Transport Modes in MaaS Packages and Their Impacts on Transport Externalities: A Literature Review

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Abstract: Mobility as a Service (MaaS) is becoming popular for solving transportation issues since it supports the integration of several shared transport modes through a single application. Even though this mobility solution is claimed to decrease the use of private cars, car users show less interest in using MaaS. Moreover, they are most interested in using car-sharing in MaaS packages instead of other more environmentally friendly transport modes such as shared micro-mobility services. Therefore, this review paper aims to examine the potential effects of transport modes that are often included in MaaS packages should be investigated. A total of 14 articles investigating the mobility packages are discussed, and information related to the included transport modes is extracted. Based on the findings, several transport modes are assessed regarding their impacts on transport externalities. Based on the findings, ride-hailing has some traffic issues, such as traffic density and the increase in total vehicle-kilometers travelled. The indirect effect of this issue is environmental problems such as CO2 emissions and energy consumption. In general, other transport modes have positive impacts on transport externalities. Finally, future studies could explore the effects of MaaS on transport externalities by using real implementation data.

1. INTRODUCTION

A car-centric paradigm has been the main foundation of the transportation system in cities around the world and is associated with wealth and freedom (Labee et al., 2022; Nikitas, 2018). Nevertheless, apart from the offered benefits, a car-centric paradigm generates more greenhouse gases, air pollution, and problems with road capacity (Labee et al., 2022). Hence, innovative mobility solutions are needed to tackle the problem. Mobility as a Service (MaaS) is claimed to be a service that can tackle negative effects of transportation, such as air pollution and congestion (Jittrapirom et al., 2017). MaaS offers the convenience of using several mobility services and supports multimodal behavior through integration (Polydoropoulou et al., 2020). MaaS is predicted to increase the use of shared mobility services (e.g., bike-sharing, scooter-sharing) and decrease private car use (Matyas & Kamargianni, 2019).

Along with the benefits, MaaS faces some challenges. Car users are proven to have less interest in adopting MaaS (Fioreze et al., 2019). To reach public transportation (PT) services, MaaS offers some transport modes that can be alternatives to the private car, such as taxi, ride-sharing, car-sharing, and bike-sharing (Jittrapirom et al., 2017). However, current car users are mostly not interested in more sustainable shared mobility services (e.g., PT, bike-sharing); instead, they are more likely to use car-sharing and ride-hailing (Farahmand et al., 2021). This condition could be contrary to the expectation of the initial objective of MaaS, since car-sharing and ride-hailing increase the total miles of vehicles, congestion, and air pollution (Henao & Marshall, 2019; Zhou et al., 2020). Therefore, several effects of MaaS should be investigated since not only positive impacts appear, but also negative ones. In past recent years, several works investigating (potential) effects of MaaS have been published. A literature review is needed to synthesize these findings. To the best of our knowledge, there are no previous review papers dealing with the transport modes included in MaaS bundles and their effects on transport externalities.

The aim of this review is to examine which transport modes are frequently included in mobility packages and investigate their impacts on externalities. This is achieved by summarizing the findings from several previously related papers. The remainder of this paper is organized as follows: Section 2 outlines the methodological steps of this research. Section 3 summarizes literature findings on the transport modes included in mobility packages. Section 4 provides the impacts of transport modes on transport externalities. Section 5 presents discussions related to the findings, policy implications, as well as directions for future studies. Finally, a conclusion is presented.

2. METHODOLOGICAL FRAMEWORK

Figure 1 illustrates the method of this literature review. The review starts with collecting the papers. Keywords are identified to help the authors target the relevant articles. Keywords used in the current study are the combination of: (1) public transportation, ride-hailing, car-sharing, and shared micro-mobility and (2) energy, emissions, traffic, and safety. Scopus and Web of Science databases are used to collect the articles. These two databases are widely used because they provide high-quality papers and are considered as best sources of bibliographic data (Baas et al., 2020; Birkle et al., 2020). The current review limits the papers that are written in English and published in peer-reviewed journals. The papers reviewed in this review are screened based on relevance. Firstly, the abstracts are read and assessed to whether they are relevant to the research aims. Second, selected papers are fully read, and relevant contributions are extracted. The timeframe for the review starts from 2010 to July 2022.

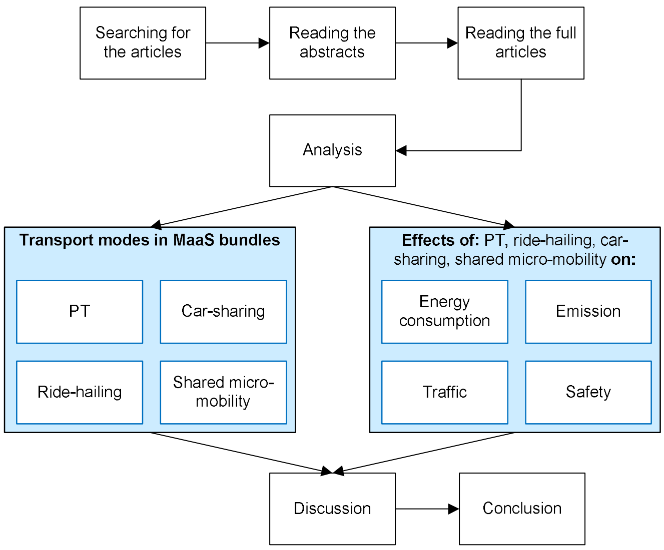

Fig. 1. The methodological framework of review

Some information is extracted after the analysis step: (1) the transport modes that often included in MaaS packages, (2) the effects of several transport modes on transport externalities. Based on the review, transport modes that are frequently included in mobility packages are PT, car-sharing, ride-hailing, and shared micro-mobility. The next part discusses the impacts of the transport modes on transport externalities, such as energy consumption, emissions, traffic, and safety. Then, a discussion and policy implications are drawn. Future research directions are presented, and some main findings are summarised in conclusion.

3. TRANSPORT MODES INCLUDED IN MAAS PACKAGES

Studies investigating the impacts of MaaS on mode share indicate a positive shift to environmentally friendly transport modes. Liljamo et al. (2021) argue that implementing MaaS and automated vehicles could decrease car ownership. Ho et al. (2020) indicate that PT use could be increased thanks to MaaS since people are more interested in MaaS plans containing PT services. Feneri et al. (2020) state that individuals have a higher tendency to choose PT, followed by bike-sharing and car-sharing in their mobility bundles. Increasing travel time and travel cost leads to the decrease in willingness to use bike-sharing. Moreover, Storme et al. (2020) argue that it is easier to reduce car use for commuting trips but not leisure trips. Table 1 shows the transport modes included in the mobility packages based on several studies.

In the case of other shared transport modes, car-sharing is the most common transport mode included in the MaaS bundle. On the one hand, car-sharing can reduce private vehicle usage and ownership, thus encouraging the use of alternative transport modes (Martin et al., 2010). On the other hand, car-sharing can increase traffic congestion, parking congestion, and air pollution (Zhou et al., 2020). The preferences of users regarding car-sharing are somewhat positive (Guidon et al., 2020). Similarly, ride-hailing is also a popular service commonly found in MaaS bundles. On the one hand, ride-hailing can support advanced mobility options, provide convenience, and reduce private vehicle possession (Wang et al., 2021). On the other hand, this service is proven to increase the total miles of vehicles (Henao & Marshall, 2019).

Table 1. A summary of transport modes included in MaaS bundles

Literature	PT	Car-sharing	Ride-hailing	Shared micro-mobility
Ho et al. (2018)	x	x	x	
Matyas and Kamargianni (2019)	x	x	x	x
Ho et al. (2020)	x	x	x	
Caiati et al. (2020)	x	x	x	x
Feneri et al. (2020)	x	x		
Vij et al. (2020)	x	x	x	x
Guidon et al. (2020)	x	x		x
Tsouros et al. (2021)	x	x		x
Ho et al. (2021)	x	x	x	
S. Kim et al. (2021)	x	x		x
Hensher et al. (2021)	x	x	x	
Jang et al. (2020)	x	x	x	x
E. J. Kim et al. (2021)	x	x		
Farahmand et al. (2021)	x	x		x

Surprisingly, more environmentally friendly shared transport modes (e.g., bike-sharing, scooter-sharing) are not really popular to be included in MaaS. To the best of the author's knowledge, only four papers include bike-sharing in their predefined MaaS bundles (Guidon et al., 2020; S. Kim et al., 2021; Tsouros et al., 2021; Vij et al., 2020). In fact, the effect of bike sharing in mobility packages shows mixed results. A study in London finds that bike-sharing is proven to decrease the uptake of MaaS packages (Matyas & Kamargianni, 2019). Respondents negatively value bike-sharing if this service is included in MaaS packages (Guidon et al., 2020). A study in Seoul also finds that bike-sharing is the least popular transport mode in MaaS bundles (S. Kim et al., 2021). However, Tsouros et al. (2021) argue that the presence of bike-sharing has a positive effect on the utility of the packages; but, it is worth noting that in the study, bike-sharing is treated as a dummy variable that only interacts with high-frequency of cycling (i.e. five times a week).

It is worth mentioning that most people tend to include non-environmentally friendly transportation modes in their MaaS bundles (Jang et al., 2020). The study finds that people choose environmentally friendly modes in their mobility packages where the time commitment is longer, and the subscription fee is lower. Thus, the inclusion of particular transport modes in MaaS system should be carefully administered.

4. TRANSPORT MODES' IMPACTS ON TRANSPORT EXTERNALITIES

MaaS is expected to reduce the negative externalities of transportation, such as air pollution, congestion, and excessive space consumption (Jittrapirom et al., 2017). However, in most studies, the reduction in car usage (Feneri et al., 2020; Liljamo et al., 2021) is generally discussed as the effect of MaaS implementation, while the impact on other externalities are not well discussed. Only one study examined the effect of MaaS on reducing emissions (Labee et al., 2022). The study finds that the optimistic scenario could decrease the number of various pollutants from 43% to 54%. Therefore, this section will provide the effects of transport modes that could be highly part of MaaS.

PT is considered the backbone of MaaS (Esztergár-Kiss et al., 2020; Ho et al., 2018) and many research agree that PT can moderate the negative externalities of private car usage. A study in Greater Dublin Area finds that the shift from private cars to PT could reduce the emissions of CO_2, NO_x, and PM25, which could also generate monetary savings (Carroll et al., 2019). Similarly, a study in Kuwait also confirms that the positive impacts of shifting from private cars to PT are the reduction of CO, NO_x, and VOC emissions (AlKheder, 2021). The study also finds a decrease in traffic delay as a result of the increased use of PT. Improving PT service and increasing users' satisfaction with the services could decrease private car usage and reduce traffic congestion and air pollution (L. Zhang et al., 2018). Moreover, a study in India argues that the maximum reduction in CO_2 emissions is attained when PT and non-motorized transport infrastructure are improved (Tiwari et al., 2016). The study also confirms that improving PT and non-motorized transport infrastructure could increase traffic safety. Regarding climate change mitigation, Kwan & Hashim (2016) finds the different approaches between developing and developed countries, where PT is more suitable as a first step for developing countries to tackle the negative externalities of transportation.

Table 2. A summary of transport modes and their impacts on externalities

Literature	Energy consumption	Emissions	Traffic	Safety
PT services				
Tiwari et al. (2016)				+
L. Zhang et al. (2018)		+	+	
Carroll et al. (2019)		+		
AlKheder (2021)		+	+	
Ride-hailing				
Greenwood & Wattal (2015)				+
Dills & Mulholland (2018)				+
Erhardt et al. (2019)			-	
Tirachini (2020)			-	
Car-sharing				
Firnkorn & Müller (2011)		+	+	
Rabbitt & Ghosh (2016)		+		
Nijland & van Meerkerk (2017)		+	+	
Amatuni et al. (2020)		+		
Tsuji et al. (2020)		+		
Akimoto et al. (2022)	+	+		
Shared micro-mobility				
Fishman & Schepers (2016)				+
Brunner et al. (2018)	+			
Y. Zhang & Mi (2018)		+		
Qiu & He (2018)	+	+	+	
Li et al. (2020)	+			
Chen et al. (2020)		+		
Saltykova et al. (2022)	+	+		
Reck et al. (2022)		-		
Fan & Harper (2022)		+	+	

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Ride-hailing is redefining the idea of car access by disengaging it from private car ownership (Alemi et al., 2018). Ride-hailing can be positioned as a complementary service and a substitute for PT (Tirachini, 2020). Ride-hailing is responsible for half of the increase of vehicle-kilometers travelled in San Fransisco between 2010 and 2016 (Erhardt et al., 2019). Similarly, the increase in average vehicle-kilometers travelled is caused by the ride-hailing trip in Santiago (Tirachini & Gomez-Lobo, 2020). The increase in vehicle-kilometers travelled is more likely to lead an increase in traffic congestion, especially if ride-hailing trips are made during peak periods. In San Fransisco, the traffic delay increased by 62% between 2010 and 2016, and the most responsible actors behind the congestion in the city center and the main roads are ride-hailing services (Erhardt et al., 2019). In terms of environmental effect, there is still no clear evidence about the impact of ride-hailing on energy consumption. However, as a result of the increase of vehicle-kilometers travelled, ride-hailing is more likely to cause the increase in greenhouse gas emissions if the case vehicles used are powered by fossil fuels. In terms of reducing car ownership, ride-hailing might decrease energy usage, emissions, and pollutants from car manufacturing. Meanwhile, in the case of traffic safety, studies confirm that ride-hailing could decline the fatal crashes caused by the influence of alcohol (Dills & Mulholland, 2018; Greenwood & Wattal, 2015).

Car-sharing has drawn great attention partly due to its green image (Nijland & van Meerkerk, 2017). Car-sharing could be positioned as a substitute for private car ownership. A study in the Netherlands finds that car-sharing could decline the vehicle-kilometers travelled, as well as CO2 emissions (Nijland & van Meerkerk, 2017). Car-sharing also has potential in terms of travel-related CO2 emission (Amatuni et al., 2020; Tsuji et al., 2020) and increased cost savings (Rabbitt & Ghosh, 2016). Meanwhile, the free-floating car-sharing system could decrease CO2 emissions due to the reduced number of vehicles in the city (Firnkorn & Müller, 2011). Besides reducing CO2 emissions, car-sharing can also increase the share of sustainable modes of transport (e.g., active transport, PT) (Rabbitt & Ghosh, 2016). A recent study, which tries to estimate the impact of autonomous car-sharing, finds that car-sharing could potentially reduce travel-related energy consumption and CO2 emissions (Akimoto et al., 2022)

Meanwhile, micro-mobility services such as bike-sharing and scooter-sharing are undoubtedly promising transport modes to reduce private car use for short-travel distances. These services make PT more accessible since they can substitute long walks to PT stops (Abduljabbar et al., 2021). Bike-sharing has been implemented in major cities around the world and is widely used to serve trips up to 20 km, especially in urban areas (Shaheen et al., 2010). Electric-driven micro-mobility services show the lowest values of fuel consumption compared to passenger cars (Brunner et al., 2018). Bike-sharing is considered a more environmentally friendly mode, especially in terms of reducing energy consumption if suitable strategies are incorporated (Li et al., 2020). Bike-sharing is also claimed to have positive impacts on the environment since it reduces greenhouse gas emissions (Chen et al., 2020; Fan & Harper, 2022; Y. Zhang & Mi, 2018). Besides reducing energy consumption and emissions, bike-sharing also decreases traffic, improves public health, and promotes city economic growth (Qiu & He, 2018). When bike-sharing trips substitute cars, walking, and PT (bus and subway), energy consumption and greenhouse gas emissions are significantly reduced (Saltykova et al., 2022). The congested road also experiences positive improvements since the short private vehicle trips are replaced by micro-mobility (Fan & Harper, 2022). However, in contrast, a study in Zurich finds that e-bike-sharing and e-scooter-sharing produce more CO2 emissions than the transport modes they replace in the short term (Reck et al., 2022). Regarding safety issues, compared to private bike riding, bike-sharing has less risk of fatal and non-fatal bicycle injuries (Fishman & Schepers, 2016).

5. DISCUSSION AND POLICY IMPLICATIONS

The intention of people to include non-environmentally friendly transportation modes should be anticipated by stakeholders. Jang et al. (2020) argue that the early adopters of MaaS are expected to be PT users. The study adds that the adoption of MaaS would be higher if the share of PT is high in the target city. Thus, MaaS operators and related stakeholders could focus the first wave of promotion on regular PT users. Meanwhile, several aims of MaaS are reducing private car usage (Tsouros et al., 2021), and providing a mobility service that can attract car users to shift to more environmentally friendly transport modes (Jang et al., 2020). Therefore, private car users should be included in targeted promotional activities. Farahmand et al. (2021) imply that car-lovers are more inclined to use car-sharing than PT and mostly find MaaS not attractive. To anticipate this issue, MaaS can be promoted as a substitute for the second car in a household (Ho et al., 2020). A free trial could be a good idea to promote MaaS for car-lovers, while the potential reduction of travel cost, energy consumption, and air pollution information can be displayed, as well. Matyas & Kamargianni (2019) imply that people are willing to try transport modes that they never use if their MaaS packages included them. This could be a good opportunity to promote unpopular transport modes (e.g., bike-sharing, scooter-sharing)

In terms of air pollution, several transport modes that are potentially included in MaaS have different effects. As the backbone of MaaS, PT services should be able to provide more environmentally friendly transport modes. It is suggested that PT should use fossil-free and renewable energy to maximise the service's environmental savings. A successful story comes from Sweden, where almost 60% of bus fleets are running on renewable energy in 2014, compared to 8% in 2007 (Xylia & Silveira, 2017). Meanwhile, ride-hailing might produce more air pollution since the vehicle-kilometers travelled increase due to this mobility service. The effect can be alleviated if ride-hailing providers use electric cars, but it is also worth noting that the source of electricity must be from the renewable energy, not from non-renewable sources like coal. A similar policy for ride-hailing can be applied to car-sharing, as well. In the case of bike-sharing and scooter-sharing, even though most studies agree that these services can reduce air pollution, a study by Reck et al. (2022) say otherwise. Thus, Reck et al. (2022) suggest the city administrations require shared micro-mobility providers to improve the main sources of CO2 emissions (vehicle manufacturing and operational services).

The impact of transport modes on traffic conditions is varied. In general, most transport modes that are often included in MaaS package (PT, car-sharing, and shared micro-mobility) could ease traffic congestion unless ride-hailing. Tirachini & Gomez-Lobo (2020) suggest two different approaches to tackle the increased congestion problem of ride-hailing. The first measurement is related to traditional supply restrictions where quotas should be defined. The second mechanism is a more sophisticated approach where the pricing system is based on the congestion conditions of the area. However, the dynamic pricing might be only suitable for a pay-as-you-go scheme since mobility packages mostly use a predefined amount of each mobility service based on some parameters, such as distance, duration, and the number of trips.

In the case of safety, shared micro-mobility services often have safety problems. Most users of the services do not wear safety equipment, such as helmets (Fishman & Schepers, 2016), since incorporating helmets within bike-sharing services is difficult (Fishman et al., 2012). Mandatory helmet regulation might be applied, but the unwillingness to use bike-sharing due to the regulation should be anticipated. There might be some reasons why people are reluctant to wear a shared helmet, such as hygiene and style issues. Safety issues and the unwillingness to wear a helmet can be alleviated by improving the safety of bike lanes, especially lanes with motorized traffic.

Several research gaps are identified in the present review. Most studies use stated choice experiments since a comprehensive implementation of MaaS is not widely available. Future studies could examine the impact of MaaS based on real data of large-scale MaaS implementations. While some studies have examined the effects of MaaS on emissions and mode choice, no studies have investigated the potential effect of MaaS on traffic safety. It is recommended that future research could focus on this issue since MaaS offers a wide range of transport mode options, and even unskilled users can access almost any offered transport modes.

6. CONCLUSIONS

This review paper presents the transport modes that are frequently included in mobility bundles by several pieces of literature and their impacts on transport externalities. Most studies agree that car-sharing and ride-hailing could increase the uptake of MaaS. Meanwhile, despite their capabilities to reduce the negative effects of transportation, shared micro-mobility services show a mixed impact on the uptake of MaaS packages. The results indicate that MaaS could alter individuals' travel behaviour to more environmentally friendly transport modes, since the service most probably decreases private car ownership and increases PT use. However, it is worth noting that private car users tend to use car-sharing in MaaS, and this service has a mixed effect on the environmental aspect. Meanwhile, shared micro-mobility seems not to be the popular choice.

In this study, the environmental effects of MaaS are defined by the effects of transport modes that are usually included in the service. As a backbone of MaaS, PT is mostly considered to have fewer negative impacts on the environment, especially when the services are combined with non-motorized transport modes. In general, shared micro-mobility services have positive effects on transportation externalities. Meanwhile, some studies agree that ride-hailing has negative impacts on environmental aspects.

This study contributes to both policymakers and the literature. This study provides policymakers and MaaS operators with some considerations related to which transport modes should be included in mobility packages. This study also contributes to the literature by investigating some transport modes' potential impacts on transport externalities. Furthermore, this review presents the research gaps that could be further investigated.

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