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Mobility as a Service Inclusion Index (MaaSINI): Evaluation of inclusivity in MaaS systems and policy recommendations

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ABSTRACT

According to UN statistics, the population of people in vulnerable social groups, namely elderly people, people with disabilities, and low-income populations, has increased over the recent decades. It is projected that this trend will continue in the future. Thus, their mobility and access to transport services are important areas to study. Mobility as a Service (MaaS) is a digital platform (smartphone application) that aims to encourage more sustainable travel. MaaS is promoted as being accessible to all user groups. However, there are limited studies linking MaaS with vulnerable social groups and their particular needs. This paper comprehensively reviews studies on the emergence of such platforms since 2014 until today to identify the research gaps with respect to vulnerable social groups. A framework and MaaS Inclusion Index (MaaSINI) are then proposed to evaluate the inclusion in MaaS services, focusing on vulnerable social groups' needs at a service level instead of a city/area level. The framework and policy recommendations proposed in this study will make a significant contribution in guiding stakeholders and policymakers in implementing accessible-for-all-users MaaS services targeting sustainable and inclusive transport.

1. Introduction and background

Transport accessibility and associated mobility of all social groups is an essential and important research topic given the UN sustainable development goal no.11: Inclusive, Safe, Resilient, and Sustainable Transport (United Nations, 2015). To achieve the "transport for all" goal, there should be a specific focus on Vulnerable Social Groups (VSGs). There are different definitions and categorisations for vulnerability of transportation users in the literature (Coleman et al., 2020; Dadashzadeh et al., 2022; Durand et al., 2022; Khayesi, 2020; Pereira et al., 2017; Roorda et al., 2010; Wong et al., 2020; Zhao et al., 2010). Zhao et al. (2010) defined vulnerable transportation groups as elderly, disabled persons, and low-income groups. Roorda et al. (2010) grouped vulnerable transportation users into single-parent families, low-income households, and the elderly and found that these groups faced considerable degrees of social exclusion. In terms of accessibility, in particular to key services, some groups of people have systematically reduced accessibility levels such as the elderly, disabled, ethnic minorities or poor families (Lucas, 2012). Regarding the concerns on disruptive justice and equity (Pereira et al., 2017), argued that accessibility as a human capability should be considered by transport researchers and policy-makers, particularly for elderly and disabled persons. Coleman et al. (2020) evaluated the vulnerability of populations during service disruptions and concluded that low-income families, racial minority groups, and households with younger residents are socially vulnerable groups. Wong et al. (2020) defined vulnerable populations as older adults, individuals with disabilities, low-income households, and non-English (Spanish) speaking households, while evaluating the performance of a carsharing platform in response to a disaster during the California Wildfires. In terms of road safety, vulnerable users are pedestrians and cyclists who are frequently injured or killed in the car-dominant World. While in terms of transport planning, vulnerable users are pedestrians, cyclists, children, the elderly, persons with disabilities (PwDs), and highway-adjacent communities (Khayesi, 2020).

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Vulnerability can be caused by transport poverty as some conventional (e.g. private car) or emerging transportation services (e.g. shared mobility modes) are not affordable for all social groups. For example, low-income people who are a socially disadvantaged population prefer fixed-route transit systems such as the bus rather than ride-hailing and/or mobility-on-demand transit (Wang et al., 2022).

Considering the VSGs definition in the literature above, this research focuses on the following VSGs: i) **Elderly People (ELD)** (aged 65+, including all genders and income levels), ii) Persons with Disabilities (**PwDs)** (including all ages, genders, income levels), and iii) **Low-Income people (LIP) (**all low-income individuals regardless of age, disability, and gender) to have a broader view on equity issues of transportation. VSGs have specific travel behaviour characteristics and needs. For example, elderly people rate personal security particularly highly. In the US, the availability of any non-car modes is a barrier to 1/3 of PwDs, and in Australia PwDs reported feeling socially excluded due to the lack of mobility (Currie et al., 2009; Currie and Delbosc, 2011; Fatima et al., 2020; Field and Jette, 2007; US DoT, 2017).

1.1. Smart mobility and digital inequality in transportation

As the need to change mobility patterns towards sustainable transport modes has increased, Information Communication Technology (ICT) applications such as mobility apps have gradually become very popular (Antoniou et al., 2018, 2019; Antoniou et al., 2019; Shaheen et al., 2013). These apps can greatly affect the mobility and travel choices/experiences of all social groups (Gössling, 2018; Thomopoulos et al., 2015). Mobility apps aggregate mobility options and travel information (timetables, etc.) as well as optimise routes to make travel easy (Shaheen et al., 2015). However, they may create a form of transport disadvantage and digital inequality (vulnerable to digitalisation) in transport services if everyone is not willing or able to use them (Durand et al., 2022). In this regard, Fig. 1 shows three main themes namely digitalisation, social exclusion, mobility, and three sub-themes including digital inequality, digitalisation in transport services, and transport disadvantage.

Smartphones can provide PwDs, in particular those who are visually impaired, with more equal access to transport services (Locke et al., 2020). ICTs can also empower the mobility and travel of elderly and/or disabled people as a navigation tool (Heinonen and Siira, 2016; Siira and Heinonen, 2015) by providing the following alerts: user is walking in the wrong direction, missed stop while travelling by Public Transport (PT), missed PT vehicle while waiting for the transport at a stop, GPS signal lost on tunnels or metro, and mobile data connection lost (message sent to relatives). However, some elderly people have difficulties in using smartphones due to the digital divide, financial limitations, visual impairments, and lack of interest and knowledge in using technological devices and their advanced functions (Williams et al., 2015; Caiati et al., 2020b). Sourbati and Behrendt (2020) studied converging trends in ageing, digitalisation and datafication in the UK, and the rise of data-driven policy-making, and its potential impacts on mobility provision for elderly people. They found that there is a significant gap in mobility data of elderly people available to policy makers. Loos et al. (2020) developed a justice-informed perspective and a so-called "mobility digital ecosystem" framework for older people's ICT capability in relation to the role of the urban environment (technologies and systems of transport/communications). It is suggested that further studies should ideally take into consideration mobility practices, digital data, digital networks, material geographies, digital devices and access to services, rather than only focusing on one of them. Digital platforms-based transportation services may be a barrier to use for elderly people (Wang, 2019). Some VSGs are more PC versions of the platforms rather than smartphones, and smart cards (virtual ticket) (Kamargianni et al., 2015). PwDs are faced with difficulties in booking accessible vehicles through a uniform mobile-based vehicle reservation system, restrictions on cross-regional journeys, and the absence of assessment systems. To address these limitations, Wu et al. (2020) proposed a social business model, and a mobile-based barrier-free platform for PwDs for using RehaBus (government rehabilitation bus services) in Taiwan. This platform serves PwDs by offering diverse transportation options, however its effectiveness has not been measured.

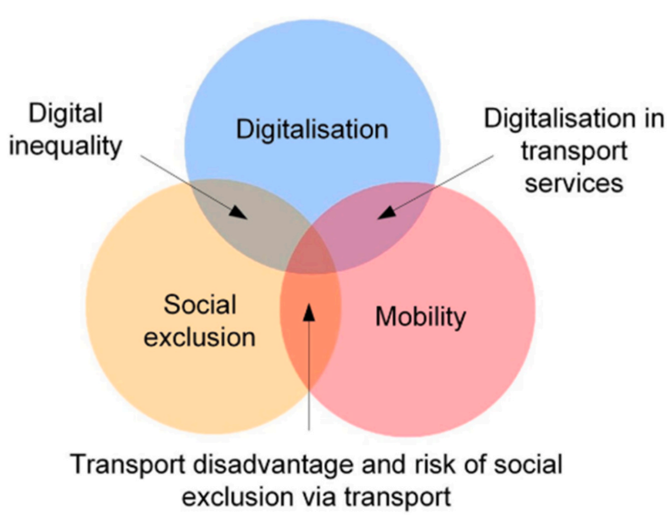

Fig. 1. Intersection of transport services, digitalisation, and social exclusion (Source: Durand et al., 2022).

1.2. Mobility as a service (MaaS) system

The Mobility as a Service (MaaS) concept is a digital platform introduced by Heikkilä and Hietanen (2014) to integrate on-demand shared mobility modes with PT services via a single smartphone application for registration, booking, and payment. MaaS consists of the following steps: registration and package selection (similar to telecommunication or media service packages), journey planning, booking, on-boarding, and payment (Kamargianni et al., 2015). Registration and core package payment have to be done once, while package selection can be modified over time to better match the user needs (Matyas and Kamargianni, 2017, 2019a). Based on users' characteristics and registration information such as age, driving licence possession, and health condition (with/without disability), there can be different MaaS bundle designs as follows:

- People with a driving licence, and no physical/cognitive disabilities can be offered mobility plans that include both car-share and PT modes.
- People that do not have a driving licence can be offered mobility plans that contain no car-share options.
- PwDs (physical or cognitive difficulty) preventing them from using PT can be offered mobility plans excluding PT, in case there is no access to PT for PwDs.
- Current mobility tool ownership: if users have a bike, scooter, car, or wheelchair, MaaS plans can offer "park and ride" or "park and pool" options. This allows the users to travel the first-mile of the trip by their own vehicle and then continue the rest of their journey using other modes (Rijavec et al., 2020).
- Some MaaS providers have already provided reduced-price packages such as a student package. However, LIP who rely on affordable transportation modes like PT should also be considered during the package design. Then, in the bundle configuration, users can choose which transportation modes should be included into the bundle based on their socio-demographic and transportation-related characteristics. These factors have a significant impact on the intention to subscribe to MaaS (Caiati et al., 2020a, 2020b).

Matyas and Kamargianni (2021) found that age, gender, income, education and current travel behaviour all play an essential role in determining an individual's propensity to purchase MaaS packages. Although MaaS is supposed to offer potential benefits for sustainable transportation development identified by existing studies, some questions still remain (Pangbourne et al., 2020), particularly linked with equity issues: How will MaaS fit with the increasing number of VSGs living in urban and rural areas? Will addressing the barriers to MaaS for VSGs cause a cultural shift from personal car ownership towards MaaS?

Relying on the MaaS to improve mobility and accessibility of individuals may create some equity issues which have received limited attention to date within the transport policy and practice field (Martens, 2017; Thomopoulos et al., 2015). Equity, here, is referred to as providing an inclusive MaaS platform, considering all end-users' needs, and their physical and sociodemographic characteristics.

The aim of this study is to propose a framework and an index to evaluate the inclusion level of MaaS in order to address the research gap related to VSGs and the equity challenges. The remainder of the paper is structured as follows: Section 2 describes the systematic literature review method conducted to select existing MaaS documents focusing on VSGs needs. Section 3 presents a critical review of MaaS studies. Considering research gaps identified in the existing MaaS, Section 4 proposes a new framework and MaaS Inclusion Index that enables practitioners and policy makers to achieve an inclusive MaaS service with respect to VSGs' needs and challenges. Lastly, Section 5 concludes the findings of this study, and proposes policy recommendations and some directions for further studies.

2. Research method

To identify the research gaps regarding VSGs, a systematic literature review has been conducted on the MaaS studies between 2014 and 2021. The selection of the articles for the literature review follows a Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol (Moher et al., 2009) that has been used in similar transport reviews (Thomopoulos et al., 2021). Google Scholar (in English) has been used to get the most relevant publications as it is a superset of Web of Science and Scopus databases as well as being able to include all citations to a publication better than other databases (Martín-Martín et al., 2018). The following expressions were used to create three queries. Boolean AND has been used between two sets of keywords as shown below:

- Mobility as a Service MaaS AND elderly,
- Mobility as a Service MaaS AND disability,
- Mobility as a Service MaaS AND low-income.

Furthermore, publication type and year were also used as search filters. Publication type was set to: journal papers, book chapters, conference abstracts and papers, book reviews, and mini reviews; and publication year was set to 2014–2021. Titles, abstracts, and keywords of the identified publications were screened. Then, forward and backward snowball review techniques were used to check the eligibility of screened documents. Fig. 2 shows the PRISMA method applied to the MaaS studies considering the key words mentioned above.

As an output of the PRISMA method, 38 MaaS-focused publications were considered for full-text review. Some studies have only focused on one specific group, while others include all three main themes. For more information on the focus of the selected papers on VSGs, please see Appendix, Table A1. Europe, with 32 studies on MaaS [mostly from Sweden and Finland (18), UK (9), other EU countries (5)] has the highest number of studies which is followed by Asia and Oceania [Australia (5) and China (1)], and North America (2 studies from US). Then, these studies were grouped into two main categories to be reviewed critically in the section below: I) supply-side studies which focus on the MaaS from an operator, provider, or policy maker perspective, and II) demand-side studies which to understand the attitudes of people towards joining MaaS.

3. MaaS and VSGs: supply and demand sides' highlights

The MaaS app benefits both supply and demand sides of transportation services. On the supply side, the MaaS app benefits transport service providers with a new sales channel and payment management, and dynamic travel demand data of potential users. On the demand side, the MaaS app provides users with single or multimodal journey planning by facilitating booking and payment.

3.1. Supply side perspective; government, service provider, and operator roles

There are observational studies regarding acceptance and willingness of the government, and transport service providers and operators to provide MaaS services (Jittrapirom et al., 2020; Kamargianni and Matyas, 2017; Lajas and Macário, 2020; Mulley et al., 2017, 2018, 2020; Wong et al., 2020). Although some of them present limited information about VSGs, they have not directly studied MaaS service implementation for VSGs. The Governments have a vital role in the implementation of MaaS that can influence urban mobility and the daily lives of citizens (Saud and Thomopoulos, 2021). Therefore, it is crucial to understand, design, and deploy a coherent and effective policy framework for MaaS. Although a government agency or quasi-government entity (including a PT authority) can play the broker role (Kamargianni and Matyas, 2017), transport operators are the preferred service integrator, followed by a

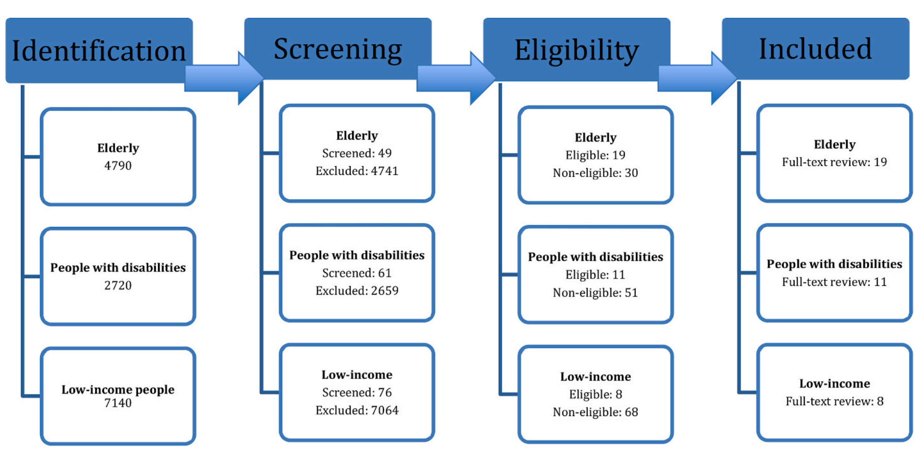

Fig. 2. PRISMA steps for MaaS article selection.

third-party mobility provider (Jittrapirom et al., 2020). Polydoropoulou et al. (2020a) determined three key actors in a MaaS partnership: mobility service providers, PT authorities, and regional authorities. In the exploration of dialogues with potential bidders in West Sweden, it was found that seven aspects are important to be considered by potential bidders when procuring MaaS: cross-sector collaboration, allocation of responsibilities, governance, business models, target groups, service design and technical integration (Smith et al., 2017). For example, how an end-user's data is used, who is eligible to resell PT tickets and ensure that services account for people with physical and cognitive disabilities. Lajas and Macário (2020) developed a MaaS public policy framework and argued that using MaaS, as a mobility management tool, requires PT to be redefined including its financing. Recently, a government-contracted model for MaaS was proposed by Wong et al. (2020) to maximise urban efficiency considering societal equilibrium. This model consists of road pricing based MaaS packages that consider the time of the day, geography, modal efficiency (both spatial and temporal), environmental impacts, and subsidies (means-tested for social inclusion). Mulley et al. (2017) examined the potential of MaaS to provide equitable transport services; so-called Community Transport (CT), for medical-based trips of elderly people in Australia. The interviews of CEOs of five Australian CT operators found that the CTs are enthusiastic about offering MaaS packages to their existing users and to non-users/new users (Mulley et al., 2018). Although CT operators received a block grant to offer a subsidy per trip to their client group of vulnerable users, they recommend that public subsidies are better when given directly to users instead of operators (Mulley et al., 2020). CTs promised to give adaptive transport services to VSGs through MaaS. CT services can improve the mobility for low-income populations and/or for people living in rural areas or suburbs, as these users can easily subscribe to one of the offered MaaS models that best meets their needs. Considering the benefits for the societies, CTs can be supported financially by the government to lower costs for VSGs (Mulley et al., 2018).

3.2. Demand side perspective; MaaS users and non-MaaS users

The public acceptance and willingness to subscribe and pay for MaaS bundles have been studied by several scholars (Durand and Harms, 2018; Ho et al., 2020, 2018; Matyas, 2020; Matyas and Kamargianni, 2019a, 2017; Polydoropoulou et al., 2020c; Ratilainen, 2017; Vij et al., 2020; Zijlstra et al., 2020); however, they have not directly focused on VSGs and relevant equity issues. In the Netherlands (Ratilainen, 2017), it was found that: a) MaaS subscription plans with unlimited PT were more attractive for potential users; b) Elderly people were likely to join MaaS if off-peak travel discounts were offered to them; and c) MaaS bundle price was important for price-sensitive users like young individuals and low-income people. Zijlstra et al. (2020) developed a Latent Demand for MaaS Index (LDMI) using five denominators of MaaS: innovative, tech-savvy, travel information need, multimodal mindset, and freedom of choice. Results show that a) Older adults aged 75+ and retirees had strong negative coefficients in all five dimensions of the LDMI; b) Older adults who never fly, live in rural areas, take few trips per week, and who have poor health, will never be MaaS adopters; and c) Early MaaS adopters are young people, active, healthy, frequent users of trains and airplanes, highly mobile, have a high socio-economic status, have high levels of education, and high incomes. Naturally, such findings are based on the studies conducted before the COVID-19 pandemic, so further research is required to assess contemporary WTP and any changes since.

According to the results of a survey in the Netherlands, younger generations (Generation Z, Millennials) are more likely to be early MaaS adopters, whereas Baby Boomers and the so-called Silent Generation are more likely to be followers or non-MaaS adopters (Caiati et al., 2020a). Additionally, it was found that car ownership rates among older adults is higher than young millennials. Caiati et al. (2020a) found that life stage and car ownership are critical determinants of MaaS adoption, meaning that young participants are more likely than older adults to subscribe to MaaS. Therefore, MaaS might be a convenient solution for young millennials that do not own a car compared to older adults that own a car. People living on their own, both millennials and older generations, or people from older cohorts living with other family members and owning at least one car might find MaaS to be a better solution to travel, probably as an alternative to car ownership. Caiati et al. (2020b) found that the price of the monthly subscription and the social influence variables have important impacts on the subscription intention for all user groups. In addition, PT plays a crucial role in the MaaS platform as the most preferred transportation mode. Among participants, 26.8% are aged 51–65 and 13.9% are 65 years old and more. Participants aged 50+ are most willing to use traditional transportation modes such as PT in their customised MaaS bundle; however younger generations (aged between 25 and 35 years old) are less interested in PT. Polydoropoulou et al. (2020a) also found that young people and professionals were identified as the main users of MaaS in Manchester and Budapest. In Budapest older people were also identified as MaaS users. Pangbourne et al. (2020) developed a new model for accessing and questioning MaaS in terms of the unanticipated societal implications (wellbeing, emissions and social inclusion) and challenges for urban governance. Matyas et al. (Matyas, 2020; Matyas and Kamargianni, 2017, 2019a, 2019b) explored users' preferences towards subscription on MaaS plans in the UK. They categorised MaaS potential users into three classes including: Class 1, MaaS plans avoiders (52%); Class 2, MaaS plan explorers (23%) which were more likely to be a bike user; and Class 3, MaaS plan enthusiasts (25%). Kamargianni and Matyas (2017, 2018) findings' are summarised below:

- There is heterogeneity in users' attitudes on MaaS plans based on their socio-demographic characteristics and travel habits. Less expensive plans including PT and bike sharing modes can attract students, retired individuals, middle-income people who are more price sensitive. While more expensive plans including taxi and car sharing modes in addition to PT, can attract younger, male, well-educated individuals.
- Elderly people, low income people, and those who are not using any transport modes or use only one mode are least likely to use MaaS plans, while young age (20s and 30) are most likely to subscribe to MaaS plans.
- Impact assessment on "*whether London residents would delay buying a car or not at all if they had MaaS*" shows that MaaS has showed positive impact on the younger generations aged under 30, while MaaS has showed minor positive impacts on elderly aged 50+ (lowest among all age groups) and PwDs travellers. One of the reasons elderly individuals find MaaS difficult and complicated is using smartphones (see Section 1). Although this study argued that MaaS can assign a specific vehicle for PwDs, there is no concrete evidence how this service can be implemented.

Results of a survey with 4000 participants in Australia showed that full-time employed young people are early adopters of MaaS, while retired elderly people and elderly who do not live with their children are least likely to adopt MaaS (Vij et al., 2020). MaaS has become popular in Chinese cities as well. A small and car-dependent town in the suburbs of Shanghai with 314 households and 600 residents was selected in a survey by Ye et al. (2020). They proposed some strategies for the promotion and application of MaaS and argued that different services can be launched for different groups such as providing customised MaaS travel packages for middle-aged, elderly people and minors, making more detailed tutorials for people without membership experience, and inviting free experiences. Ho et al. (2020, 2018) argued that the lack of information and data collection bias in surveys are the challenges faced by the MaaS studies. To address this data collection bias, they asked participants to watch a 2-min introductory video about the MaaS concept and its potential benefits before starting the survey and found that:

- In Sydney, Australia (Ho et al., 2018): for a sample size of 252 participants with the average age of 39 years (standard deviation of 14 years), 50% of participants are willing to take one of MaaS plans. Infrequent car users or no-car users are the most likely MaaS adopters. Participants are willing to pay $6.40 on average for an hour of access to car-share with one-way car-share, and $5.90 per day which is much lower than the current daily cap ($15) for unlimited use of PT.
- In Tyneside, UK (Ho et al., 2020): for a sample size of 290 participants with the average age of 49 (standard deviation of 17 years), participants aged 55+; so-called older adults are less likely to take MaaS plans.

However, neither this video nor other MaaS introductory videos, which are publicly available, provide residents with information on potential benefits for VSGs. In simpler terms, VSGs might have different answers to survey questions if they had sufficient knowledge of the potential of MaaS for improving their mobility. Table 1 presents a summary of existing studies on VSGs.

The survey results on Table 1 have shown that VSGs are not early adopters of MaaS. This is due to the fact that VSGs have different needs and challenges to use transportation services and technologies (Battarra et al., 2018; Gössling, 2018; Vergnani, 2018). These needs include access to the following:

- VSGs-friendly MaaS app in terms of size and/or colour of texts, size and/or colour of icons, etc. for the people with visual and/or hearing impairments;
- Real-time information, such as crowding and seat availability in PT services;
- Real-time navigation information (access route and time, station locations, waiting time in stations) while transferring in multi-modal journeys;
- Customised (e.g., wheelchair-accessible) transportation services for the people with mobility impairments;
- Subsidised mobility packages/bundles or Pay-As-You-Go (PAYG) options based on income levels.

4. MaaS Inclusion Index (MaaSINI) and Inclusive MaaS Services

Kamargianni et al. (2016a) proposed a MaaS Maturity Index (MMI) to assess how mature and ready cities/areas are to incorporate MaaS services considering availability and density of transport modes. However, the MaaS maturity index does not explicitly consider the following:

1. Parking data and its integration to MaaS platform,
2. User-friendliness and accessibility of MaaS platforms for VSGs,
3. Accessibility of transport modes offered by MaaS bundles for VSGs,
4. Customised journey planning considering accessibility,
5. Customised mobility packages/bundles considering socio-demographic characteristics.

Therefore, to address these limitations, this paper proposes "MaaS Inclusion Index: MaaSINI" to consider MaaS platforms' capabilities to provide these services for elderly people, people with disabilities, and low-income people. The MMI (Kamargianni et al., 2016a) is useful, but has been developed for a different purpose to that of the MaaSINI. The MaaSINI evaluates the MaaS at a service level instead of city/area level, which is considered by MMI. The MaaSINI focuses on a service level, because the service level provides greater granularity than the city level. The MaaSINI can thus be used to assess the individual mobility services that VSGs use, instead of looking at a city as a generic entity.

To this end, a general framework for scoring the inclusivity of MaaS services is proposed to include accessible transport services, accessibility data and data sharing, and an accessible platform. Fig. 3 shows the proposed framework for measuring MaaSINI. The suggested framework thus consists of the following three main categories: (i) Accessible transport services (ii) Accessibility data and data sharing, and (iii) Accessible platform.

The following formulas are proposed to quantify the accessibility issues of the framework shown on Fig. 3. Accessible Transport Index (*ATI*) (equation (1)) measures the accessibility of transport service (i) and vulnerability type (j) resulting in a score (T_{ij}). The Accessible Data Index (*ADI*) (equation (2)) checks whether the infrastructure accessibility data (D_I) of each transport service (e.g., wheelchair accessibility of buses or trains) is collected by service providers/operators and can be shared with the MaaS developer or not. This study does not measure the general data accessibility of low-income people, due to the lack of access to smartphones or internet. Accessible Platform Index (*API*) (equation (3)) indicates whether the MaaS platform is accessible for VGSs in terms

Table 1
Findings on "MaaS and VSGs".

VSGs	Findings	Study area & Source
Elderly	Early adopters of MaaS are the younger generation, while elderly are less likely to adopt.	Netherlands (Zijlstra et al., 2020)
Elderly	Demand responsive transportation is popular among older users who have a better appreciation of seating arrangement.	Finland, Sweden (Finger and Audouin, 2019)
Elderly	Elderly are less likely to subscribe to MaaS than other age groups. They are more likely to include PT in their MaaS bundle than younger generations.	The Netherlands (Caiati et al., 2020b)
PwDs	Information on the disabilities of the travellers need to be registered in the subscription of the MaaS package. Disability is a factor of mode choice in the MaaS and it is crucial to exclude certain modes (e.g., excluding car-sharing).	UK (Kamargianni et al., 2015)
PwDs	Relevance of framing MaaS in order to make sure that services account for PwDs and the use of user data to propose a personalised travel suitable for PwDs.	Sweden (Smith et al., 2017)
PwDs	MaaS will enhance the accessibility of PwDs transport users because MaaS can assign special vehicles to this population group.	UK (Kamargianni et al., 2018)
PwDs	Being less likely to use private cars or PT and having more reliance on ride-hailing, MaaS represents opportunities for PwDs as ridesharing and taxi services can be more affordable as part of MaaS.	Worldwide (Utriainen and Pöllänen, 2018)
Low-income	As LIPs are less likely to own a car, they represent an interesting target group for MaaS providers. However, LIPs tend to spend less money on their travel habits. The challenge is then to generate sufficient revenue with LIPs and ensure a comprehensive transportation service that meets LIP's needs.	Finland (Pöllänen et al., 2017)
Low-income	LIPs and people with high incomes are likely to use MaaS, while people with very low incomes and people with average incomes are less likely to use MaaS. People with a very low income and people with average income are more likely to include car sharing in their bundle.	The Netherlands (Caiati et al., 2020b)
Low-income	Importance to have fair framing and regulation in order to ensure the accessibility for every social user groups including LIPs. LIPs have historically been less likely to use mobility on demand services. Mobility on demand presents a potential way to expand mobility in underserved neighbourhoods. The requirement to own a smartphone to access those services can be a barrier to access mobility on demand for LIPs.	US (Shaheen and Cohen, 2020a)

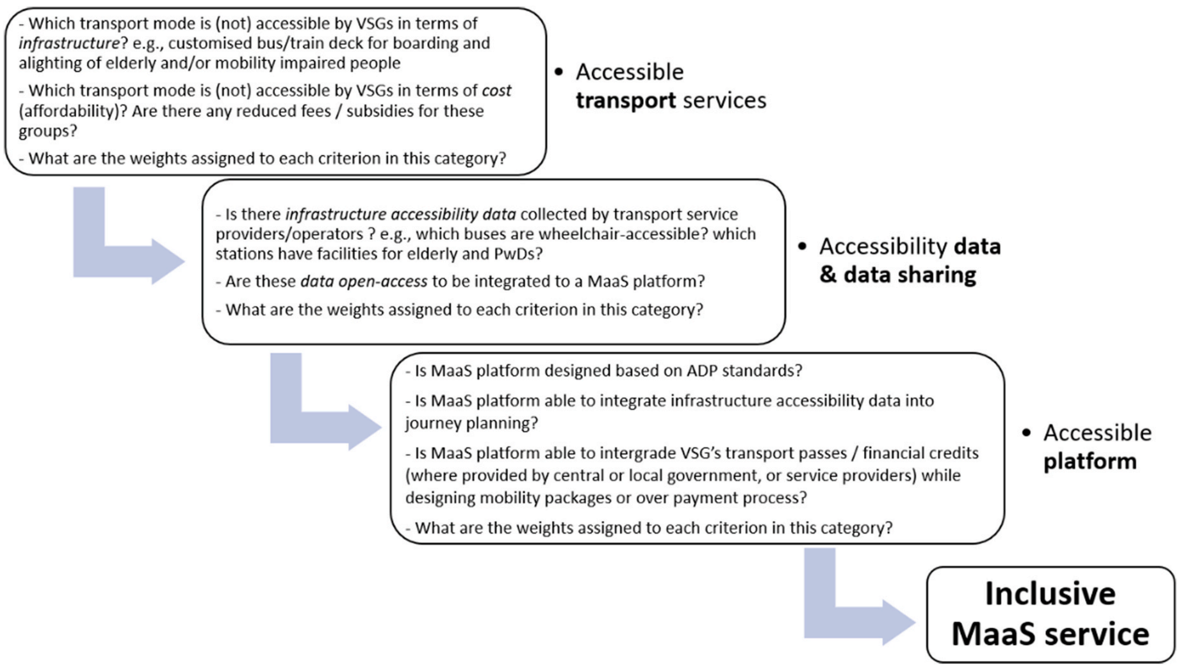

Fig. 3. Proposed framework for the MaaSINI.

of inclusive design criteria (P_k) e.g., accessibility of MaaS for people with visual impairment, customised journey planning (integrating accessibility data into the platform), and customised mobility bundles/payment (ability to use financial credit/vouchers, where provided by government for VSGs).

$$ATI = \sum_{j=1}^{J}\sum_{i=1}^{I}(\alpha_i.T_{ij}) \times 100 \tag{1}$$

$$ADI = \sum_{l=1}^{L}(\beta_l.D_l) \times 100\ D_l > 0 otherwise \tag{2}$$

$$API = \sum_{k=1}^{K}(\gamma_k.P_k) \times 100\ P_k > 0 otherwise \tag{3}$$

$$MaaSINI = \mu_1.ATI + \mu_2.ADI + \mu_3.API \quad ATI, ADI, API > 0 otherwise \tag{4}$$

where:

$$ATI = \left(\frac{[(\alpha_1.T_{11} + \alpha_2.T_{21} + \alpha_3.T_{31} + \alpha_4.T_{41} + \alpha_5.T_{51} + \alpha_6.T_{61}) + (\alpha_1.T_{12} + \alpha_2.T_{22} + \alpha_3.T_{32} + \alpha_4.T_{42} + \alpha_5.T_{52} + \alpha_6.T_{62})]}{2}\right) \times 100 \tag{5}$$

- α, β, γ, μ are the weights allocated to each criterion depending on the priority given.
- i is the index of transportation services, e.g. if there are five transport modes available, then $i = 1,2,..,5$.
- j is the type of vulnerability which can be type = 1; mobility impairments (elderly people, PwDs, pregnant females, etc.), or type = 2; affordability (low-income people). For instance, if carsharing ($i = 1$) is accessible for low-income people in terms of physical access ($j = 1$), then $T_{11} = 1$. However, if carsharing is not affordable ($j = 2$) for low-income people, then $T_{12} = 0$.
- l is the index of ADI elements, e.g. if there are two criteria, then $l = 1$ and 2.
- k is the index of API elements, e.g. if there are three criteria, then $k = 1$, 2, and 3.
- ATI, ADI, and API are the weighted average of scores given to each criterion.

To have a thorough understanding of the application of the proposed MaaSINI framework, we have evaluated as an example the inclusivity of a real-World MaaS service, the Sydney MaaS trial (Hensher et al., 2021; SkedGo, 2021), and four alternative MaaS services for different scenarios (i.e. combination of scores and weights) which are shown in Table 2. In Sydney, there are lots of transportation services, such as bus, tram, carsharing, taxi, and ride hailing. If, for example, there are two ATI elements [physical accessibility to transport services (bike, bus, tram, carsharing, taxi, multimodal), and affordability of those transport services], two ADI elements (data collection, data sharing), and three API elements (inclusive design, customised journey planning, and customised payment options). Then:

$$ADI = (\beta_1.DC + \beta_2.DSH) \times 100 \tag{6}$$

$$API = (\gamma_1.InD + \gamma_2.CJP + \gamma_3.CPay) \times 100 \tag{7}$$

$$MaaSINI = (\mu_1.ATI + \mu_2.ADI + \mu_3.API) \times 100 \tag{8}$$

where:

- T_{ij}: Transport service i and vulnerability type j, here: I = 6 (i = 1 to 6), and J = 2 (j = 1 and 2).
- DC: accessibility data collection, DSH: Data sharing availability.

Table 2
MaaS Inclusion Index (MaaSINI) calculation for MaaS services.

MaaS Service		Accessible Transport Services							Accessibility Data			Accessible Platform				MaaSINI
		Micro	B	Rail	CSH	T/RH	MM	ATI	DC	DSH	ADI	InD	CJP	CPay	API	
1	Weight	0.1	0.2	0.2	0.1	0.1	0.3	0.6	0.5	0.5	0.1	0.33	0.33	0.33	0.3	**58%**
	Accessibility score	0	1	0.5	0	0.5	0.5	50%	0.5	0.5	50%	0.5	1	0.5	66%	
	Affordability score	0.5	1	1	0	0	0.5	60%	–	–		–	–	–		
2	Weight	0.1	0.2	0.2	0.1	0.1	0.3	0.6	0.5	0.5	0.1	0.33	0.33	0.33	0.3	**68%**
	Accessibility score	0	1	0.5	0	0.5	0.5	50%	0.5	0.5	50%	1	1	1	100%	
	Affordability score	0.5	1	1	0	0	0.5	60%	–	–		–	–	–		
3	Weight	0.1	0.2	0.2	0.1	0.1	0.3	0.6	0.5	0.5	0.1	0.33	0.33	0.33	0.3	**38%**
	Accessibility score	0	1	0.5	0	0.5	0.5	50%	0.5	0.5	50%	0	0	0	0%	
	Affordability score	0.5	1	1	0	0	0.5	60%	–	–		–	–	–		
4	Weight	0.1	0.2	0.2	0.1	0.1	0.3	0.6	0.5	0.5	0.1	0.33	0.33	0.33	0.3	**63%**
	Accessibility score	0	1	0.5	0	0.5	0.5	50%	1	1	100%	0.5	1	0.5	66%	
	Affordability score	0.5	1	1	0	0	0.5	60%	–	–		–	–	–		
5	Weight	0.1	0.2	0.2	0.1	0.1	0.3	0.6	0.5	0.5	0.1	0.33	0.33	0.33	0.3	**65%**
	Accessibility score	1	1	1	1	1	1	100%	0.5	0.5	50%	0	0	0	0%	
	Affordability score	1	1	1	1	1	1	100%	–	–		–	–	–		

- Micro: Bike, B: Bus, Rail: Tram, CSH: Car sharing, RH: Ride hailing (Uber.), MM: Multimodal Journey.
- *InD*: Inclusive Design, *CJP*: Customised Journey Planning, *CPay*: Customised payment options.
- α, β, γ, μ are the weights allocated to each criterion depending on the priority given.

Weights (α, β, γ, μ) can get any value between 0 and 1 depending on the importance of the elements for practitioners and policy makers in evaluating inclusivity of the MaaS. For instance, one could assume that MaaS should offer the best multimodal journeys to users so that multimodal journeys in *ATI* should get the higher weight (0.3) compared to single-mode journeys, which is followed by the public transport modes such as bus (0.2) and tram (0.2). Therefore, the weight α (weight of each transport service in *ATI*) is assumed to be 0.1, 0.2, 0.2, 0.1, 0.1, 0.3 for bike, bus, tram, carsharing, taxi, and multimodal, respectively. The weight β is assumed to be equally 0.5 for both data collection and data sharing. The weight γ is assumed 0.33 for all *API* elements. The share of *ATI, ADI*, and *API* in MaaSINI is assumed to be equal ($\mu = 0.33$). The scores can only be 0 (not accessible/affordable), 0.5 (partly accessible/affordable), and 1 (fully accessible/affordable). For instance, if one of the transport services is fully accessible/affordable for VSGs, it is associated with a value of "1", otherwise it might be assigned a "0" or "0.5" depending on its accessibility/affordability level. In the Sydney example (see Table 2, MaaS service no. 1 to 4), *ATI* elements have different accessibility/affordability scores for each transport mode. For example, carsharing is neither accessible (for example for wheelchair users) nor affordable (for example for low-income people) so that get a score of 0, while rail transport is affordable (affordability score = 1), but not fully accessible (accessibility score = 0.5). As seen in Table 2, MaaS service 1: Sydney MaaS platform (TripGo) is considered fully accessible in terms of providing customised journey planning (it has high-level setting options for users), however partly accessible in terms of inclusive digital platform (menus, icons, fonts), and customised payment options (there is no way to incorporate vouchers if provided by the government). We keep *ATI* and *ADI* as they are in the MaaS service 1, however make some sensitivity analysis on *API* elements. Therefore, we have created an example MaaS service 2 (fully accessible digital platform), and MaaS service 3 (not accessible digital platform) to show how the accessibility of the digital platform can influence the inclusivity of a MaaS service. Based on the calculated MaaSINI, MaaS service 2 is 10% more inclusive and MaaS service 3 is 20% less inclusive compared to MaaS service 1 (Sydney MaaS trial). In MaaS services 4 and 5, we keep *API* elements as they are in MaaS service 1, then we improve the *ADI* and *ATI* elements, respectively, in order to show their influence in MaaSINI. This comparison helps digital platform developers and policy makers to quantify how changes in the various elements influence the inclusivity of the MaaS service. For example, the user can realise the impact of giving reduced prices (subsidies/vouchers) to some transport services to make them affordable or of the increase of the accessibility of vehicles for mobility impaired people and/or investments on data collection, data sharing or accessibility of MaaS digital platform.

Clearly, the choice of weights could have an impact on the final results. It is good practice to perform a sensitivity analysis, using different candidate values for the considered weights. Based on the various outcomes, the stability of the results should be evaluated. For example, if the same ranking of alternative systems is maintained even when the values of the weights change, then the analyst can be rather comfortable with the conclusions that can be drawn from this analysis. If, on the other hand, small changes in the weights' values result in changes in the outcome, then caution should be exercised.

5. Conclusion and policy recommendations

MaaS has a strong potential to enhance sustainable transport services for all users. Yet such aspirations can only be achieved if all transport users benefit through an inclusive mobility service, regardless of their socio-economic status, such as gender, age, or (dis)ability. Such an approach would improve accessibility to employment opportunities, training and education facilities, healthcare services, and recreational activities both for commuting and non-commuting travel (Alyavina et al., 2020; Nikitas et al., 2017; Polydoropoulou et al., 2020b; Thomopoulos et al., 2021). Not considering the needs of specific user groups, in this case VSGs, will have a negative impact on MaaS adoption, since a similar trend has been found by studies on autonomous vehicles (Kyriakidis et al., 2020; Polydoropoulou et al., 2021). Therefore:

- This research highlights the importance of addressing the needs of VSGs.
- Moreover, it highlights the need for further studies to incorporate equity in transport policy evaluation and policy implication, particularly focusing on the distinction between different types and principles of equity, such as equality of opportunity or equality of outcome (Martens, 2017; Thomopoulos et al., 2015; van Wee and Geurs, 2011).
- MaaS affordability is another key issue highlighted within this research, which is directly linked with Sustainable Development Goal no. 11 (United Nations, 2015) and can be facilitated through VSGs subsidies for mobility services. In deregulated jurisdictions, where subsidies are less common, providing the incentive for operators to engage on MaaS schemes can be challenging, let alone ensuring that the MaaS offers are affordable and inclusive services.
- Technology development and acceptance of new services are key concerns for practitioners and policy makers. However, the lack of

attention to VSGs' accessibility to digital mobility services has been highlighted through this research. Martens et al. (2021) stressed the need for inclusive transport services and this can only be achieved by addressing the digital divide.
- Despite MaaS providers claiming its potential for VSGs, there is no concrete evidence that MaaS services are designed to be used by all people. Considering barriers for VSGs to the uptake of the MaaS, the MaaSINI proposed in this research enables practitioners to consider the accessibility issues while designing and developing a MaaS system. The general framework proposed in this study quantifies the inclusivity of MaaS system in terms of accessible transport services, accessibility data and data sharing, and an accessible platform. This framework and index helps policy makers in selecting and implementing a MaaS platform for all users.

It is found in this research that there is no study exploring the effectiveness of MaaS on mode choice and mobility patterns of VSGs through an accessibility lens. Advanced stated choice techniques should be further used to examine and model the travel behaviour of the elderly people, PwDs, and low-income people in the presence of inclusive MaaS services. Future research should also focus on testing diverse mobility packages to assess the Willingness to Pay (WTP) and respective business models for new mobility services promoting both sustainability and equity considering VSGs' needs. Having acknowledged the difficulty in satisfying such competing demands within existing business models (Section 3), this research offers insight to mobility suppliers about potential profits by focusing on VSGs and whether any government subsidies are essential, which could be facilitated through Public Private Partnerships (PPPs). Furthermore, more research is required about efficient business models, particularly regarding their relationship to PPPs and subsidies for mobility services. Equally, the use of flexible weights (see Section 4) to reflect policy priorities is an area, which needs to be tested in practice to enhance integrated transport policy and planning. As a limitation of this research work, it is worth mentioning that the framework presented is not totally validated and depends on the experience of the user.

Although not within the scope of this research, it should be noted that there are several barriers to the implementation of MaaS in different national and regional regulatory contexts. This research describes only the ability of a MaaS app to address inequity and proposes a method of measuring this. However, the recommendations proposed in this research to the policy makers and practitioners is nuanced and needs to reflect the regulatory frameworks within which MaaS platforms are developed. In highly regulated systems, with direct public ownership and/or control of operations, MaaS may be developed either in-house, or in partnership with a commercial MaaS platform provider. In more deregulated and private contexts, the role of policy makers may be to broker agreements on ticket integration and data sharing that might require financial incentivisation from public funds in the formation of the MaaS. In both scenarios presented here, it is proposed that policymakers use the index provided here to either evaluate bids supplied by MaaS operators, or to set clear minimum scores that all bidders would be expected to meet in order to be considered as partners in the MaaS platform development. In areas where there are existing MaaS systems, developed and controlled by municipalities, it is suggested here that the MaaS index could be used as an auditing tool to determine the current performance of the system in serving VSGs, to identify areas for improvement and to set targets/goals for future index scores.

Overall, this research work has demonstrated that attention to VSGs should evolve hand in hand with technological advancements to enhance sustainable (economic, environmental and social) development.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this research.

Data availability

No data was used for the research described in the article.

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Appendix

Table A1 summarise the MaaS studies which are directly or indirectly related to VSGs and ICTs. The column entitled "# of Cita" shows the number of citations of each article. The last four columns show whether the corresponding study has information regarding low-income population (LIP), elderly people (ELD), PwDs, and ICTs or not, in which "●" sign means there is evidence from the study, "○" sign means there is some evidence from other studies and mentioned in this study, and "-" sign means there is no evidence.

Table A1
Selected MaaS studies and VSGs' information available (ranked based on number of citations obtained from Google Scholar on 24/01/2022).

#	Title	Source	Study Area	Pub. Year	# of Cita.	LIP	ELD	PwDs	ICTs
1	Mobility as a service: a critical review of definitions, assessments of schemes, and key challenges	Jittrapirom et al. (2017)	Worldwide	2017	564	○	–	–	○
2	A critical review of new mobility services for urban transport	Kamargianni et al. (2016b)	Worldwide	2016	431	–	–	–	○
3	'Mobility as a service' – the new transport model?	Hietanen (2014)	Finland	2014	302	–	–	–	○
4		Hensher (2017)	Australia	2017	290	–	●	○	–

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Table A1 (*continued*)

#	Title	Source	Study Area	Pub. Year	# of Cita.	LIP	ELD	PwDs	ICTs
	Future bus transport contracts under a mobility as a service (MaaS) regime in the digital age: are they likely to change?								
5	The business ecosystem of mobility-as-a-service	Kamargianni and Matyas (2017)	UK	2017	226	–	–	–	●
6	Mobility as a service – a proposal for action for the public administration: case Helsinki	Heikkilä (2014)	Finland	2014	189	–	●	○	–
7	A topological approach to mobility as a service: a proposed tool for understanding requirements and effects, and for aiding the integration of societal goals	Sochor et al. (2018)	Sweden	2017	179	–	–	–	●
8	Trying out mobility as a service: experiences from a field trial and implications for understanding demand	Sochor et al. (2016)	Sweden	2016	172	–	–	–	●
9	Mobility as a service (MaaS): challenges of implementation and policy required	Li and Voege (2017)	N.A.	2017	171	–	○	–	–
10	Implementing mobility as a service: challenges in integrating user, commercial, and societal perspectives	Sochor et al. (2015a)	Sweden	2015	170	–	–	–	●
11	Developing the 'service' in mobility as a service: experiences from a field trial of an innovative travel brokerage	Karlsson et al. (2016)	Sweden	2016	155	–	–	–	●
12	Potential uptake and willingness – to –pay for mobility as a service (MaaS): a stated choice study	Ho et al. (2018)	Australia	2018	151	–	●	●	–
13	Mobility as a Services (MaaS) – does it have critical mass?	Mulley (2017)	Australia	2017	145	–	●	–	–
14	Questioning mobility as a service: unanticipated implications for society and governance	Pangbourne et al. (2020)	N.A.	2020	133	○	○	○	–
15	The potential of mobility as a Service bundles as a mobility management tool	Matyas and Kamargianni (2019a)	UK	2018	129	●	–	–	–
16	Review on mobility as a service in scientific publications	Utriainen and Pöllänen (2018)	Worldwide	2018	117	–	–	○	○
17	Trying on change - trialability as a change moderator for sustainable travel behaviour	Strömberg et al. (2016)	Sweden	2016	101	–	–	–	○
18	Community transport meets mobility as a service: on the road to a new a flexible future	Mulley et al. (2018)	Australia	2018	93	–	●	●	○
19	Mobility as a service: comparing developments in Sweden and Finland	Smith et al. (2018)	Sweden Finland	2018	84	–	–	–	●
20	Prototype business models for mobility-as-a-service	Polydoropoulou et al. (2020b)	Budapest, Manchester Luxembourg	2020	74	–	●	–	–
21	Bundling, pricing schemes and extra features preferences for mobility as a service: sequential portfolio choice experiment	Caiati et al. (2020b)	Netherlands	2020	72	●	●	–	●
22	Travellers' motives for adopting a new, innovative travel service: insights from the UBIGO field operational test in Gothenburg, Sweden	Sochor et al. (2014)	Sweden	2014	64	–	–	–	●
23	An innovative mobility service to facilitate changes in travel behaviour and mode choice	Sochor et al. (2015b)	Sweden	2015	62	–	–	–	○
24	Mobility as a service-MaaS: describing the framework	Holmberg et al. (2016)	Europe	2016	61	–	–	–	●
25	Inviting travellers to the smorgasbord of sustainable urban transport: evidence from a MaaS field trial	Strömberg et al. (2018)	Sweden	2018	61	–	–	–	●
26	Londoners' attitudes towards car-ownership and mobility-as-a-service: impact assessment and opportunities that lie ahead	Kamargianni et al. (2018)	UK	2018	59	–	●	●	–
27	The Ws of MaaS: understanding mobility as a service from literature review	Arias-Molinares and García-Palomares (2020)	Worldwide	2020	50	○	○	○	○
28	Conceptualizing mobility as a service: a user centric view on key issues of mobility services	Giesecke et al. (2016)	Finland	2016	42	–	●	●	●
29	The impact of mobility as a service concept to land use in Finnish context	Rantasila (2016)	Finland	2016	41	–	–	–	○
30	Mobility as a service in community transport in Australia: Can it provide a sustainable future?	Mulley et al. (2020)	Australia	2020	39	–	●	–	–
31	Mobility as a service: exploring the opportunity for mobility as a service in the UK	Catapult (2016)	UK	2016	35	–	–	–	●
32	Governing mobility as a service: insights from Sweden and Finland	Finger and Audouin (2019)	Sweden Finland	2018	33	–	○	○	○
33	A comprehensive review of "mobility as a service systems	Kamargianni et al. (2016a)	Worldwide	2016	32	–	–	–	●
34	Modelling the effect of mobility-as-a-service on mode choice decisions	Feneri et al. (2020)	Netherlands	2020	31	–	●	–	–
35	A study on users' willingness to accept mobility as a service based on UTAUT model	Ye et al. (2020)	China	2020	31	–	●	–	–
36	Procuring mobility as a service: exploring dialogues with potential bidders in west Sweden	Smith et al. (2017)	Sweden	2017	30	–	–	●	–
37	Demand responsive transport: generation of activity patterns from mobile phone network data to support the operation of new mobility services	Franco et al. (2020)	UK	2020	28	–	–	–	●
38	The added value of a new, innovative travel service: insights from the ubigo field operational test in Gothenburg, Sweden	Sochor et al. (2015d)	Sweden	2014	24	–	–	–	●
39	Challenges in integrating user, commercial, and societal perspectives in an innovative mobility service	Sochor et al. (2015c)	Sweden	2015	25	–	–	–	●
40	A stated preference experiments for mobility-as-a-service plans	Matyas and Kamargianni (2017)	UK	2017	20	–	–	●	–

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Table A1 (*continued*)

#	Title	Source	Study Area	Pub. Year	# of Cita.	LIP	ELD	PwDs	ICTs
41	Challenges in the paradigm change from mobility as a self-service to mobility as a service	Pöllänen et al. (2017)	Finland	2017	7	●	–	–	–
42	Investigating heterogeneity in preferences for mobility-as-a-service plans through a latent class choice model	Matyas and Kamargianni (2021)	UK	2021	7	–	●	–	●
43	Feasibility study for MaaS as a concept in London	Kamargianni et al. (2015)	UK	2015	6	○	○	○	●
44	Who benefits from mobility as a service? A GIS-based investigation of the population served by four ride-pooling schemes in Hamburg, Germany	Raub (2020)	Germany	2020	6	–	●	–	–
45	Mobility as a service for the older population: a transport solution to land use changes in essential services?	Mulley et al. (2017)	Australia	2017	4	–	○	–	●
46	Investigating the interconnectedness of active transportation and public transit usage as a primer for mobility-as-a-service adoption and deployment	Biehl and Stathopoulos (2020)	US	2020	4	–	–	–	○
47	Investigating individual preferences for new mobility services: the case of "mobility as a service" products	Matyas (2020)	UK	2020	3	–	–	–	●
48	Mobility on demand in the United States	Shaheen and Cohen (2020)	US	2020	2	●	–	–	●
49	Mobility-as-a-service (MaaS) business model and its role in a smart city	Jian-Xing et al. (2019)	N.A.	2020	–	○	–	–	●

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