration and service personalisation.

This paper is primarily interested in the level 4 integration (established in Socher et al. (2017)) and the extent to which an economic appraisal framework can support MaaS schemes that progress societal goals.

2.3 Mobility-as-a-Service business model and bundle structure

MaaS is in its infancy and there is a range of studies that examine optimal business models and bundle structure. A brokered model, whereby several services are accessed through a centralised smartphone app, is widely discussed and has been featured in recent Australian trials (Hensher et al., 2021; iMOVE CRC, 2021). Other models, such as a Walled Garden, have been explored and may occur as private operators aim to provide MaaS while maintaining control of their project, however, this can come at the expense of user choice (iMove CRC, 2020). Walled Gardens are often used in the technology industry, such as Apple's App Store which allows users to download apps but they must meet Apple's strict development requirements. As MaaS matures, there may be a move to an open marketplace whereby operators share their data and cannot withhold their services from a particular platform (iMove CRC, 2020).

The bundle structure and pricing model have a significant influence on user behaviour. A European study (Esztergár-Kiss & Kerényi, 2020) has explored various MaaS packages based on city-specific parameters. In Australia, the two Australian trials have examined bundles that target different user markets, encourage changes in travel behaviour and test the extent to which bundles effectively manage traffic demand (Hensher et al., 2021; iMOVE CRC, 2021). For example, six MaaS bundles were examined in the trial between late 2019 and early 2020, which ranged from Pay As You Go (PAYG) with no financial discounts to the Green Pass which provided unlimited public transport trips and discounts on Uber and taxis (Hensher et al., 2021). The subscribers could access the bundles using the Tripi smartphone app through a monthly subscription (Hensher et al., 2021).

The Queensland Department of Transport and Main Roads (TMR) and the University of Queensland (UQ) is currently undertaking a MaaS trial in Brisbane, Australia (iMOVE CRC, 2021). The trial focuses on increasing public transport and active transport patronage. Students and staff of UQ can access eight bundles that have a base offering of unlimited public transport and a range of complementary services such as e-scooters, e-bikes, taxis and hire vehicles, depending on the purchased bundle. The subscribers can access bundles through the ODIN PASS smartphone app and pay upfront for the monthly bundles.

2.4 Modal shift due to Mobility-as-a-Service

MaaS is expected to disrupt the transport system and at the same time, can be used to promote travel behaviour change (Sochor et al., 2016) that better fits into societal goals. For example, it can be developed with a strategic or societal goal in mind, such as reducing emissions.

When the demand for driving decreases, the number of cars on roads decreases which would provide benefits such as decongestion, reduction of vehicle operating costs (VOC), reduced exposure to crash risk and reduced environmental impacts. The reduced driving demand will also reduce fuel tax, other vehicle-related tax revenues and parking revenue. This paper does not quantify these tax revenues or parking costs due to a lack of reliable data and differing costs by jurisdiction. Additionally, the overall crash risk can be reduced through decongestion (Chee, 2006; Retallack & Ostendorf, 2020). There is also strong evidence that as congestion worsens, the likelihood of fatal crashes increases (see Albalate & Fageda, 2021).

Changes in demand due to MaaS can shift some travellers to modes other than what they have been using. In the example of offering cheaper PT services, the modal shift can occur due to changes in the perceived costs of driving and PT. The perceived cost of PT becomes less than driving by reducing fares, reducing waiting time and/or improving the PT level of service and accessibility. Theoretically, when the reduction becomes larger than the difference between the perceived costs of driving and PT service, the traveller would make the switch. In practice, promotional activities are important to help travellers become aware of the reduction as people are not always aware of these changes in a timely manner in real life. In fact, the trial of corporate MaaS resulted in minimal modal shift, which authors suggest is due to a lack of awareness of MaaS offerings (Hesselgren, Sjöman, & Pernestål, 2020).

Some studies observed modal shifts from private cars under MaaS in a real-life setting. For instance, a Finnish study observed a modal shift from private cars to demand responsive transport (DRT) minibuses (Eckhardt et al., 2020). Also, another study in London showed the potential for MaaS to decrease private vehicle dependence (Matyas, 2020). However, the recent Sydney-based trial resulted in a limited modal shift from driving, which may reflect the objectives of the MaaS bundles, attitudes of user groups and other factors specific to the trial and study (Hensher et al., 2021). To change the use of cars in a more sustainable way, the MaaS scheme and subscription need to be well-designed (Hensher et al., 2021).

When a modal shift occurs between vehicles with different occupancy rates, such as cars and buses, it can influence the average occupancy rate at a city-wide level. For instance, a MaaS pilot study in Finland resulted in improving vehicle occupancy rates through the integration of services (Eckhardt et al., 2020). The higher vehicle occupancy rate can contribute to reducing vehicle distance travelled by not needing as many vehicles to carry the demand. Reducing vehicle distance travelled provides various benefits including reduction of emissions.

Interestingly, a preference study showed that drivers were more willing to change their travel behaviour than cyclists and pedestrians (Feneri, Rasouli, & Timmermans, 2020). This finding is favourable because then the cyclists and pedestrians will continue to accrue health benefits that they would not otherwise accrue using other modes. The health benefits are derived from (Australian Transport and Infrastructure Council, 2016a):

- Morbidity and mortality benefits because active people get sick less often and have a longer life expectancy than inactive people
- Reduction in health system costs because active people are less likely to need medical and hospital care

Due to improved quality of service through MaaS, travellers may benefit from travel time reliability. In this paper, the travel time reliability benefit is not quantified as it highly depends on existing delays within the network and how they are improved. Also important to note is that when a modal shift to a particular mode occurs, for example, buses, the increase in bus demand can overcrowd the bus system. Without interventions, bus users will experience poor quality of service and increased travel time.

2.5 *Impacts on overall travel demand due to Mobility-as-a-Service*

As discussed previously, MaaS improves mobility services and the improvement can attract more travellers and increase the overall travel demand (i.e. induced demand). For instance, those who usually choose to stay at home due to poor transport accessibility may choose to go out more often when accessibility is improved through the MaaS scheme. Also, MaaS can induce demand by improving multi-modal travel (Pangbourne et al., 2020).

While induced demand for driving would be counter to the societal goal of reducing traffic, an increase in cycling and walking demand would be favourable. An increase in PT demand can overcrowd the existing PT system and increase the perceived cost of PT as a result. A study suggests that due to this phenomenon, infrequent travellers who would not purchase a subscription can increase their private car uses under MaaS (Hörcher & Graham, 2020). Contrary to this, another study claims integrating mobility services reduce vehicle kilometres travelled (Eckhardt et al., 2020).

2.6 *Impacts on private vehicle ownership due to Mobility-as-a-Service*

Many studies suggest the potential for MaaS to reduce private vehicle ownership (Liljamo et al., 2021; Matyas, 2020; Strömberg et al., 2018; Wright, Nelson, & Cottrill, 2020). Also, a study suggests increased demand for shared modes under MaaS (Matyas & Kamargianni, 2019), such as bike and car-sharing services, which can further encourage a reduction of private vehicle dependence. However, there are also other studies (Alyavina, Nikitas, & Tchouamou Njoya, 2020; Hörcher & Graham, 2020; Storme, De Vos, De Paepe, & Witlox, 2020) that oppose these claims. For travellers to give up on their private vehicle ownership, the improvements due to MaaS must be significant, and the services need to be reliable. A major reform of mobility services and their overall design, along with travel demand management strategies would be needed to reduce private vehicle ownership (Alyavina et al., 2020). Also, reducing the use of private vehicles for leisure purposes is particularly difficult (Storme et al., 2020).

The reduction of private vehicle ownership can be expected if the perceived costs of MaaS are far less than the perceived costs of driving. What makes this complex is that congestion is usually only evident during peak hours. The perceived costs of driving between peak-time commuters and non-commuters can be considerably different. Hörcher and Graham (2020) pointed out that theoretically, the more congested roads are, the more encouraging it is to give up on private vehicle ownership and use other mobility services, and therefore, reducing private vehicle ownership may not be the best policy goal. To reduce congestion, the key is to reduce the use of private vehicles with a low occupancy rate. For instance, the policy should encourage to use of vehicles with higher occupancy rates such as buses and trains, shared mobility services, and active travel modes. In addition, the bundle offer also needs to be priced strategically to achieve the reduction.

Reduced car ownership can decrease required parking space, reduce tax revenues from vehicle-related taxes and avoid costs of ownership. However, these impacts are not quantified in this paper due to the lack of reliable data and their complexity.

2.7 *Impacts on Public Transport (PT) fare revenues due to Mobility-as-a-Service*

There would be two ways MaaS can impact the revenues of PT fares. First, changes in PT demand can influence PT revenues and impact operating costs. If the demand is reduced, PT services should also be reduced to avoid any excess. If the demand is increased, additional PT services need to be provided to avoid an increase in travel costs such as crowding and longer wait time. When not addressed, the increase in travel cost can reduce the demand which may be counter to what an agency intended to achieve through a MaaS scheme. Second, offering bundled mobility services would drastically change how PT users are charged. Understanding the uptake and preferences of the MaaS subscription is the key to ensuring that MaaS demand is at the desired level to maintain the PT operation.

An Australian study found that WTP for unlimited PT access is significantly lower than the current daily cap of PT fare (Ho, Hensher, Mulley, & Wong, 2018). Similarly, a Finnish study found that Finnish travellers are willing to pay about 64% of their current mobility costs for a mobility package (Liljamo, Liimatainen, Pöllänen, & Utriainen, 2020). While the WTP may change over time once the full MaaS scheme is in operation and travellers are fully aware of what it is and what it offers, these claims suggest that uptake of MaaS would be poor unless the subscription is heavily subsidised.

Also important to note is that in some circumstances, the changes to the fare revenues can be considered a financial transfer.

When designing the pricing of the MaaS bundle, transport disadvantages and equity need to be taken into consideration. This is because, under MaaS, there is strong potential for increased mobility among only those who can pay for it (Pangbourne et al., 2020). This not only contributes to increasing transport demand but also does not address the need of those who cannot afford to pay for mobility services. As MaaS can be developed in different ways for different purposes (Smith, Sochor, & Karlsson, 2018), the bundle offer needs to be priced strategically to address these issues to achieve societal goals.

2.8 Impacts on the utilisation of existing assets, infrastructure and facilities due to Mobility-as-a-Service

As previously highlighted, MaaS can disrupt the existing transport network by influencing travel demand, causing modal shifts and/or creating induced demand. When demand is changed, the level of utilisation of existing assets and facilities also would be affected. For instance, when people are driving less frequently due to the provision of a MaaS scheme, roads are less utilised resulting reduction in road infrastructure needs. This impact is considered a disruption that affects functionality and utilisation of assets, infrastructure and facilities which is a well-studied area (see Elms, McCahon, & Dewhirst, 2019; Marcelo, House, & Raina, 2018).

The disruption due to MaaS does not occur overnight. It will take some time to occur and the utilisation can either increase or decrease. For instance, the demand for driving is reduced, the demand decreases gradually over time as more people use other modes of transport through MaaS, which results in a reduction in road utilisation. Similarly, MaaS can also increase PT demand in which case the utilisation of PT assets and facilities increases. When utilisation is reduced, operation and maintenance costs also reduce, and vice-versa when utilisation is increased. The impacts due to changes in the utilisation of assets and facilities are however not quantified in this paper as they highly rely on the status quo of the existing asset and facilities.

2.9 Summary of key findings of the literature review

Although the review identified many publications (i.e. 85 articles) that study MaaS as the main focus, none quantified and monetised various MaaS impacts and estimated net impacts of MaaS. The two Australian trials (Hensher et al., 2021; iMOVE CRC, 2021) explored bundle structures through the trials to identify the one that effectively manages traffic demand. The trials provide a real-life case study on the potential uptake and preference of MaaS bundles, however, did not provide overall net quantified impacts to society. An economic appraisal provides economic justification based on the net impacts which provide perspectives from users, governments and communities. Making decisions based on the economic appraisal is crucial in holistic planning and ensuring that public funds are invested in the option that provides the most net benefits to society.

The review identified potential impacts of MaaS which are modal shift; the impacts on overall travel demand; the impacts on PT fare revenues; and the impacts on the utilisation of existing assets, infrastructure and facilities. The mechanism of these impacts is also explored in the review. Based on the literature review findings, economic impacts due to these impacts can be quantified and monetised using CBA. Through monetisation, net impacts that consider all the identified MaaS impacts can be estimated.

3. Methodology

The following section describes the methodology for modelling the economic benefits of Maas, options that are included in the analysis and base-case assumptions.

3.1 Study approach

Within the context of this paper, MaaS is aiming to progress the societal goal of reduced transport related environmental emissions and road network externalities, such as congestion and crashes. This paper quantifies the economic benefits of a hypothetical MaaS scheme that encourages a shift from private vehicles to other modes of transport, aligning with the nominated societal goal. A series of high-level mode shift assumptions that reflect findings in the literature are applied to overcome limitations in the availability of localised trial data.

Multi-modal integration that is promoted by MaaS is reflected as mode shift within the economic model. As a starting point, the model assumes private vehicle users will simply complete the same journey through another mode available in the MaaS options discussed in Section 3.3. Adjustments have been made within the model where journeys would be too far to walk or cycle and need to be combined with PT. The limitation of the model is that it does not consider a single-mode journey (e.g. driving) to be replaced by a journey that involves many modes and transfers (e.g. driving to a bus stop and catching several different buses).

Figure 1 provides an overview of the approach to estimating the economic benefits of MaaS within this paper.

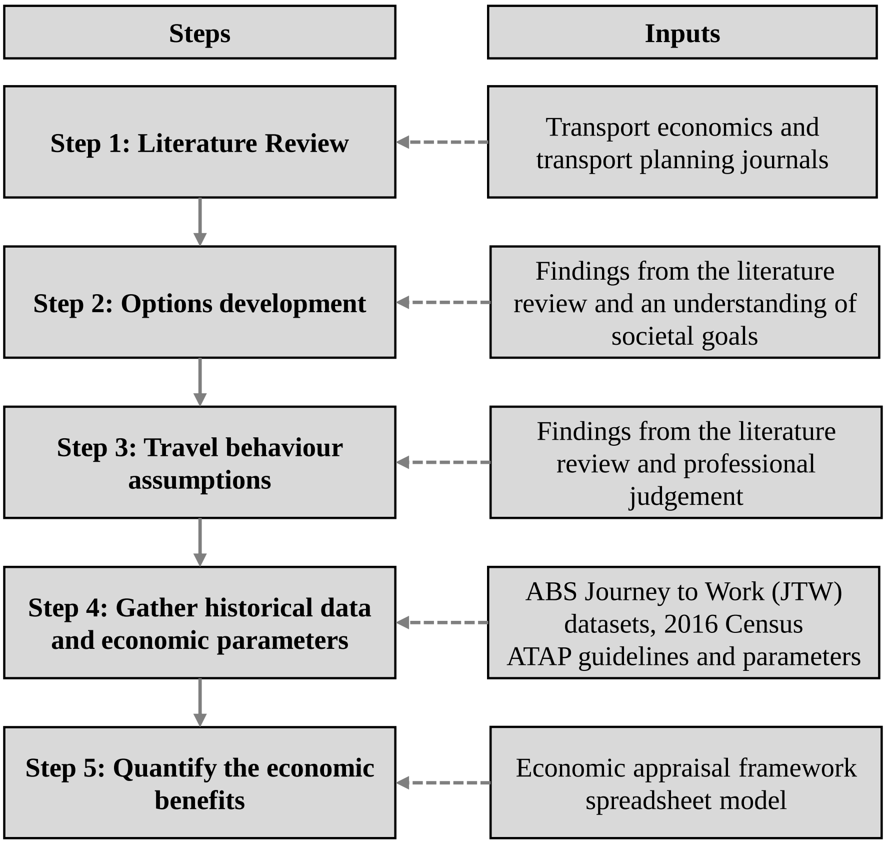

Figure 1. Overview of the approach

Step 1 involves a detailed literature review to identify research and trials that measure the changes in travel behaviour. A range of potential cost and benefits streams were identified based on conventional transport economics principles.

Step 2 focuses on developing four hypothetical options that are applied in the analysis, closely aligning with the nominated societal goal of reduced transport environmental emissions and road network externalities. The options aim to reflect MaaS trials that have focused on encouraging a shift away from private vehicles to other more sustainable modes of transport. The options reflect MaaS trials to date that have focused on increasing the PT mode share and the expectation that transport policy will encourage more sustainable travel in the future.

Step 3 establishes overarching assumptions on the change in travel behaviour due to MaaS. Currently, there are no longitudinal MaaS trial datasets available in Australia. The first major MaaS trial in Sydney (Hensher, Ho, & Reck, 2021) was significantly disrupted by the COVID-19 outbreak in early 2020. The second MaaS trial in Brisbane is underway and is not ready to share results (iMOVE CRC, 2021). In the absence of suitable data, we assume a 1% mode shift from private vehicle trips to other modes of travel across all options. The proportion of demand for other modes by those who shift is informed by the Australian Bureau of Statistics Journey to Work (JTW) dataset from the 2016 Census.

Step 4 involved collecting data on the Greater Perth road network and travel behaviour which forms a basis for quantifying the economic benefits and costs associated with each option. The Australian Bureau of Statistics JTW dataset is the basis of the estimates. While the COVID-19 pandemic has impacted travel behaviour since early 2020, the JTW dataset provides a useful reference to test the economic benefits of MaaS. Additional assumptions were developed to reflect typical travel behaviour (e.g. it was assumed that people travel to and from work).

Step 4 also involved gathering economic parameters associated with the selected benefit and cost streams. The economic parameters and guidance for estimating the benefits and costs are detailed in the ATAP guidelines (Australian Transport and Infrastructure Council, 2016b, 2016c, 2018, 2021b).

Step 5 focused on modelling the options to quantify the economic benefits and costs of MaaS. The model was developed in Microsoft Excel with the results and supporting commentary provided in this paper.

3.2 Economic model

Economic appraisals are used by government transport agencies to evaluate initiatives, programs and projects. Appraisals may help compare options that provide the highest economic benefits to society (i.e. options analysis) or to provide economic justification for a preferred option (which may have been selected for various reasons) (see Infrastructure Australia, 2021). When a proponent of the initiative, program or project develops a business case to seek public funding approval, the business case normally includes an economic assessment to estimate the overall economic costs and benefits to society (as outlined in Infrastructure Australia, 2021). The business cases are then ranked for decision making. This process is consistent across Australia and ensures that the public fund is invested wisely, maximising net societal benefit (Chi & Bunker, 2020).

The most commonly used economic assessment tool for transport projects is CBA (Chi & Bunker, 2020). The CBA systematically quantifies economic costs and benefits, and represents the assessment outcome as a ratio, the benefit-cost ratio (BCR). The CBA methodology for transport projects is well-established and is detailed in the Australian Transport Assessment and Planning guidelines (Australian Transport and Infrastructure Council, 2021a).

Equation 1 outlines the approach for quantifying the estimated level of demand on the Perth transport network, assuming that MaaS encourages a 1% mode shift away from private vehicles. Base Case Trips and Average Vehicle Kilometres Travelled (VKT) are inputs gathered from the data sources discussed above. The JTW dataset is the basis for demand and mode share.

$$\sum VKT_m\ (Vehicle\ Demand * 1\%\ modeshift * Modeshare) * Average\ VKT_m$$

Where m = mode of transport (e.g. driving, public transport) (1)

The benefits of MaaS are quantified by multiplying the MaaS option VKT by economic parameter values sourced from the ATAP guidelines. The economic parameter values are specific to each mode. The economic benefits are expressed in dollars. Equation 2 outlines the quantification approach.

$$\sum Economic\ benefits\ (\$)_m = \sum VKT_m * Economic\ parameter\ values\ per\ VKT_m$$

Where m = trips by mode (e.g. driving, public transport) (2)

3.3 Mobility-as-a-Service options for appraisal

The following summarises the hypothetical MaaS options for appraisal based on the potential impacts identified in the literature (see Sections 2.5 to 2.9 for details):

- Option A. Modal shift from driving to PT modes with higher vehicle occupancy rates
- Option B. Modal shift from driving to PT modes with higher vehicle occupancy rate, and increased cycling and walking (travellers walking or cycling to bus stops or train stations, instead of driving)
- Option C. Modal shift from driving to all PT modes, including taxis
- Option D. Modal shift from driving to all PT modes, with increased demand for taxis as a result of induced demand

It is important to note that this paper considers taxis due to the availability of data. Rideshare services such as Uber could be included in a MaaS bundle, however, publicly available demand estimates are limited for those services. The appraisal accounts for mode-specific variations in distance travelled. For instance, the average travel distance of driving will be replaced with the average travel distance of PT that is longer than driving, when a modal shift from driving to PT occurs. When shifting to cycling and walking (in Option B), it is assumed that the traveller is using PT and cycling or walking to complete their journey, as it is unrealistic to assume that they can complete the whole journey by cycling or walking. The diversion users that shift to cycling and walking are informed by ATAP guidelines (Australian Transport and Infrastructure Council, 2016b) which focus on travel behaviour change initiatives.

All options assume that 1% of existing drivers will shift to other modes and be distributed based on the assumptions within each option (i.e. distributed to PT, walking, cycling or taxi). Option C assumes that in addition to the mode shift to PT, there will be a 10% increase in the number of new taxi users (equivalent to 560 travellers) as a result of the increased convenience and choice provided by the hypothetical MaaS bundle. Option D assumes the increased demand plus a further induced demand of 10% by existing taxi users, equivalent to 173 travellers. The induced demand reflects guidance from ATAP guidelines (Australian Transport and Infrastructure Council, 2016b) which indicates travel behaviour change initiatives, such as MaaS, can result in increased demand for services from existing and new users. The increased and induced demand is calculated with an uplift factor in Equation 1.

In the economic assessment, the rule of half applies to the costs and benefits of induced demand (Australian Transport and Infrastructure Council, 2021a). The modal shift and split of each option are illustrated in Figure 2. Note, the modal combinations are based on the average distance travelled. Shorter journeys may be completed by active transport, rather than being combined with public transport.

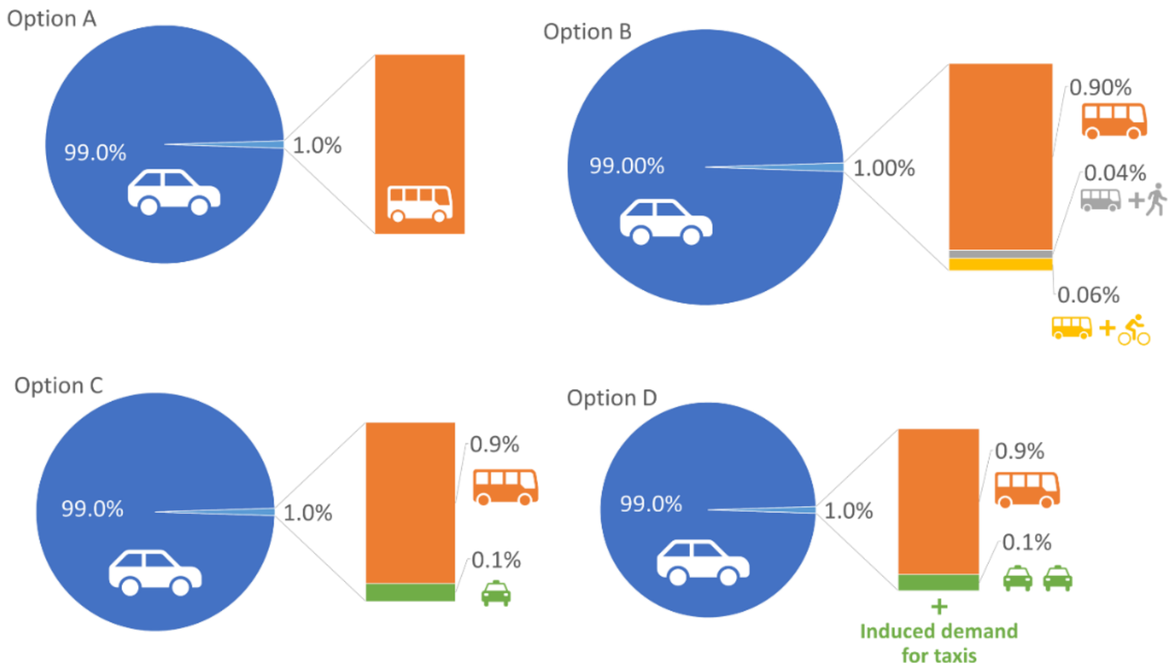

Figure 2. MaaS options modelled

The anticipated benefits and costs of each option are summarised in Table 1. The road costs include decongestion benefits, VOC savings, safety benefits and environmental impacts. The mode-changer (i.e. traveller) benefits are the net total of all the savings and costs that the average mode-changer perceives they are incurring when changing to the new mode (Australian Transport and Infrastructure Council, 2016b). The mode changer benefits include the perceived costs component of the VOC. Therefore, adjustments were applied in the model to appropriately account for the resource costs of VOC. Decongestion refers to the reduced congestion costs (time and vehicle operating cost) experienced by remaining road users and does not include the saving to the mode changers themselves as this is part of their internalised benefit (Australian Transport and Infrastructure Council, 2016b).

Table 1. Anticipated benefits and costs of the options

Option	A	B	C	D
Impacts due to reduction of driving	Reduced road costs	Reduced road costs	Reduced road costs	Reduced road costs
Impacts due to an increase in PT trips	Mode changer benefits and increased environmental impacts from buses and trains	Mode changer benefits and increased environmental impacts from buses and trains	Mode changer benefits and increased environmental impacts from buses and trains	Mode changer benefits and increased environmental impacts from buses and trains
Impacts due to an increase in cycling	None considered	Health benefits and mode changer benefits	None considered	None considered
Impacts due to an increase in walking	None considered	Health benefits and mode changer benefits	None considered	None considered
Impacts due to an increase in taxi trips	None considered	None considered	Increased road costs	Increased road costs
Impacts due to induced demand	None considered	None considered	None considered	Increased road costs from increased taxi trips

3.4 Base case assumptions

As CBA estimates incremental costs and benefits, establishing a base case is crucial. The travel patterns of Perth, Australia (Australian Bureau of Statistics, 2018) are used as the base case in this paper (summarised in Table 2). This paper quantifies the impacts on commuters as it is a key focus area of many MaaS studies to date. The quantification, therefore, assumes each traveller does two trips a day. The estimation uses the Australian economic parameters, supplemented with Western Australian-specific values where available.

Table 2. Base case travel patterns, based on Australian Bureau of Statistics JTW 2016

Travel mode	Average daily travel distance (km)	Number of daily travellers	Modal share (proportion of travellers)
Driving	16	559,744	83%
PT – train	23	55,379	8%
PT – bus	10	29,128	4%
PT – ferry	24	343	0.1%
PT – tram	14	171	0.0%
Taxi	10	1,726	0.3%
Cycling	8	9,176	1%
Walking	4	16,343	2%

4. Results

The following sections present the estimated mode shift from MaaS and the benefits quantified through the economic appraisal framework.

4.1 Modal shift

Across all the options, a 1% modal shift from driving was assumed, which equates to 5,597 people. Those ex-drivers were assumed to be now using PT, cycling, walking and/or taxis instead. The changes to these modes across the options are summarised in Table 3.

Table 3. Changes to the number of travellers of different modes, per average weekday

Option	A	B	C	D
PT – train	3,646	3,646	3,281	3,281
PT – bus	1,918	1,918	1,726	1,726
PT – ferry	23	23	20	20
PT – tram	11	11	10	10
Taxi	0	0	560	560
Induced demand for taxi	0	0	0	173
Cycling	0	224	0	0
Walking	0	336	0	0

Due to the underlining modal shift assumption, the total number of travellers of each option may seem inflated. However, this does not represent any inflation or induced demand, instead represents the journeys that consist of two modes (e.g. PT and cycling etc).

4.2 Reduced demand for driving and increased demand for taxi

All options result in 5,597 fewer people travelling by private vehicle per average weekday which reduces the number of vehicles on the road, contributing to decongestion benefits. The reduction in vehicles also contributes to improved safety outcomes through fewer crashes and lower environmental emissions (e.g. greenhouse gas, well-to-tank emissions and noise). A VOC adjustment is included in all options which reflects the difference between perceived costs and resource costs that users experience when switching from private vehicles to other modes offered in the MaaS options.

Table 4 outlines the economic results of a reduction in private vehicle use. The benefit per reduction in users is $0.51, assuming 5,597 fewer users per average weekday.

Table 4. Benefits due to reduction of driving (September 2021 dollars, per average weekday)

Benefit	Reduction of driving
Decongestion benefits	$2,651
Safety benefit	$619
Environmental benefits	$182
VOC adjustment	-$588
Total benefits	**$2,864**
Benefit per reduction in vehicle user	**$0.51**

Table 5 outlines the results of the increased and induced demand for taxis. The benefit categories are similar to the table above and reflect the scale of demand for the services. Overall, the demand by travellers is assumed to contribute to increased vehicles on the road network and an overall disbenefit of -$286 and -$11 for increased and induced demand for taxis, respectively, per average weekday. The rule of half is applied to the induced demand for taxis (i.e. new users) which results in a lower disbenefit per user.

Table 5. Disbenefits due to increased demand for taxi (September 2021 dollars, per average weekday)

Benefit	Increased demand for taxi	Induced demand for taxi
Decongestion disbenefit	-$265	-$41
Safety disbenefit	-$62	-$10
Environmental disbenefits	-$18	-$3
VOC adjustment	$59	$9
Total benefits (negative reflects disbenefits)	**-$286**	**-$11**
Disbenefit per increase in taxi user	**$0.51**	**-$0.26**

4.3 Increased demand for PT

Travel behaviour change initiatives, such as MaaS, can result in users receiving information that makes them better understand the unperceived costs of their current mode or overcome the disadvantages of an alternative mode. The mode changer benefit reflects the change in perceived generalised costs as private vehicle users switch to public transport. For example, they may now appreciate previously unperceived costs such as road safety and environmental emissions which influences their decision to switch to a mode with lower generalised costs.

There is a marginal increase in environmental impacts for buses and trains. The higher costs for trains reflect the level of demand in Greater Perth (more than twice that of buses) and the longer distance travelled, despite lower unit costs of environmental emissions.

Table 6 summarises the results for public transport, noting the benefits for Option C and D are lower as some users are switching to taxi services too.

Table 6. Benefits due to increased demand for PT (September 2021 dollars, per average weekday)

Benefit	Option A and B	Option C and D
Mode changer benefits	$4,429	$3,986
Environmental impacts of buses	-$229	-$206
Environmental impacts of trains	-$897	-$807
Total benefits	**$3,303**	**$2,972**
Benefit per increase in PT user	**$0.59**	**$0.53**

4.4 Increased demand for cycling and walking

Private vehicle users that shift to cycling or walking accrue mode changer benefits as the perceived generalised costs are now lower than travelling by car. Users that switch also benefit from improved physical health outcomes as they cycle or walk to work and public transport connections. However, some safety disbenefits arise which reflect crashes that may occur.

Table 7 summarises the results for increased cycling and walking which occurs in Option B. The relatively high benefit per user who switches to cycling or walking reflects the significant health outcomes, assuming an average distance walked of 4km each way.

Table 7. Benefits due to increased demand for cycling and walking (September 2021 dollars, per average weekday)

Benefit	Increased demand for cycling	Increased demand for walking
Mode changer benefits	$127	$190
Health benefits	$1,999	$2,638
Safety disbenefits	-$981	-$511
Total benefits	**$1,144**	**$2,273**
Benefit per increase in active transport user	**$5.11**	**$6.77**

4.5 Appraisal results

The results of the appraisal are summarised and illustrated in Table 8 which indicated Option B as the most beneficial option with $9,584 of benefits per average weekday. The significant mode shifter benefits realised by private vehicle users that switch to PT, coupled with a reduction in congestion and road safety disbenefits make a significant contribution to the outcome. The opportunity to cycle or walk in Option B also contributes to significant health outcomes for private vehicle users that make the switch, noting there are some minor safety disbenefits.

Table 8. Appraisal results (September 2021 dollars, per average weekday)

Impacts due to	Option A	Option B	Option C	Option D
Reduced demand for driving	$2,864	$2,864	$2,864	$2,864
Increased demand for taxi	$0	$0	-$286	-$286
Induced demand for taxi	$0	$0	$0	-$44
Increased demand for PT	$3,303	$3,303	$2,972	$2,972
Increased demand for cycling	$0	$1,144	$0	$0
Increased demand for walking	$0	$2,273	$0	$0
Total benefits	**$6,166**	**$9,584**	**$5,550**	**$5,506**
Total benefits per user reduced	**$1.10**	**$1.71**	**$0.99**	**$0.98**

Figure 3 illustrates the benefits of the hypothetical MaaS options that were tested in the economic appraisal framework. The figure shows the scale of the active transport benefits in Option B and taxi disbenefits across Options C and D. Overall, all options deliver a net benefit when compared to doing nothing whereby demand for private vehicles remains unchanged.

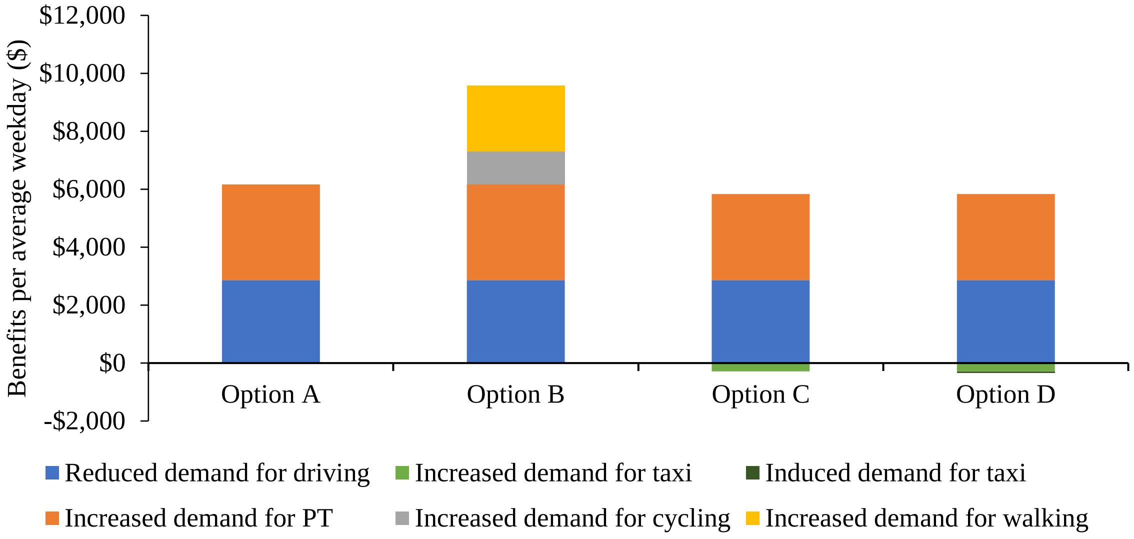

Figure 3. *Benefit profile per option (September 2021 dollars, per average weekday)*

Table 9 provides a breakdown of the economic benefits for Option B which is estimated to deliver the greatest benefits per average weekday on the Great Perth transport network. The mode shifter benefit makes the largest contribution to the total result ($4,746), followed by health benefits for people that cycle and walk ($4,637) and decongestion impacts ($2,651). Safety outcomes and environmental impacts of trains are the largest disbenefits.

Table 9. **Breakdown of benefits for Option B (September 2021 dollars, per average weekday)**

Benefit	**Reduction in driving**	**Increased PT**	**Increased cycling**	**Increased walking**	**Total benefits**
Mode changer benefits	$0	$4,429	$127	$190	**$4,746**
Decongestion impacts	$2,651	$0	$0	$0	**$2,651**
VOC adjustment	-$588	$0	$0	$0	**-$588**
Environmental impacts of cars	$182	$0	$0	$0	**$182**
Environmental impacts of buses	$0	-$229	$0	$0	**-$229**
Environmental impacts of trains	$0	-$897	$0	$0	**-$897**
Safety outcomes	$619	$0	-$981	-$555	**-$917**
Health benefits	$0	$0	$1,999	$2,638	**$4,637**
Total benefits	**$2,864**	**$3,303**	**$1,144**	**$2,273**	**$9,584**
Benefit per reduction in vehicle user	**$0.51**	**$0.59**	**$0.20**	**$0.41**	**$1.71**

4.6 Sensitivity testing

The sensitivity of some modal shift assumptions is tested to account for uncertainty. The original results are shown as the "central case" for comparison. Firstly, the sensitivity of the level of modal shift from driving is tested, which is summarised in Table 10. The options consistently showed significant changes to the appraisal outcome across all options. This indicates that the level of modal shift from driving is one of the key assumptions that drive the outcome.

Table 10. Sensitivity of modal shift assumption (September 2021 dollars, per average weekday)

Sensitivity testing	Option A	Option B	Option C	Option D
Central case (modal shift of 1%)	*$6,166*	*$9,584*	*$5,550*	*$5,506*
Modal shift of 0.5%	$2,531	$4,240	$2,278	$2,233
Modal shift of 2%	$10,125	$16,960	$9,113	$9,068

Second, the sensitivity of the modal split assumption for cycling and walking (for Option B) is tested, which is summarised in Table 11. As shown, this resulted in minimal changes and indicated that the sensitivity to the assumption is minimal.

Table 11. Sensitivity of modal split of cycling and walking (September 2021 dollars, per average weekday)

Sensitivity testing	Option B
Central case (cycling 4% and walking 6%)	*$9,584*
Cycling 6% and walking 4%	$8,295
Cycling 5% and walking 5%	$8,387

Similarly, the sensitivity of the modal split assumption for PT and taxi (for Option C) is tested, which is summarised in Table 12. The results showed significant sensitivity to the assumption.

Table 12. Sensitivity of modal split of PT and taxi (September 2021 dollars, per average weekday)

Sensitivity testing	Option C
Central case (PT 90% and taxi 10%)	*$5,550*
PT 50% and taxi 50%	$2,531
PT 0% and taxi 100%	$0

5. Discussion

In this section, how MaaS schemes that benefit society can be offered is discussed from the long-term impacts and policy perspective. The limitations of this study and future research needs are also identified.

5.1 Maximising the benefits of Mobility-as-a-Service

The appraisal showed that a MaaS scheme that encourages travellers to drive less and instead, use PT, cycle and walk more, will benefit society the most. This reflects cycling and walking accruing to the greatest benefits through a reduction in road network impacts and health outcomes for individuals. While cycling and walking lead to benefits, the MaaS scheme that promotes demand for taxis can reduce the overall benefits due to growth in road network activity and the associated costs. This highlights the need for careful consideration of modal shifts and incentive structures within the MaaS scheme, in order to maximise benefits. Without management, the increased demand for road-based modes can overturn positive appraisal outcomes.

It is also important to highlight that demand for emerging rideshare services, such as Uber, accrues road costs without improving vehicle occupancy rates. From an economic perspective, taxis and rideshare accrue the same road costs and their travel patterns are similar. Therefore, similarly to taxis, the demand for rideshare services needs to be managed.

The appraisal suggested that decongestion benefits are the greatest outcome of a reduction in driving. This suggests a reasonable level of congestion is required on the road network to realise improvements in travel time, a key aspect of decongestion benefits (Australian Transport and Infrastructure Council, 2016b). Simply reducing the number of car trips on an uncongested road network is unlikely to generate strong benefits (i.e. improving operating efficiency that does not result in decongestion).

The appraisal outcome inherently reflected the aim of the MaaS scheme, such as reducing environmental emissions and increasing PT patronage, which can be achieved through a selection of available modes and the incentive assumptions that impact mode choice. The societal objectives and their influence on transport policy decisions and advocacy are key considerations going forward as they will directly inform the development and nature of future MaaS schemes.

Although travel patterns in other cities (i.e. base case) would be different, the benefits per traveller who have changed their travel behaviour would be similar across different locations, as economic parameters do not differ significantly. While detailed economic appraisals should be conducted individually, similar results are expected in other cities. However, the aggregated or city-wide benefits are likely to change as they reflect varying levels of demand and characteristics of the local transport networks.

5.2 Do the benefits of Mobility-as-a-Service substantiate government subsidies?

The literature (Ho et al., 2018; Liljamo et al., 2020) identified that the WTP for MaaS will likely lead to the need for government subsidies for MaaS users. The appraisal demonstrated that without increased demand for cycling and walking, the benefits of MaaS do not substantiate the subsidies. The benefits of cycling and walking resulted in benefits of $5.11 to $6.77 per cyclist/pedestrian increase, which would be substantial enough to support the subsidies.

It is acknowledged that there is a range of costs beyond subsidies, such as MaaS deployment and operation, that are not included in the appraisal. Including costs within the economic appraisal of MaaS is a potential future area of research.

5.3 Appraising Mobility-as-a-Service

Incorporating economic appraisal into the MaaS scheme development process will support policymakers to advocate for its structures and financial incentives that yield the greatest benefits to society. This may include a nuanced and societal-based discussion on how benefits can arise, rather than pursuing the uptake of MaaS without a holistic assessment. For example, circumstances, where the MaaS scheme induces demand for taxi and rideshare services, can negatively impact the road network, despite the modal shift from driving.

A consistent framework of the economic costs and benefits for MaaS will be required to ensure that the appraisal is robust and comparable to other transport initiatives. The establishment of such a framework at a local level may fall within the remit of state-based transport agencies and the Australian Transport Assessment and Planning at the national level. Further research and studies are also important inputs to future frameworks.

This paper provided a simplified economic view of MaaS and did not consider wider impacts, including the impacts on crash risk due to decongestion (as seen in Chee, 2006; Retallack & Ostendorf, 2020). Further work is needed to quantify impacts, such as increased PT crowding and safety implications due to modal shift, financial implications (e.g. farebox revenues) and asset management responses. As identified in the literature review, the benefits and costs of MaaS including those that were not quantified in this paper are summarised as follows which indicate the limitations of this study and future research needs:

- The costs and benefits that were quantified in this paper
  - Decongestion, VOC saving, safety and reduced environmental impacts due to modal shift from driving
  - Health benefits due to increased cycling and walking
  - Crash costs of cycling and walking
  - Environmental impacts of buses and trains
- The costs and benefits that were not quantified in this paper
  - Changes in vehicle occupancy rates
  - Safety implications when congestion is worsened or relieved
  - The financial costs of MaaS schemes (e.g. planning, procurement, delivery and operation costs)
  - Reduced fuel tax and other vehicle-related tax revenues due to reduced driving and/or reduced private vehicle ownership
  - Avoided costs of private vehicle ownership when the ownership is reduced
  - Reduced parking costs and parking space due to reduced driving
  - Increased travel time due to crowding
  - Improved travel time reliability for PT users
  - The costs and benefits due to changes in the utilisation of existing assets and facilities

6. Conclusions

This paper presented an economic appraisal of MaaS by quantifying the benefits of various MaaS options with different modal shift assumptions. It first explored literature to identify the benefits of MaaS. Of those, those that can be are then quantified. These included benefits due to reduced demand for driving and increased demand for cycling, walking and taxi.

The appraisal resulted in three key findings. First, increasing the demand for cycling and walking, and managing the demand for taxi and other mobility services that accrue economic costs similarly to taxis (e.g. Uber) will maximise the benefits of MaaS. Particularly, the benefits per cyclist/pedestrian were considerably higher than the benefits associated with other modes. Encouraging active travel needs to be one of the key objectives of the MaaS scheme to maximise benefits.

Second, the appraisal outcome inherently reflected the aim of the MaaS scheme. Therefore, the societal objectives that inform the policy decisions and advocacy need to directly feed into the development of the MaaS scheme.

Third, without increasing the demand for cycling and walking, the benefits of MaaS do not substantiate government subsidies for MaaS. Further analysis is needed to determine if subsidising MaaS aligns with government policy and delivers the desired benefits or if the private sector should be encouraged to identify a sustainable model.

Applying an economic appraisal framework within the MaaS scheme development process will support policymakers to advocate for its structures and financial incentives that yield the greatest benefits to society. This also encourages the discussion on how benefits can arise, rather than pursuing the uptake of MaaS without a holistic assessment.

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