Cities 154 (2024) 105360

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Socially Sustainable Mobility as a Service (MaaS): A practical MCDM framework to evaluate accessibility and inclusivity with application

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ARTICLE INFO

Keywords:
Sustainable mobility
Mobility as a service
Accessible MaaS
Inclusive MaaS
Sustainable transport
Accessible transport
Social inclusion
Transport equity

ABSTRACT

Promoting socially sustainable mobility services for all social groups is one of the key elements for sustainable development according to the UN's sustainable development goals. Mobility as a Service (MaaS), a rapidly growing smart mobility concept, has the potential to achieve this goal. However, measuring societal impacts of MaaS considering vulnerable social groups' (elderly, disabled, low-income people) needs is still a question for scholars, practitioners, and policy makers. This paper presents a practical 3-stage framework to evaluate the accessibility and inclusion of MaaS systems based on a range of indicators, and a multi-criteria decision making (MCDM) method. A worldwide experts' view survey was conducted among transportation academics and practitioners with 105 valid responses to prioritise the main and sub-criteria in proving an accessible and inclusive MaaS system. The results of MCDM analysis show that accessible transport services, accessible MaaS platforms, and accessibility data collection have a share of 51 %, 29 %, and 20 %, respectively. The functionality of the proposed framework has been illustrated on a real-world multi-city MaaS implementation within the Solent area, in particular Portsmouth city located in Southeast England (UK). The policy recommendations proposed in this study shed light on guiding stakeholders and policymakers to select and implement an accessible and inclusive MaaS system.

1. Introduction and background

Providing residents with socially sustainable mobility, recognizing barriers to access, and implementing necessary measures for enhancement pose a common challenge for many cities in the context of sustainable development. In this paper, we advance the field of evaluation for Mobility as a Service (MaaS) by addressing the gap in practice and knowledge of social equity and inclusion in relation to MaaS, which is often framed as improving access to transport. Transport-related social exclusion can lead to unemployment, lower educational attainment, and progressive detachment from services including health (Chatterjee et al., 2019; Motability, 2022). Improving accessibility and inclusivity of transportation services is a win-win deal for both users and governments and is compatible with the UN Sustainable Development Goals, which highlight the importance of accessible and affordable transport, multimodality, integrated transport services and intelligent transport systems (United Nations, 2015).

This strategic alignment in transportation underscores the broader societal and environmental objectives, when considering the issues faced by socially excluded individuals who have challenges with mobility (i.e. people with reduced mobility). In the past, access to a private car was seen as an indicator of higher mobility and reduced risk of social exclusion, but maintaining access to a car can cause significant economic stress (Mattioli, 2017). Consequently, with climate change and targets towards Net Zero, relying on private car ownership is not a good solution for widening access to mobility and reducing the risk of social exclusion. Transport poverty is determined by various factors such as income, vehicle ownership, distance to public transport (PT), distance to public services, physical or mental disability and age. This explains the importance of recognizing transport poverty as a multi-dimensional problem and a result of different socio-economic factors (Ranchordás, 2020), enabling access to all transport modes in affordable, efficient, equitable and sustainable ways is needed for inclusive mobility (United Nations, 2015). It is also shown that social groups have different mobility patterns at an aggregate level (Shi & Yeh, 2023).

In this paper, we adopt the term Vulnerable Social Groups (VSGs) to

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https://doi.org/10.1016/j.cities.2024.105360
Received 1 March 2024; Received in revised form 12 July 2024; Accepted 5 August 2024
Available online 20 August 2024

describe those vulnerable to facets of transport poverty for various reasons, including being elderly, disabled or on a low income. Our aim is to improve mobility for all, including VSGs, as this is key for sustainable development (Dadashzadeh, Larimian, et al., 2022; UK KTN, 2023; United Nations, 2015). According to Motability (2022), the annual economic benefit of improving transport accessibility for the UK was estimated to be around £72.4 bn including improved well-being of individuals (£43.4 bn), access to employment (£28.9 bn), and access to education (£0.11 bn).

Mobility as a Service is an Information and Communication Technology (ICT) enabled concept that provides a personalised and real-time journey planning and payment across various forms of transport in a convenient and compelling way (Kamargianni et al., 2016). By aiming to provide user-friendly, seamless access to a wider range of mobility services, it is thought that MaaS can, directly and indirectly, help to decrease the risk of social exclusion caused by the lack of mobility and transport poverty. MaaS has also gained a lot of attention for its potential to improve sustainability by changing individual travel behaviour towards more sustainable modes (Alyavina et al., 2020; Butler et al., 2021; Dadashzadeh, Bliemer, et al., 2022; Kamargianni et al., 2016).

Although MaaS proponents make grand promises about efficiency, choice, and freedom, Pangbourne et al. (2020, 2018) questioned the capability of MaaS in terms of its real benefits for societies and governments regarding key issues such as well-being, emissions, and inclusiveness for a range of vulnerable social groups. Overall, it is not entirely clear what the causal pathway is by which MaaS can deliver the claimed benefits. Firstly, since ICT-based innovations assume that individuals have access to the internet, own a smartphone or a tablet, are digitally literate and can afford public or private transportation, such innovations are not always sufficiently inclusive (Ranchordás, 2020). Secondly, poor digital platform designs that neglect the needs of VSGs can lead to slow adoption and lower uptake of digital tools. Kolotouchkina et al. (2022) emphasised the necessity of standardising digital access and examining the needs of VSGs for a humane, livable, and inspiring transformation of cities. However, >20 % of UK customers' needs are not fully met for digital products, and even basic web accessibility standards are only met by <1 % of website homepages (Inviqa, 2020). Therefore, smart mobility innovations may exacerbate the exclusion of certain users by increasing the so-called 'digital divide' or digital inequality with unwanted negative impacts on both the platforms' accessibility and the accessibility of the overall transport system.

In the case of MaaS, as an ICT-centric concept, having a certain level of digital literacy is required by the MaaS users. To develop a more robust approach to evaluating the inclusivity of MaaS, we need to include digital literacy factors. Potential MaaS users can be divided into two groups in terms of digital literacy: I) Digitally Literate people (those who have access to digital platforms and know how to use them for example for planning a journey, booking, and payment); and II) Digitally Illiterate people (those who do not have access or ability to use digital platforms for journey planning, booking, payment, and mostly rely on non-digital channels such as phone number based services). Furthermore, there is a digital divide in relation to making payments online. For example, in the UK 4 % of the population has no access to a bank account (the so-called 'unbanked') (Merchant Machine (2021)). Given that having access to a bank card is necessary for online payment, we can also group potential MaaS users into two further groups - those who have a bank card and are willing and able to make an online payment, and those who prefer or need to rely on cash or in-person payment. Fig. 1 shows different types of potential MaaS users, demonstrating various intersectionalities, including between digital literacy and banking access. For the purposes of this paper, we are not accounting for those in non-vulnerable social groups (NVSGs) who have bank cards but who choose not to use online payments.

Measurement of performance using indicators is widely considered to be essential for a thorough and objective post-hoc evaluation (the degree to which something (a policy, an intervention, a system) has met important objectives). Indicators of performance are also important tools in the ongoing monitoring of progress towards goals and targets that deliver the goals. Targets can be expressed in terms of inputs, outputs, or outcomes (Marsden & Bonsall, 2006). The literature on measuring performance and designing indicators covers an enormous range of fields and utilises an eclectic range of terminology. For example, the study of performance evaluation for PT dates back at least to the 1970s (Phillips, 2004), and a full review is outside the scope of this paper.

In the context of MaaS, some studies proposed indicators to assess/evaluate some aspects of the MaaS (Eckhardt et al., 2020, Smith & Hensher, 2020, Pham et al., 2021, Richardson et al., 2022, Nikolaidou et al., 2023) or proposed maturity/readiness or inclusion indices regarding MaaS (Aba & Esztergár-Kiss, 2024; Corazza & Carassiti, 2021; Dadashzadeh, Woods, et al., 2022; Goulding & Kamargiannia, 2018). These studies are discussed in brief in Section 2. However, to the best of the researcher's knowledge, there are no studies that identify indicators to specifically evaluate the MaaS concept in relation to inclusivity and accessibility for VSGs. To address this research gap, we explore the following research questions:

- What does it mean for a MaaS project to be accessible and inclusive for all social groups, in particular VSGs?
- What are the main criteria and subcriteria and their weights in improving the accessibility and inclusivity of MaaS?

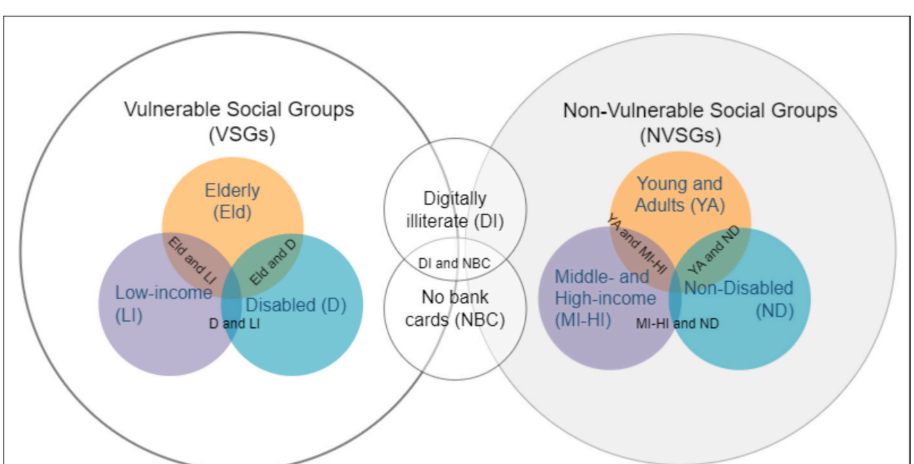

Fig. 1. Categorization of potential users of MaaS in terms of vulnerability determinants.

- Which indicators can be considered to evaluate the inclusivity and accessibility of a MaaS project?
- How does the proposed set of indicators work in a demo case for Portsmouth, UK?

The novelty and contribution of this work to the transport literature is twofold. First, the paper proposes a conceptual framework based on Multi Criteria Decision Making (MCDM) method to determine the weights of criteria and subcriteria regarding accessibility and inclusivity of MaaS. Second, it advances the knowledge of how the public sector and policymakers can enhance the inclusivity and accessibility of MaaS projects considering a set of indicators proposed and tested using a real-world MaaS project. The aforementioned indicator-based assessment framework has been tested in the context of the MaaS project currently running in the city of Portsmouth, as part of a wider MaaS project (Solent MaaS, UK).

The rest of the paper is organised as follows: Section 2 presents the practical indicators developed to measure the inclusivity and accessibility of MaaS systems, followed by Section 3 which describes the data collection and data analysis framework based on the MCDM approach. Section 4 demonstrates a case study analysis to test the functionality of the proposed framework and indicators in evaluating the inclusivity of MaaS systems and discusses the findings of the scenario analysis. Finally, Section 5 presents the research findings, proposes recommendations for policy implications, and some future directions.

2. MaaS accessibility and inclusion indicators

To develop the list of accessibility and inclusivity indicators proposed in this study, we drew on existing typologies, indicators and indices in the context of the MaaS, and other transport studies, amending where necessary to align with our research objectives. If necessary, we used judgement and literature to create new indicators, if one did not exist.

For example, Sochor et al. (2018) proposed a topology consisting of MaaS Levels 0 to 4 where level 4 is the integration of societal goals. From the societal (or policy) perspective, the aspects considered were the effect of MaaS on private car ownership and use (congestion and emissions), sustainable accessibility, urban planning and, in the long term, a city's attractiveness and liveability, management of traffic and mobility, attitudes and awareness, equitable access (social and geographical), innovation, employment. Eckhardt et al. (2020) conducted an impact assessment of MaaS pilots spanning individual/user (incl. perceived accessibility to transport), business/organisational (including data sharing), and societal levels (incl. Citizens' accessibility to transport services). In this study, accessibility is defined as access to the nearest services, not physical accessibility (usability) of transport services. Smith and Hensher (2020) developed a framework for analysing MaaS policy programs and demonstrated how it can be applied mostly on at Strategic, Tactical, Operational, Reflexive levels. Pham et al. (2021) conducted a literature review on interactions between stakeholders through accessibility Indicators under MaaS context and found that there are limitations in integrating psychological indicators (Flexibility, comfort, safety, usefulness, and perceived new physical indicators) and dynamic pricing into the existing models. However, there is no recommendation on how this integration can be implemented or evaluated. Richardson et al. (2022) proposed indicators only for MaaS digital platform useability and other elements of MaaS were not considered. Nikolaidou et al. (2023) proposed a standardised methodological approach with a range of innovative Key Performance Indicators (KPIs) for the assessment of an eMaaS scheme. The proposed KPIs refer to the evaluation of the scheme based on four pillars: (a) society, (b) users, (c) operators, and (d) internal operation.

In terms of MaaS maturity and readiness index, Goulding and Kamargiannia (2018) proposed the MaaS Maturity Index that measures a city's readiness for MaaS implementation based on characteristics across five dimensions: 1. Transport operators data sharing and openness, 2. Citizen familiarity and willingness, 3. Policy, regulation and legislation, 4. ICT infrastructure, and 5. Transport services and Infrastructure. Corazza and Carassiti (2021) investigated the maturity requirements to operate MaaS with a case study in Rome and determined additional barriers to implement MaaS strictly related to its social acceptance, rather than to its technical viability, for which the city is mature. Aba and Esztergár-Kiss (2024) also proposed a MaaS readiness index and considered the maturity of a region regarding smart mobility solutions including technology, business, and competition aspects. However, there is no consideration of inclusivity and accessibility of MaaS for vulnerable social groups' needs. Dadashzadeh, Woods, et al. (2022) comprehensively reviewed the VSGs needs in the context of MaaS, proposing a MaaS Inclusion Index (MaaSINI) to evaluate the accessibility and inclusivity of MaaS systems as shown in Fig. 2. Functionality of the proposed MaaSINI index showcased for a hypothetical MaaS.

In the MaaSINI framework, μ is the weight allocated to each criterion depending on the priority given, and ATI, ADI, and API are the weighted average of scores given to each criterion, as seen in Fig. 2. However, how the weights (μ) of the criteria should be calculated was not clarified. In addition, subcriteria and indicators to assess inclusivity and accessibility were not proposed. We addressed these limitations by proposing a conceptual framework for calculating the weights and a scoring approach for a set of practical indicators (see Section 3), and by illustrating its functionality in a real MaaS study (see Section 4).

It is important to note that this study does not aim to evaluate accessibility in terms of access to places. In this paper, we use the terms accessibility and inclusivity to refer to the inclusiveness of transport infrastructure (vehicles, stations, routes), information about that, and features of the MaaS platform that enable it to be used by all social groups with particular emphasis on VSGs (e.g. elderly people, people with disabilities, and low-income groups). The principles of universal design consist of equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance of error, low physical error, and size and space for approach and use (FIA, 2021). Reinforcing accessibility standards assists in the identification of the indicators for a robust evaluation of sustainable mobility systems. The indicators proposed in this study are also linked with the universal design principles which are modified for the MaaS concept and aim to facilitate the evaluation of accessibility and inclusivity of MaaS by identifying the points relevant for VSGs.

2.1. Accessible and inclusive transport services

MaaS concept promises to provide alternatives to the private car by presenting combinations of all available modes across active transport, PT, and shared mobility modes. However, some of these transport alternatives operate to different standards of accessibility and affordability, which is not generally transparently addressed in MaaS platforms, leaving users to judge for themselves whether the proposed journey is suitable for their needs. For example, the rise of shared mobility modes such as e-bike and e-scooter hire in cities introduces a range of additional challenges resulting in conflicts between different categories of users of urban mobility space, particularly for certain VSGs (UK KTN, 2023).

PT is often referred to as being the backbone of MaaS (UITP, 2019). This should be good for VSGs. Almost a third of the adult UK population do not have personal car access and are reliant on PT. This lack of car access is more common among unemployed people and those with low incomes (Chatterjee et al., 2019). Therefore, accessible, and inclusive PT services are important for these people. Social inclusion in EU PT (Samek Lodovici & Torchio, 2015) report suggests that to ensure the accessibility for PT, all stages of a journey (i.e. walking between modes, transfers, waiting times) need to be improved for reach and use of VSGs. On the other hand, active transportation namely walking, wheeling, and

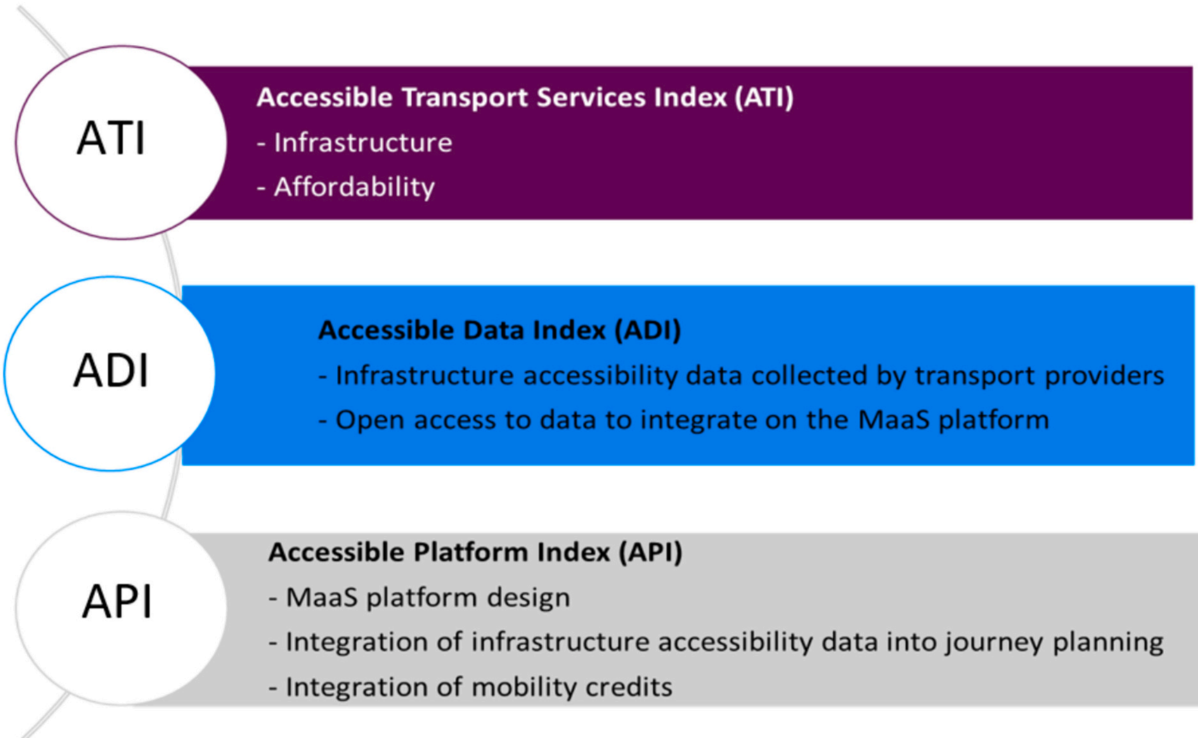

Fig. 2. The MaaS Inclusion Index (MaaSINI), adopted from Dadashzadeh, Woods, et al. (2022).

cycling should be the most accessible and inclusive means of transport (Sustrans, 2023). Additionally, to ensure a higher usage of passengers using PT, the fares need to be affordable to all income classes (Serebrisky et al., 2009). Therefore, apart from the indicators that represent the universal design, the affordability of the commercially available smart mobility solutions needs to be investigated for the low-income, low-educated, and other socially marginalised VSGs. Therefore, as part of assessing accessibility to transport services in a more holistic manner, the affordability of the available transport modes in the area should be considered.

In this study, to evaluate the accessibility of the transport services for VSGs, a set of indicators is proposed for the following sub-criteria (for a full list of indicators, see Appendix Table A4). The indicators are designed in a way that these factors are evaluated per transport mode for all VSGs.

- Route accessibility - wheelchair-friendly, walking-friendly, and cycling-friendly routes/sidewalks/crossings with enough footway width.
- Vehicle accessibility - vehicles with ergonomic designs for all, designated seats for people with disabilities, inclusive screens, and an announcement information system.
- Station accessibility - stations and stops with waiting areas with designated seats for people with disabilities, an inclusive screen and announcement information system, step-free access, and lighting.
- Accessible assistance - MaaS trained staff help passengers who need personal assistance with routing, delays, disruptions, transfers, tickets, payments, boarding, and alighting at stops/stations and vehicles.
- Affordability - subsidised travel costs (vouchers, PT passes) provided by the government or local authorities for VSGs.

2.2. Accessibility data collection and sharing

Transport data including transport services, infrastructure, and travel patterns of individuals plays a crucial role for the transport services providers and operators to improve and adapt their services based on the users' needs. However, there should be standards and guidelines for central governments, local authorities, and other stakeholders on how transport data should be collected and shared (make it anonymized and publicly open) (CIHT, 2023; DfT, 2023). For instance, one of the important features of MaaS which differs from the conventional journey planning platforms, is to provide a higher level of information to the users which can support them for making informed choices towards the seamless travel for their journeys. MaaS platforms should be able to give access to real-time information about the incidents, delays, and congestion that affect the roadway, PT and micromobility networks so that the users can use this information when planning their journeys (Murati, 2020).

Although the information mentioned above is needed for a well-designed and well-functioning MaaS, they are not sufficient for an inclusive and accessible MaaS system. Nicklas et al. (2015) suggest that the integration of intelligent transportation systems with smart technologies can facilitate barrier-free mobility for all individuals, including those with limited mobility or sensory limitations. Based on their study, this integration requires the following three key aspects: (i) real-time passenger information, (ii) specific representation of passenger information for various disability situations, and (iii) travel assistance functions that provide added value to passengers with reduced mobility. In another study, Melis et al. (2018) developed the Smart Mobility for All (SMAll) prototype, focusing on presenting information tailored to diverse user needs through case studies.

Considering these studies, it is obvious that an inclusive and accessible MaaS system requires data on the accessibility status of the transport infrastructure and vehicles. This data should be collected by the service operators/providers, and it should be shared with MaaS platform developers to integrate into the MaaS platforms. The data includes, but is not limited to wheelchair access, tactile pavement, accessible lifts, hearing aids facilities, braille-based text and map, existence of audio/visual message system, crowding levels (number of passengers at stations and vehicles), zebra crossings, audible traffic lights, steps and stairs, etc. In this study, to evaluate the transport accessibility data collection and sharing for VSGs, a set of indicators are proposed for the following sub-criteria (for full list of indicators, see Appendix Table A4).

- Routes accessibility data collection & sharing
- Stations accessibility data collection & sharing
- Vehicles accessibility data collection & sharing
- Real time journey data collection & sharing

2.3. Accessible and inclusive MaaS platforms

One of the disadvantages of the digitalisation of transport services is that it causes the exclusion of users lacking a certain level of digital literacy (Durand et al., 2023, 2022; Ranchordás, 2020). That is why it is crucial to evaluate digital platforms and mobile apps for sharing mobility services from users' perspective in the context of smart cities (Savastano et al., 2023). Currently, most MaaS systems provide their services through online platforms, with heavy reliance on smartphone apps (though website alternatives are also usually an option). Cash payment for digital mobility solutions is also a challenge (Kriswardhana & Esztergár-Kiss, 2023; Spitzer & Wimmer, 2021; Wang et al., 2022) which creates a barrier to uptake for people who do not have a bank account/card, or ability to pay online or contactless for potential users who rely on cash payment for their purchases. However, to ensure that users who are not digitally literate can also benefit from MaaS, alternative solutions that can give access to MaaS for these people are needed. Therefore, an accessible and inclusive MaaS should consider providing MaaS both in digital and non-digital format. To overcome this problem, the MaaS platform is expected to provide an accessible and user-friendly interface (digital and non-digital) for all, including VSGs. To this end, different aspects of an inclusive MaaS platform should be considered. Due to data privacy regulation existing in many countries, it may not always be possible to collect and save users' socio-demographic characteristics (age, driving licence, type of disability, income, and monetary voucher, etc.). In this case, MaaS users should be able to filter the customization of journeys and payment options at the point of inquiry such as max number of transfers, max number of modes, max travel cost, and being able to eliminate modes that cannot be used due to disability, etc. In this study, to evaluate the accessibility of the MaaS platforms for VSGs, a set of indicators are proposed for the following sub-criteria (for full list of indicators, see Appendix Table A4).

- Accessible digital platform (e.g. smartphone app) is an accessible app interface in terms of colour, font, icon, language, menu, etc. (see more information at Richardson et al., 2022; Molla et al., 2024). It is assumed that the digital interface will be mainly used by users who have already installed the MaaS app and are able to use the app comfortably.
- Accessible non-digital platform (e.g. telephone based MaaS) is a 24/7 customer service that allows people to plan, book and pay for their journeys through a phone call. It is assumed that the non-digital interface will be mainly of interest to the users who have access to a (mobile) phone (can be smart or not) but are not able to use a smartphone to plan, book, and pay for their journeys (as an example, see Karlsson et al., 2016, a support service offered by UbiGo).
- Customised journey planning uses the accessibility data of transport infrastructure and user preferences for journey planning that meets customers' needs.
- Customised Pay-As-You-Go option uses the user-specific payment options by cash (for those who do not have bank card), credits/vouchers, pass card (e.g. bus pass for the elderly), and by bank card during the payment process.
- Customised mobility bundle provides an integrated package of several transport alternatives and a collective price considering the user's socio-demographic characteristics (see more information at; Guidon et al., 2020).

3. Conceptual framework for MaaS inclusivity and accessibility evaluation

This section proposes the conceptual framework to evaluate the inclusivity, accessibility, and affordability aspects in MaaS systems using the indicators described in the previous section (set out in Fig. 3). The framework consists of three main steps: scene setting, criteria weighting using Multi-Criteria Decision Analysis (MCDA), and scoring the indicators with a weighted sum approach.

3.1. Scene setting (step 1)

The first step of the framework (Step 1 of Fig. 3) is to decide on the study area (city, rural), user groups (e.g., wheelchair users), and transport modes (e.g., PT) that will be evaluated. This decision has to be made by the local authorities who would like to evaluate the inclusivity of a MaaS system in their region. In addition, some statistics should be evaluated for the target user group, such as smartphone ownership, internet penetration rate and its affordability, digital literacy, and bank account/card ownership. For the evaluation, the following questions are asked to the evaluators:

1. Where is the **study area** located?

Metropolitan area, City area, Rural area

2. For which **user group** would you prefer to make the evaluation?

Elderly, People with disabilities, Low-income, Women, People with pushchair/trolley, People without a car

3. Which **transport modes** are available in the region (study area) for the selected user group?

Walking (or wheelchair), Bike, Bike sharing, e-Scooter, Bus, Train, Ferry, Taxi, Car-sharing, Ride-hailing (Uber, etc.), Demand Responsive Transit (DRT)

4. Which **transport modes** are available in the MaaS app for the selected user group?

Walking (or wheelchair), Bike, Bike sharing, e-Scooter, Bus, Train, Ferry, Taxi, Carsharing, Ride-hailing (Uber, etc.), DRT

3.2. Criteria weighting using AHP (step 2)

The next step (Step 2 of Fig. 3) is the consultation of the experts about the importance of criteria and subcriteria through the MCDM approach. This step consists of the following sub-steps: 1. Analytical Hierarchy Process (AHP) method design, 2. Experts' selection process and criteria, and 3. Pairwise comparison of criteria by selected experts and weights' calculation which are described below.

3.2.1. MCDM method using AHP

Various methods have been developed to determine the criteria weights in MCDM approach, such as AHP, Fuzzy AHP (FAHP), entropy method, user's preference rating method, Analytic Network Process (ANP), and Best-Worst Method (BWM) (Camargo Pérez et al., 2015). The choice among these methods depends on the specific requirements and constraints of the decision problem (Singh & Pant, 2021). For example, the BWM is a simpler method compared to AHP and ANP, often used when direct pairwise comparisons to identify the best and worst criteria or alternatives within a set (Rezaei, 2015). Among these methods, AHP is suitable for hierarchically organised criteria, breaking down complex problems into manageable components through pairwise comparisons. With a large sample size of experts, AHP is more robust, aggregating

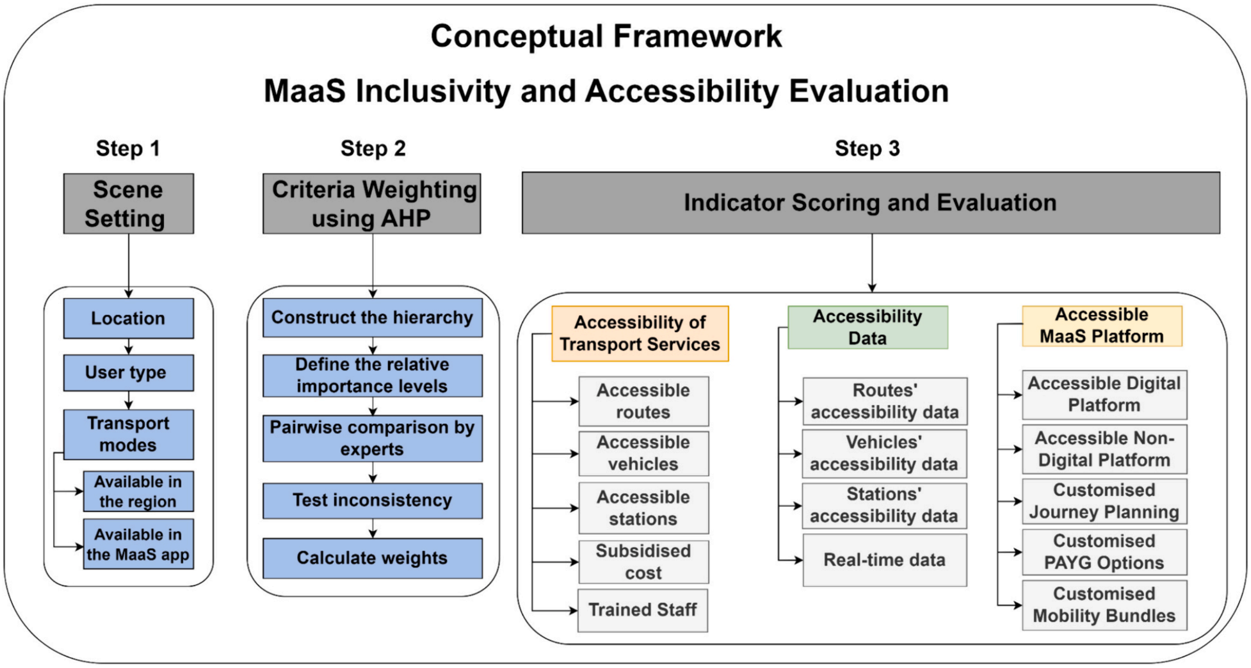

Fig. 3. The conceptual framework for MaaS inclusivity and accessibility evaluation.

diverse opinions effectively for comprehensive decision-making (Singh & Pant, 2021).

AHP is a powerful and flexible decision-making process based on mathematics and psychology to help people set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered (Saaty, 1987). Fuzzy AHP has addressed the limitations of the traditional AHP by considering the uncertainty in judgement that can happen during the pairwise comparison between criteria (Chang, 1996; Liu et al., 2020). AHP and FAHP have been widely used in transportation and mobility projects to prioritise criteria (Aba & Esztergár-Kiss, 2024; da Silva et al., 2022; Eren & Katanalp, 2022).

In this study, both traditional AHP and FAHP methods are employed to determine criteria weighting. AHP methods (AHP and FAHP) consist of following steps: Construct the hierarchy (goal, criteria, subcriteria), define the relative importance levels, pairwise comparison, Inconsistency test, and weights calculation. The ultimate goal of this AHP is to achieve an accessible and inclusive MaaS system. The main criteria are accessible transport services, accessibility data, and accessible MaaS platform. The sub-criteria are i) accessibility of routes, stations, vehicles, trained staff, and subsidised travel cost; ii) data availability on the accessibility of routes, stations, vehicles, and real-time information for transport services and infrastructure; and iii) accessible digital interface, accessible non-digital platform, customised journey planner, customised payment (Pay-As-You-Go: PAYG) options, and customised mobility bundles.

3.2.2. Survey dissemination and experts' selection process

An online questionnaire was designed using Qualtrics survey platform. The survey was distributed through social media such as LinkedIn, Facebook, as well as emailed to academics and practitioners who attended the following transport and MaaS conferences and forums: 3rd International Conference on MaaS (ICoMaaS (International Conference on Mobility as a Service), 2022, Tampere, Finland, November 2022); (Future Transport Forum, n.d) Portsmouth, UK, January 2023, and (Reimagining Transport, n.d) Coventry, UK, March 2023).

This questionnaire consisted of two parts: demographic questions and criteria weighting. Thus, the experts were asked to answer (self-reported) some demographic questions (Age, Gender, Disability status, Country of their workplace), industry/employer type, job role, transport projects involved (active travel, public transport, shared mobility, digital mobility platform such as MaaS, etc.), and projects experience with elderly people, people with disabilities, and low-income people.

A total of 193 responses were collected through this survey, consisting of a mix of academic and practitioner experts. Academics means universities and research organisation staff who have a transportation background. Practitioners means policy makers and decision makers at the local, state, and government level, transport planners, transport/mobility service providers or operators. The experts were selected based on their involvement in at least one transport-related project (active travel, public transport, shared mobility mopeds, mobility platforms such as MaaS) that explicitly considered at least one of the VSGs in this study. Out of the total responses (193) and after data cleaning (eliminating incomplete responses, and the experts' background check), 105 experts were considered in this study whose professional background met the criteria explained above. Then, the constancy ratio (CR) was calculated for each expert to only include consistent responses ($CR < 0.10$) in the MCDM analysis (see Section 3.2.3 for more information). In the context of a specific geographical area where the analysis would be performed, it is important to involve only local experts and stakeholders to express their opinions, including policy makers, service providers, etc. Among the valid responses, 48 responses are from the UK and 57 from other countries. Almost half of the experts are local (UK based), and these local experts have ideas and preferences that deviate from those of the international experts due to specific characteristics of the area. In addition to local experts, we have also considered the opinion of international experts on criteria weighting. The aim of recruiting non-UK experts was to see how the criteria weighting can be different between UK and non-UK experts. In terms of gender, there are 67 'Males', 36 'Females', one 'non-binary', one 'prefer to self-describe, and two 'prefer not to say'. Other information (employer, expertise, etc.) has been presented in Appendix Table A3.

Fig. 4a illustrates the geographical breakdown of the sample (experts per country), while Fig. 3b shows the workplace postcode of the experts located across the UK.

3.2.3. Pairwise comparison by selected experts

When experts completed the demographic questions, the pairwise comparison between criteria and subcriteria was conducted. For each set

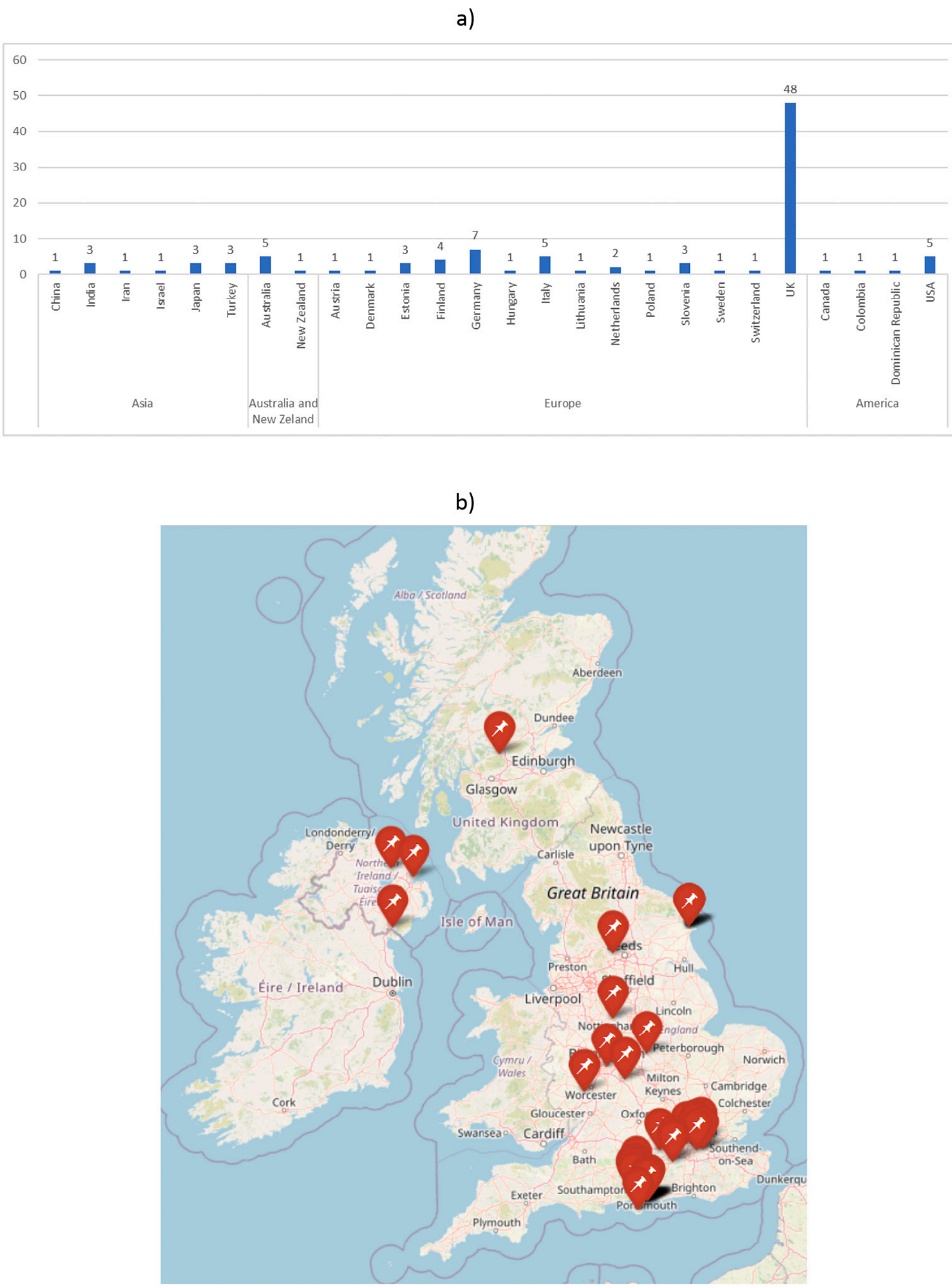

Fig. 4. Geographic breakdown of the selected experts: a) Worldwide, b) UK.

of criteria and subcriteria, experts were given a brief definition of the criteria and sub-criteria to ensure that all experts have the same level of information and understanding regarding each criterion, to improve judgement consistency among experts in the pairwise comparison stage. The experts were then introduced to the 9-level relative importance (Saaty, 1987) to use when setting the importance level of a criterion during pairwise comparison stage (where 1: equal importance, 3: moderate importance, 5: strong importance, and 9: extreme importance, and 2,4,6,8: values between the levels above). The experts then carried out pairwise comparisons for the main and sub-criteria. These were used to later generate pairwise comparison matrices. A Consistency Ratio (CR) for each matrix per expert was calculated using an online platform (OnlineOutput, 2023) which is based on the methods developed by Saaty (1987) and Gogus and Boucher (1998). Only experts were included in the MCDM analysis that had a CR <0.1 (an acceptable range according to Saaty, 1987, Gogus & Boucher, 1998). The number of verified experts (CR $<$ 0.1) for each category was different which were as follows: Main Criteria: 29 experts, Subcriteria 1: 20 experts, Subcriteria 2: 38 experts, Subcriteria 3: 18 experts. Following the consistency ratio calculation of the matrices, the weights were calculated using the AHP and FAHP methods for the consistent responses of the experts and are shown in Figs. 5 and 6.

In Fig. 5, the first bar chart group displays the weightings obtained from the AHP and FAHP methods by considering all experts (overall). The second bar chart illustrates the weightings based on the responses of practitioners and academics using the AHP method. Having compared the AHP and FAHP weightings, the FAHP weightings indicate almost equal weightings while by AHP, more variation has been observed between the criteria. Although the weightings obtained by AHP and FAHP differ, the prioritisation of the criteria is the same. In Fig. 4b, the difference between academics and practitioners on data accessibility may result from the academics' eternal desire to access data and may not be

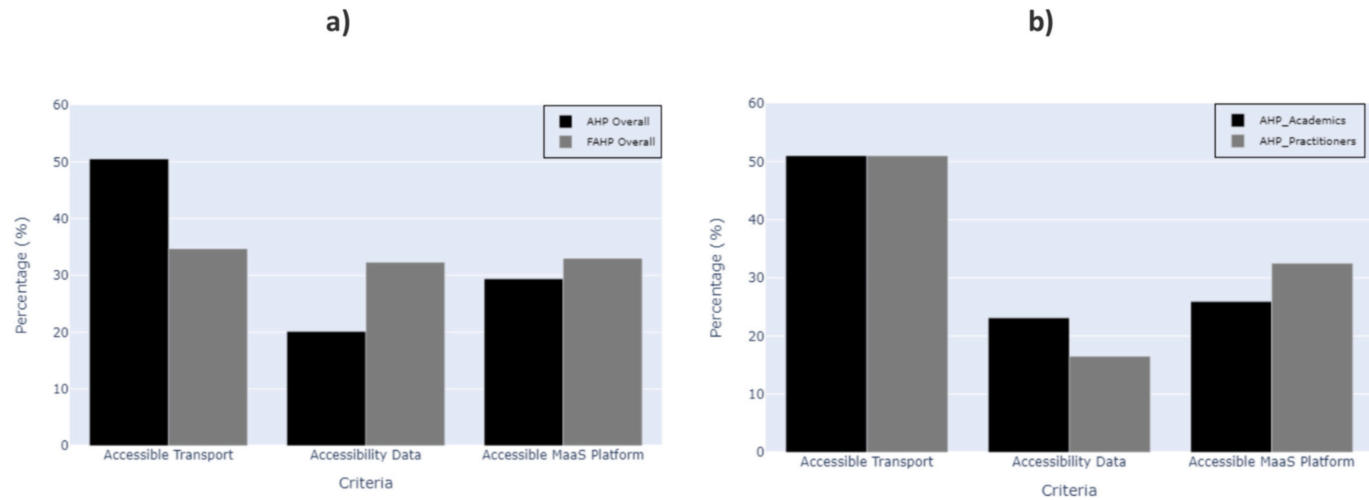

Fig. 5. Weights of main-criteria: a) overall (AHP and fuzzy AHP methods), b) academics vs. practitioners.

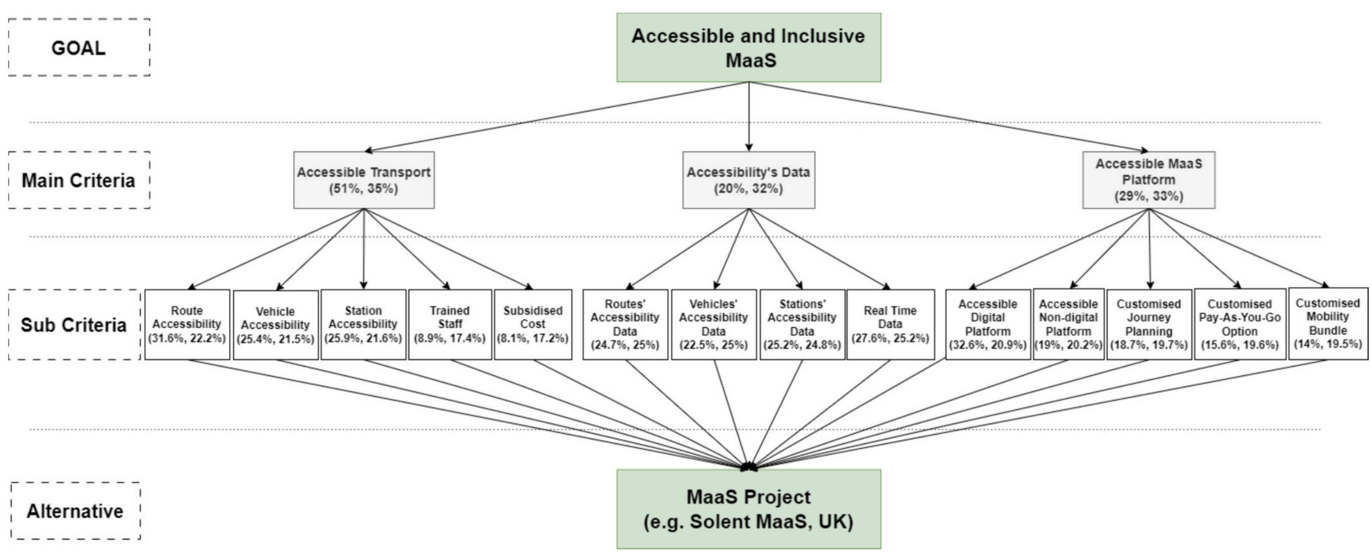

Fig. 6. Hierarchy of the MCDM approach for AHP and fuzzy AHP.

consistent with real applications of the framework to evaluate MaaS accessibility.

Fig. 6 shows the criteria weights for each main and sub indicator, found by using AHP and FAHP methods, respectively. For the main criteria, the transportation experts both from academia and practitioners gave the accessible transport services criteria with the highest preference followed by accessible MaaS platform and accessibility data. However, the weighting for the accessible MaaS platform is almost double the weighting of accessibility data for the practitioners based on the AHP method with 32.5 % and 16.5 %, respectively. Although for academics the weighting for these two criteria is almost equal (23.1 %, 25.9 %) (for full list of criteria weights calculated based on AHP and FAHP, see Appendix Tables A1 and A2). The weights obtained are almost similar to the hierarchy shown in the funnel graph by Lyons et al. (2020).

As shown in Fig. 6, for the sub-criteria of accessible transport services, route (31.6 %), vehicle (25.4 %) and station accessibility (26.1 %) are given the highest priority while subsidised cost (5.9 %) and trained staff (9.9 %) are relatively lower. The reason for the lower weight for subsidised cost could be due to the experts who believe accessibility of routes, vehicles, and stations are relatively more important than providing discounts on travel costs, as it is discussed by Hansson et al. (2019). The experts might believe that the subsidised cost cannot be helpful without accessible routes, vehicles, and stations.

In terms of the availability of accessibility data and sharing with the MaaS providers, the weighting results from both AHP and FAHP methods are almost equal for all the indicators. Real-time journey data stood out a bit with 30.2 % for the practitioners, while for the academics, route accessibility is stated the highest with 28.2 % among other indicators. Considering the sub-criterion of accessible MaaS platforms, accessible digital platforms have the highest weighting for both academics (31 %) and practitioners (35 %) based on the AHP method. Although for FAHP, among five indicators the weights are almost equally distributed. It is important to note that a relatively new concept 'Accessible non-digital platform', has more importance with (∼19 %) weighting comparing to the indicators that exists in the MaaS literature for a relatively longer time such as 'Customised journey planning' and 'Customised mobility bundles' have around 18 % and 14 % as AHP result. Therefore, it can be concluded that for more inclusive MaaS concepts, availability of non-digital MaaS should be considered as a criterion.

3.3. Indicator scoring (step 3)

In the last step of the framework (Step 3 of Fig. 3), the indicators are scored using the following 5-level scoring categories. In this study, we have adopted the scoring categories that have been used by Transport for London (TfL) for accessible bus stop design guidance (TfL, 2017a), and healthy street approach (TfL, 2017b).

- Score 0: Very low accessibility
- Score 1: Low accessibility
- Score 2: Moderate accessibility
- Score 3: High accessibility
- Score 4: Very high accessibility

To score the indicators for accessibility of transport services, transport planners/engineers and urban planners should carry-out on-site visits on the transportation infrastructure and networks, namely routes, vehicles, stations to check the accessibility status. In the scoring stage, if a transportation mode is not available or an indicator is not applicable for a specific transportation mode or VSG, no score is assigned to the indicator. Transport planners/engineers and urban planners should also communicate with the transportation services providers/operators or local authorities to evaluate the accessibility of data in terms of the availability of the data on routes, vehicles, stations, and real-time journey information.

Furthermore, it is important to evaluate whether the accessibility data has been properly collected and shared with MaaS platform developers or not. After the indicators for accessibility of transport services and data have been scored, the accessibility of the MaaS platform is evaluated. Some features of the MaaS platform can be evaluated by transportation experts, such as customised journey planning and payment options. However, the features in terms of accessible and user-friendly interfaces require in-depth analysis by Human Factor experts (Richardson et al., 2022). Once the weighting of the criteria and scoring of the indicators are determined, the MaaSINI index can be calculated by using the weighted sum approach.

4. Application of MaaS inclusivity evaluation framework

This section presents how the proposed framework can be implemented on a real-world MaaS project. To this end, the efficacy of the framework was assessed by the evaluation of the inclusivity and accessibility of Solent MaaS, exemplified for wheelchair users, although it remains adaptable for testing with various VSGs. The Solent area, in Southeast UK, consists of a couple of cities and an Island and has a population of around 1.6 M. The area is highly car dependent, accounting for 75 % of overall mode share (public transport is 20 %, walking 3 % and bicycle 1.5 %) (McIlroy, 2023; Dadashzadeh et al., 2022). The high level of car dependency is one of the factors associated with social, environmental, and economic issues in the area. Therefore, to address these issues in the area, a practical multi-city MaaS app has recently been developed to drive the change in the travel behaviour of the Solent residents, as a part of the Solent Future Transport Zone (SFTZ) program funded by the Department for Transport (Longman & Hillcoat, 2022).

The area has the following PT services: bus, train, ferry, shared mobility, taxi and ride-hailing. PT service timetables are provided via digital indicator boards at some stops and in some of them there are only printed timetables. There are some accessibility data that can be accessed by the users through the service providers' websites and the local channels. In order to manageably evaluate accessibility and inclusivity associated with the Solent MaaS, we focused on the accessibility needs of wheelchair users, and geographically on the urban area of Portsmouth (towards the southeast in Fig. 7). For this geography the following is available:

- Transport modes available for this user type in the Solent area: Wheeling, Bus, Train, Ferry, Taxi and Ride-hailing

Fig. 7. The Solent area, Southeast, United Kingdom (source: McIlroy, (2023)).

- Transport modes available for this user type in the MaaS platform: Wheeling, Bus, Train, Ferry

During the evaluation process, the Solent FTZ research team from the University of Portsmouth, who are experts in the field of transportation and knowledgeable about the transportation system in Portsmouth, assessed indicators based on transport infrastructure, data availability for various transport modes in Portsmouth, and the functionalities of the Solent MaaS platform. Each expert assigned scores to each transport mode and indicator on a scale of 0 to 4, where 0 indicates 'not accessible' and 4 indicates 'very high accessibility', according to the criteria in Section 3.2.3. In the scoring, experts' general knowledge, observation and expert judgement were the main approach as described in the Section 3.3. Subsequently, the average accessibility score for each transport mode was computed for each expert, followed by the calculation of the average score for each indicator across all experts. For the indicators related to the 'Accessible Transport' and 'Accessibility Data', if an indicator was deemed irrelevant for a particular transport mode, that mode was excluded from the average score calculation. For example, in this case study, shared e- scooters in the area is not accessible by wheelchair users. Therefore, we did not consider this mode while calculating the result. To evaluate the average score for each indicator i, Eq. (1) is used:

$$avg\ score_i = \frac{\sum_{y=1}^{Y}\sum_{m=1}^{M} score_{iym}}{MY} \quad (1)$$

where:

- *$avg\ score_i$ is the average score for indicator i*
- *$score_{i,y,m}$ is the score given to indicator i by expert y for mode m*
- *M is the total number of modes considered*
- *Y is the total number of experts*

When scoring the indicators of 'Accessible Platform', the evaluation is made independent from the mode and each expert gives a score for the indicator. After the score for each indicator is calculated, the indicator's score is multiplied by the weight of the indicator to generate the weighted score. Table A4 in the Appendix presents the criteria levels, indicator weights, the indicator scores, and the weighted sum for the overall performance of the Solent MaaS. After the scoring of indicators, the weighted sum per criterion is calculated by using the weights shown in Fig. 6. Weighted sum value of each criteria indicates the accessibility and inclusivity level of the Solent MaaS.

A colour-based assessment scale is provided to show the overall inclusivity score along with the accessibility rate calculated for the main criteria in Fig. 8, which can guide decision-makers about each criterion's weight and accessibility score. The size of segments reflects the weighting of the criteria while the colouring represents the accessibility level where 0 (not accessible) = red and 4 (very high accessibility) = green. The overall inclusivity and accessibility score for the Solent MaaS in Portsmouth is calculated as 2.04 out of 4. This score indicates that the Solent MaaS has a moderate accessibility with 51 % for wheelchair users in Portsmouth.

The proposed MaaS inclusivity and accessibility evaluation framework can identify specific challenges within the overall score, informing stakeholders with valuable insights to prioritise areas for improvement. The indicators with the highest weighting are those that have the biggest impact on the final score, and which should therefore be addressed first. There is also an important benefit in terms of transparent decision-making as budget holders and decision makers are making social choices when deciding which improvable aspects of the overall score should be addressed.

To identify which criteria, need to be improved to increase the inclusivity of the Solent MaaS, the accessibility rate of each criterion should also be evaluated separately. Figs. 9 to 12 show the accessibility rates for the indicators under the main and sub-criteria for the Solent MaaS which is based on the scale mentioned in the Section 3. The accessibility rates for the main criteria show moderate accessibility for the criterion 'Accessible Transport' and 'Accessibility Data' for the

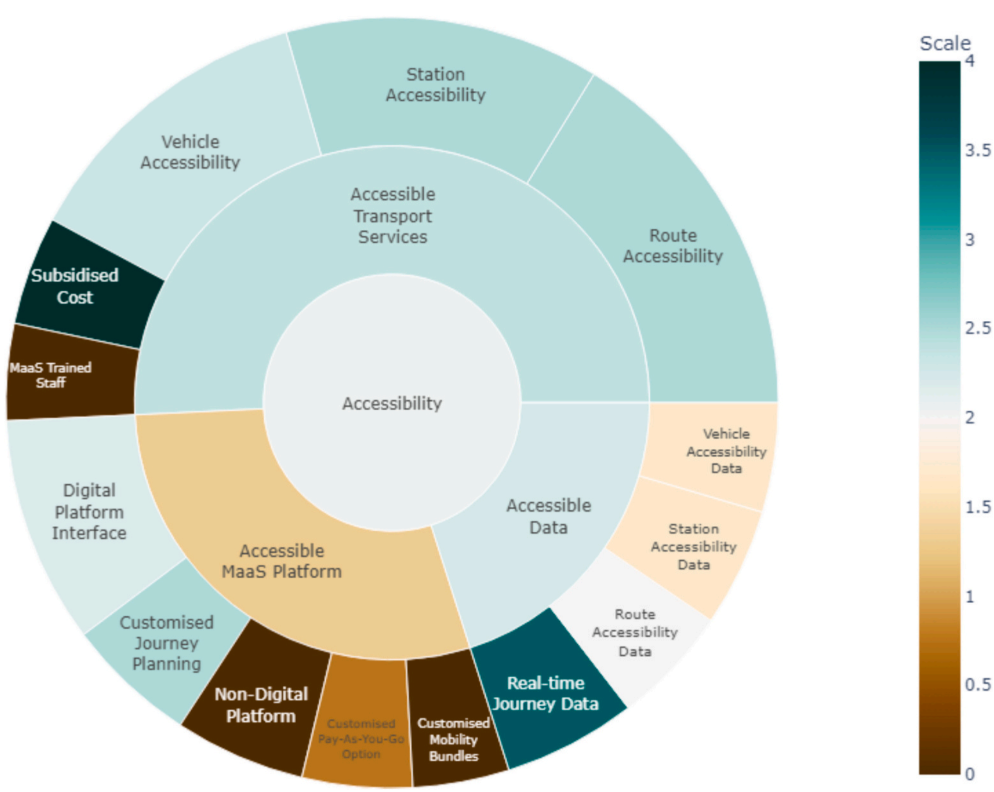

Fig. 8. Assessment scale for inclusivity and accessibility of MaaS systems.

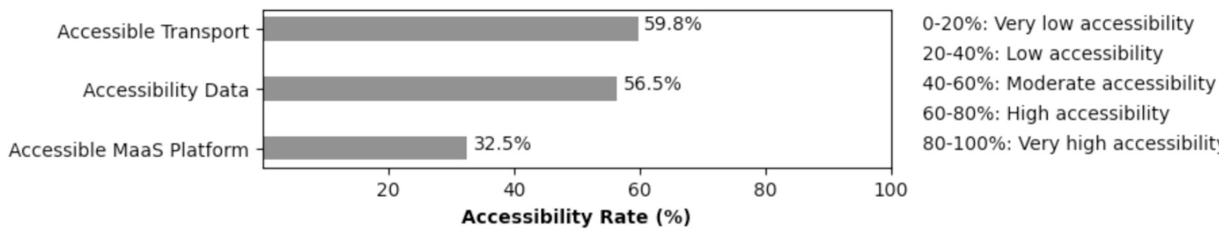

Fig. 9. Accessibility score of Solent MaaS for accessible MaaS main criteria.

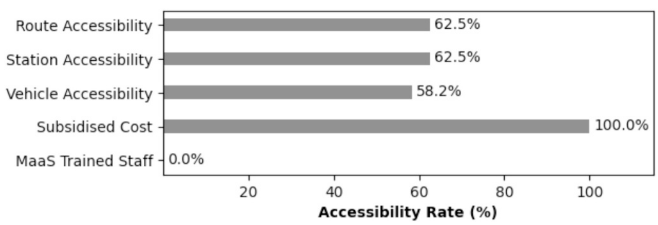

Fig. 10. Accessibility score of Solent MaaS for accessible transport services sub-criteria.

demo-case. However, the 'Accessible MaaS Platform' shows low accessibility.

To explain the reasons for the accessibility rates per main criterion, we need to investigate the accessibility rates of the sub-criteria with indicators. For example, the weighted sum score for accessible transport services is 2.39 out of 4 (59.8 %), which indicates moderate accessibility but with some small improvement it can reach high accessibility range (60–80 %). Based on the results presented in Fig. 10, MaaS trained staff are required in the stations and vehicles to help people use their tickets, have information on their journeys, cancellations, and delays. Also, the accessibility of route, station and especially the vehicles should be improved to increase the accessibility of the transport services.

Considering the sub-criteria on the accessibility data, shown in Fig. 11, the real-time journey information has high rate due to well established collaboration between PT operators and MaaS platform developers. However, other subcriteria, namely accessibility data of routes, stations, and vehicles have moderate rate due to lack of data collected and shared regarding routes, stations, and vehicles. To increase the accessibility and inclusivity of the MaaS, more data should be collected from the transportation providers/operators about the accessibility of routes, vehicles, and stations. On the other hand, to increase the accessibility rate for data accessibility criterion, data on the vehicle, station and route accessibility should be made available to the MaaS developers according to the accessibility rates. Simultaneously, MaaS platform developers should be able to make use of the shared information and provide more customised journeys and payment information to the users for a more inclusive and accessible experience.

The MaaS platform of the case study has low accessibility achieving a score of 1.3 (32.5 %). Based on Fig. 12, the low accessibility of the MaaS platform can be explained by the lack of 'Accessible Non-Digital Platform' and 'Customised mobility bundle' as well as the insufficient options for the customised pay-as-you-go of the Solent MaaS. In the meantime, the moderate accessibility of the customised journey planning can be explained by the impact of the integration of accessibility data in the platform which is also affected by the availability of the accessibility data. To improve the accessibility of the MaaS platform, the customised journey planning and payment options should have high level of integration of the accessibility data as well as a routing algorithm that considers the travel resources (mobility impairments, vehicle and driving licence ownership, etc.), and socio-demographic characteristics (age, income level, household structure etc.) of users. From the affordability point of view, the integration of the subsidised tickets and customised mobility bundles should be available both on the app and through a non-digital route to the MaaS services.

5. Discussion and conclusions

It is important that all those who need access to transport services (accessible transport) should also be able to use a MaaS system if one is introduced. Such inclusion plays a vital role in having equitable, inclusive and accessible MaaS platforms. Exacerbating the digital divide is a risk of innovation in transportation systems that mostly rely on data

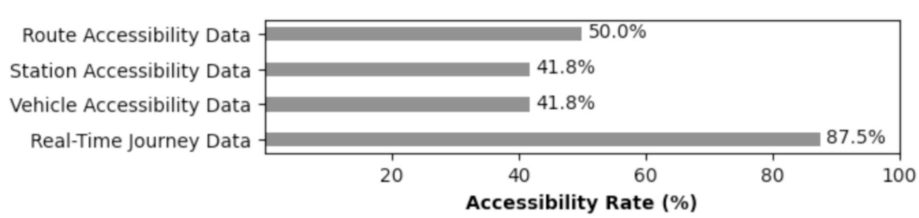

Fig. 11. Accessibility score of case study for accessible transport data sub-criteria.

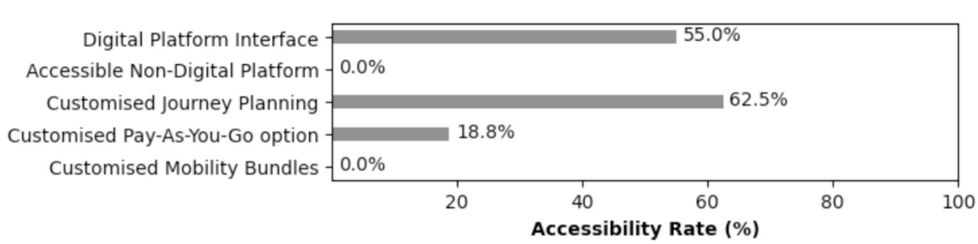

Fig. 12. Accessibility score of Solent MaaS for accessible MaaS platform sub-criteria.

and digital platforms such as MaaS platforms. In this regard, decision-makers such as local authorities, policy makers, and transport practitioners need a framework to evaluate the inclusivity and accessibility of the MaaS systems considering the operational area (city, rural), transportation modes available (active transportation, public transportation, and shared mobility modes), and the needs of vulnerable social groups (elderly, people with disabilities, people with pushchairs, low-income people, etc.). To this end, this study proposed a three-step conceptual framework that integrates the scene setting, criteria weighting, indicator scoring and MCDM approach. The traditional AHP and Fuzzy AHP methods have been employed to measure the relative importance of each criterion compared to others. Local and international experts with relevant experience were asked to prioritise (weight) the main and sub-criteria regarding the accessibility and inclusivity of MaaS. Results of AHP analysis show that accessibility of transport services, accessibility of MaaS platforms, and data collection & sharing on transport accessibility have a share of 51 %, 29 %, and 20 %, respectively, in the development of an inclusive and accessible MaaS system. In addition, three important sub-criteria in each category are as follows:

- **Transport services and infrastructure**: Route Accessibility (31.6 %), Station Accessibility (25.9 %), Vehicle Accessibility (25.4 %).
- **Data collection & sharing**: Real Time Network Data (delays, disruptions, etc.) (27.6 %), Station Accessibility Data (25.2 %), Route Accessibility Data (24.7 %).
- **MaaS platform**: Accessible digital interface (32.6 %), Accessible non-digital platform (19.0 %), Customised Journey Planning (18.7 %).

For each criterion this study proposes a set of practical indicators to measure the inclusivity, accessibility, and affordability of the MaaS systems. These indicators have been used to evaluate the performance of the proposed conceptual framework with a case study drawn from the Solent urban area, UK. The Portsmouth urban area within the Solent MaaS has been evaluated for inclusivity, accessibility, and affordability for wheelchair users. The overall score indicates that the Portsmouth area part of the Solent MaaS has moderate accessibility for wheelchair users. The visualisation developed in Section 4 provides a guide to interpret which criteria to focus on to improve the overall inclusivity and accessibility score of MaaS for VSG.

The proposed approach has been already tested in the Solent MaaS project and the outcomes are going to be used by the local authorities to improve the accessibility and inclusivity of the Solent MaaS. This approach can be applied to other regions locally and internationally, as there was no significant difference between the criteria weights obtained from local and international experts. However, the scores for each indicator need to be evaluated depending on the local context regarding the transport infrastructure and transport modes available in a specific region. Ideally, the indicators and their weighting also need to be validated by people who have lived experience of being in a VSG. The capacity to do this was outside the scope of the present study and is therefore a limitation. We also recommend that to improve the rigour of the scoring process, site visits are needed by experts with a range of perspectives, including VSGs. We have also not considered any gendered aspects within VSGs (and other intersectionalities that could deepen the experience of exclusion by some users). We also consider that the international transferability of our indicator set needs to be validated with a larger non-European expert (and indeed VSG) sample.

Solving accessibility challenges for VSGs is a complex task. Not all of the criteria can be solved from within the MaaS project. For example, in our indicator set, around half of the overall score for accessible MaaS is accounted for by the accessibility characteristics of the transport services themselves. Therefore, continued engagement of all stakeholders namely transports operators, station and vehicle designers, MaaS platform developers, and local authorities is required to resolve the accessibility and inclusivity challenges of VSGs holistically in a region where MaaS is deployed. However, in order to improve existing MaaS, policy makers and providers can use the proposed framework to transparently identify which sub-criteria should be prioritised to raise the accessibility and inclusivity score. In most cases this is likely to be investing in the accessibility aspects of the transport services as a first step, and ensuring that there is consistent data, including accessibility data, about the transport services that can be harnessed by the MaaS platform.

A significant insight from our work is that the usability of the digital interface of the MaaS platform is a very important consideration for inclusion of VSGs, but decision-makers need to recognize that digital interfaces to transport tickets and packages cannot fully substitute for human interfaces for significant numbers of VSG. A recent illustration of this, which our final recommendation below is intended to avoid for MaaS, was the 2023 consultation in the UK regarding a proposal to close nearly all ticket offices at railway stations in England. Within a short time, a public backlash resulted in >300,000 responses to the consultation (actually 13 separate consultations, one for each train operating company), the deadline for which was extended by more than five weeks as it was so controversial. The impact on VSGs was the main concern of respondents (Railnews, 2023; Transportfocus, 2023), and ultimately the proposal was dropped.

In terms of policy design and implications for inclusive and accessible MaaS considering VSGs needs, the recommended approach is to engage VSGs from design to implementation stages (Motability, 2022; Sustrans, 2023). As we show in Fig. 8, there are many elements and indicators that should be considered to deliver a successful MaaS project in terms of usability and inclusivity of all user groups. By using co-design (for example, see Tactran, 2023), the MaaS system should have a high score from the outset, and be welcoming and inclusive for VSG.

Finally, in addition to the importance of the proposed indicators for accessibility and inclusivity of MaaS, the effectiveness of collaboration among the various MaaS stakeholders has substantial importance, as also emphasised by Ye and Zheng (2024). Poor collaboration among MaaS stakeholders can result in usability problems arising for example from mismatched connecting services, service discontinuities, inconsistencies in information provision. Collaboration issues are not addressed in the paper, but significantly important if VSGs are to experience better transport access and is an important area for future investigation. This is a potential vulnerability of MaaS projects that needs to be solved especially for VSG because of in general they are more affected by a low capability to handle the consequences of a lack of collaboration, and experience higher cognitive loads to organise trips, or may experience trip suppression. Future work will conduct indicators scoring and the accessibility and inclusivity evaluation of a real-life MaaS project with practitioners (accessible transport auditors) and end-users from VSGs. Furthermore, further studies will investigate the gendered aspects within VSGs and wider international differences.

CRediT authorship contribution statement

Nima Dadashzadeh: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Seda Sucu:** Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Kate Pangbourne:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Conceptualization. **Djamila Ouelhadj:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

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 paper.

Data availability

Data will be made available on request.

Acknowledgment

This research work is part of the Solent Future Transport Zone, Mobility as a Service (MaaS) project funded by the UK's Department for Transport and led by the Solent Transport and in collaboration with the University of Portsmouth (https://www.solent-transport.com/solent-future-transport-zone/).

Appendix A

List of accessibility and inclusivity indicators developed for the main and sub criteria:

1. **Indicators for accessible transport services**

- **Route Accessibility**

1) Are there accessible routes/sidewalks/crossings for VSGs?
2) Are the public transport service frequencies adequate at day and night times?

- **Station Accessibility**

3) Are the number of public transport stations adequate in the study area?
4) Are the number of public transport stations with step free access from street to platform adequate?
5) Are there passenger information systems (audio/visual message) in the public transport stations for VSGs?
6) Are there enough seats or waiting areas for wheelchair users in the public transport stations?

- **Vehicle Accessibility**

7) Do the public transport vehicles have designated spaces for VSGs?
8) Do the designed public transport vehicles consider the ergonomics of VSGs?
9) Are there passenger information systems (audio/visual message) in the public transport vehicles for VSGs?

- **Subsidised Cost**

10) Is there any discount for wheelchair users for using the public transport service?

- **MaaS Trained Staff**

11) Are staff at public transport stops/stations or vehicles MaaS-trained to help (face-to-face) wheelchair users who have problems with delays, disruptions, transfers, etc.?
12) Are the number of MaaS trained staff sufficient to help VSGs?

2. **Indicators for accessibility data collection and sharing**

- **Route Accessibility Data**

13) Are the routes/sidewalks/crossings accessibility's data collected by the local authorities?
14) Are the routes/sidewalks/crossings accessibility data publicly available to be used by MaaS platform developers?

- **Station Accessibility Data**

15) Is the public transport stations accessibility data collected by the service providers/operators?
16) Is the public transport stations accessibility data publicly available to the MaaS platform developers?

- **Vehicle Accessibility Data**

17) Is the public transport vehicles accessibility data collected by the service providers/operators?
18) Is the public transport vehicles accessibility data publicly available to the MaaS platform developers?

- **Real-time Journey Data**

19) Is the real time information related to the transportation network collected by the service provider/operator?
20) Is the real-time information publicly available to be used by MaaS platform developers?

3. **Indicators for accessible MaaS platform**

- **Digital Platform Interface**

21) Does the MaaS app have a user-friendly interface with the same icons and colours across all sections of the app (planning, booking, and payment)?
22) Does the MaaS app have live service (vehicle) tracking and user locations functions?
23) Is the MaaS app able to present a visible map view with the important locations (POI, landmarks, destination) during navigation?
24) Is the MaaS app able to provide users with Help/FAQs (e.g. 7/24 call service, live chat with customer service, messaging, or email)?
25) Does the MaaS app have an emergency button that can detect the user's location, activate the microphone and camera, and send this information to the relevant organisations under emergency circumstances?

- **Accessible Non-Digital Platform**

26) Does the MaaS platform have a phone-based 7/24 customer service for planning, booking, and payment over the phone?
27) Does the MaaS platform have a message-based service to notify users with their approved journey information such as route, transportation modes, and confirmation of tickets purchased?
28) Does the MaaS platform have a message-based service to notify users with real-time journey information (stops/stations location, arriving PT services, delays, etc.)?
29) Does the MaaS platform have a phone-based 7/24 customer service to support users who are facing issues while travelling such as navigation, missing a PT service, transfer in multimodal journeys, payment, etc.?

- **Customised Journey Planning**

30) Is the MaaS platform able to suggest customised journeys using user preferences, transportation network accessibility and real-time disruption data?
31) Can the MaaS platform use the information collected from user feedback to improve the journey?

- **Customised Payment**

32) Does the MaaS platform have a cash payment option for users who do not have a bank card?
33) Does the MaaS platform have a credit system (MaaS account) to be charged by bank transfer for users who do not have a bank card?
34) Is all tickets and shared mobility rental fees integrated into the MaaS platform?
35) Is MaaS able to suggest customised payment options using discounts/vouchers?

- **Customised Mobility Bundles**

36) Is the MaaS platform able to propose customised mobility bundles to the users?

Table A1
Main and sub criteria weights based on **Fuzzy AHP** (FAHP) and **AHP** methods.

Criteria name	Criteria code	FAHP overall	AHP overall	FAHP academics	AHP academics	FAHP practitioners	AHP practitioners
Transport services accessibility	Main_1	34.7 %	50.5 %	36.5 %	51.0 %	34.5 %	51.0 %
Accessibility data collection & sharing	Main_2	32.3 %	20.1 %	30.1 %	23.1 %	32.6 %	16.5 %
MaaS platform accessibility	Main_3	33.0 %	29.4 %	33.5 %	25.9 %	32.9 %	32.5 %
Route accessibility	Sub1_1	22.2 %	31.6 %	23.2 %	32.3 %	26.1 %	30.7 %
Vehicle accessibility	Sub1_2	21.5 %	25.4 %	22.6 %	25.9 %	24.3 %	24.7 %
Station accessibility	Sub1_3	21.6 %	25.9 %	22.6 %	26.1 %	24.4 %	25.3 %
Trained staff	Sub1_4	17.4 %	8.9 %	19.0 %	5.8 %	6.7 %	12.2 %
Subsidised cost	Sub1_5	17.2 %	8.1 %	12.6 %	9.9 %	18.5 %	7.0 %
Routes' accessibility data	Sub2_1	25.0 %	24.7 %	25.1 %	28.2 %	25.0 %	22.5 %
Vehicles' accessibility data	Sub2_2	25.0 %	22.5 %	24.8 %	22.1 %	25.2 %	22.6 %
Stations' accessibility data	Sub2_3	24.8 %	25.2 %	24.8 %	25.8 %	24.7 %	24.7 %
Real time data	Sub2_4	25.2 %	27.6 %	25.4 %	23.8 %	25.0 %	30.2 %
Accessible digital platform	Sub3_1	20.9 %	32.6 %	21.4 %	31.0 %	21.2 %	34.6 %
Customised journey planning	Sub3_2	19.7 %	18.7 %	20.1 %	19.4 %	19.7 %	17.8 %
Customised pay-as-you-go option	Sub3_3	19.6 %	15.6 %	19.5 %	17.4 %	19.3 %	13.6 %
Customised mobility bundle	Sub3_4	19.5 %	14.0 %	18.6 %	13.4 %	19.6 %	14.8 %
Accessible non-digital platform	Sub3_5	20.2 %	19.0 %	20.5 %	18.8 %	20.1 %	19.2 %

Table A2
Main and sub criteria weights and ranks based on **AHP** method.

	Overall weight	Priority	Academics	Priority	Practitioners	Priority
Main criteria						
Transport services accessibility	50.5 %	1	51.0 %	1	51.0 %	1
MaaS platform accessibility	29.4 %	2	25.9 %	2	32.5 %	2
Accessibility data	20.1 %	3	23.1 %	3	16.5 %	3
Sub-criteria 1						
Route accessibility	31.6 %	1	32.3 %	1	30.7 %	1
Station accessibility	25.9 %	2	26.1 %	2	25.3 %	2
Vehicle accessibility	25.4 %	3	25.9 %	3	24.7 %	3
Trained staff	8.9 %	4	5.8 %	5	12.2 %	4
Subsidised cost	8.1 %	5	9.9 %	4	7.0 %	5
Sub-criteria 2						
Real time data	27.6 %	1	23.8 %	3	30.2 %	1
Station accessibility data	25.2 %	2	25.8 %	2	24.7 %	2
Route accessibility data	24.7 %	3	28.2 %	1	22.5 %	4
Vehicle accessibility data	22.5 %	4	22.1 %	4	22.6 %	3
Sub-criteria 3						
Accessible digital platform	32.6 %	1	31.0 %	1	34.6 %	1
Accessible non-digital platform	19.0 %	2	18.8 %	3	19.2 %	2
Customised journey planning	18.7 %	3	19.4 %	2	17.8 %	3
Customised pay-as-you-go option	15.6 %	4	17.4 %	4	13.6 %	4
Customised mobility bundle	14.0 %	5	13.4 %	5	14.8 %	5

Table A3
Experts sample demographic.

Region	Europe (including UK)	79	Job role	Academic (Other fields)	5
	Asia	12		Academic (Transportation / Mobility)	36
	America	8		Accessibility consultant	1
	Australia and New Zealand	6		App Developer Expert / Manager	4
Employer	Academia	41		Behaviour Change Project Officer & Green Travel Advocate	1
	Consultancy firm	22		Coordinator / Manager	16
	City Council / Municipality	13		Data Analyst / Data Scientist	5
	Department/Ministry for Transport	6		Fleet (vehicle) Operator / Manager	3
	Mobility App developer	5		Local Government	1
	Shared mobility service provider	4		MaaS Specialist	1
	National Park Authority	1		Mobility Consultant	4
	PT authority	1		Other	9
	PT service operator/provider	2		Planner / Modeller	14
	Freelance consultant	1		Public transport technology consultant	1
	Other	9		Road safety engineer	1
Expertise	Active Travel (AT)	8		Senior Manager	1
	Shared Mobility (SM)	8		Sustainable Travel Operator	1
	Public Transport (PT)	30		Transport accessibility auditor	1
	PT,SM	7	Transport mode	Bike and Public Transport (Multimodal)	1
	AT,PT	13		Car as a driver	22
	AT,SM	3		Car as a passenger	4
	AT,PT,SM	8		Personal (kick) scooter	2
	MaaS	8		Personal bike	15
	Emerging mobility technologies	4		Public transport	32
	Sustainable urban mobility	4		Shared Mobility	2
	Other	12		Walking	24
Experience (years)	<5 years	21		Wheelchair or Mobility Scooter	3
	5–10	18			
	11–20	33			
	21–30	25			
	> 30 years	13			

Table A4
Evaluation of inclusivity of the Solent MaaS for wheelchair users using the proposed framework and indicators.

Criteria Levels				Scores		AHP		FAHP	
Main	Sub		Key Performance Indicators	Indicators	Sub	Weighted Main Criteria	Overall	Weighted Main Criteria	Overall
Accessible Transport Services	Route Accessibility	1	Are there accessible routes/sidewalks/crossings for wheelchair users?	2.00	2.50	2.39	2.04	2.29	1.88
		2	Are the public transport service frequencies adequate at day and night times?	3.00					
	Station Accessibility	3	Are the number of public transport stations adequate in the study area?	3.00	2.50				
		4	Are the number of public transport stations with step free access from street to platform adequate?	2.67					
		5	Are there passenger information systems (audio/visual message) in the public transport stations?	1.67					
		6	Are there enough seats or waiting area for wheelchair uses in the public transport stations?	2.67					
	Vehicle Accessibility	7	Do the public transport vehicles have designated spaces for wheelchair users?	2.67	2.33				
		8	Do the designed public transport vehicles consider the ergonomic of wheelchair users?	2.33					
		9	Are there passenger information systems (audio/visual message) in the public transport vehicles?	2.00					
	Subsidised Cost	10	Is there any discount for wheelchair users for using the public transport service?	4.00	4.00				
	MaaS Trained Staff	11	Are staff at public transport stops/stations or vehicles MaaS-trained to help (face-to-face) wheelchair users who have problems with delays, disruptions, transfers, etc.?	0.00	0.00				
		12	Are the number of MaaS trained staff sufficient to help wheelchair users?	0.00					
ccessible Data	Route Accessibility Data	13	Are the routes/sidewalks/crossingss accessibility data collected by the local authorities?	2.00	2.00	2.26		2.21	
		14	Are the routes/sidewalks/crossingss accessibility data publicly available to be used by MaaS platform developers?	2.00					
	Station Accessibility Data	15	Is the public transport stations accessibility data collected by the service providers/operators?	1.67	1.67				
		16	Is the public transport stations accessibility data publicly available to the MaaS platform developers?	1.67					
	Vehicle Accessibility Data	17	Is the public transport vehicles accessibility data collected by the service providers/operators?	1.67	1.67				
		18	Is the public transport vehicles accessibility data publicly available to the MaaS platform developers?	1.67					
	Real-time Journey Data	19	Are the real time information related to transportation network collected by the service provider/operator?	3.67	3.50				
		20	Are the real-time information publicly available to be used by MaaS platform developers?	3.33					
Accessible MaaS Platform	Digital Platform Interface	21	Does the MaaS app have a user-friendly interface with the same icons and colours across all sections of the app (planning, booking, and payment)?	4.00	2.20	1.30	2.04	1.10	1.88
		22	Does the MaaS app have live service (vehicle) tracking and user locations functions?	3.00					
		23	Is the MaaS app able to present a visible map view with the important locations (POI, landmarks, destination) during navigation?	3.00					
		24	Is the MaaS app able to provide users with Help/FAQs (e.g. 7/24 call service, live chat with customer service, messaging, or email)?	1.00					
		25	Does the MaaS app have an emergency button that can detect the user's location, activate the microphone and camera, and send this information to the relevant organisations under emergency circumstances?	0.00					
	Accessible Non-Digital Platform	26	Does the MaaS platform have a phone-based 7/24 customer service for planning, booking, and payment over the phone?	0.00	0.00				
		27	Does the MaaS platform have a message-based service to notify users with their approved journey information such as route, transportation modes, and confirmation of tickets purchased?	0.00					
		28	Does the MaaS platform have a message-based service to notify users with real-time journey information (stops/stations location, arriving PT services, delays, etc.)?	0.00					
		29	Does the MaaS platform have a phone-based 7/24 customer service to support users who are facing issues while travelling such as navigation, missing a PT service, transfer in multimodal journeys, payment, etc.?	0.00					
	Customised Journey Planning	30	Is the MaaS platform able to suggest customised journeys using user preferences, transportation network accessibility and real-time distruption data?	3.00	2.50				
		31	Can the MaaS platform use the information collected from user feedback to improve the journey?	2.00					
	Customised Pay-As-You-Go option	32	Does the MaaS platform have a cash payment option for users who do not have a bank card?	0.00	0.75				
		33	Does the MaaS platform have a credits system (MaaS account) to be charged by bank transfer for users who do not have a bank card?	0.00					
		34	Is all tickets and shared mobility rental fees integrated into the MaaS platform?	2.00					
		35	Is MaaS able to suggest customised payment options using discounts/vouchers?	1.00					
	Customised Mobility Bundles	36	Is the MaaS platform able to propose customised mobility bundles to the users?	0.00	0.00				

References

Aba, A., & Esztergár-Kiss, D. (2024). Creation of the MaaS readiness index with a modified AHP-ISM method. *Communications in Transportation Research, 4*, Article 100122.

Alyavina, E., Nikitas, A., & Tchouamou Njoya, E. (2020). Mobility as a service and sustainable travel behavior: A thematic analysis study. *Transportation Research Part F: Traffic Psychology and Behavior, 73*, 362–381.

Butler, L., Yigitcanlar, T., & Paz, A. (2021). Barriers and risks of Mobility-as-a-Service (MaaS) adoption in cities: A systematic review of the literature. *Cities, 109*, Article 103036.

Camargo Pérez, J., Carrillo, M. H., & Montoya-Torres, J. R. (2015). Multi-criteria approaches for urban passenger transport systems: A literature review. *Annals of Operations Research, 226*, 69–87.

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research, 95*(3), 649–655.

Chatterjee, K., Clark, B., Nguyen, A., Wishart, R., Gallop, K., Smith, N., & Tipping, S. (2019). *Access to transport and life opportunities*. NatCen Social Research. Available at: https://www.gov.uk/government/publications/access-to-transport-and-life-opportunities.

CIHT. (2023). *DfT launches tTransport data strategy*. UK Chartered Institution of Highways and Transportation. Available at: https://www.ciht.org.uk/news/dft-launch-transport-data-strategy/.

Corazza, M. V., & Carassiti, G. (2021). Investigating maturity requirements to operate mobility as a service: The Rome case. *Sustainability, 13*(15), 8367.

Dadashzadeh, N., Bliemer, M., Sucu Sagmanli, S., Ouelhadj, D., Mcilroy, R., & Preston, J. (2022). Environmental and health information effects on travel behavior in the Solent region, UK. In P. Turner, T. Rushby, L. Blunden, S. Gauthier, & A. Baha (Eds.), *3rd international conference on evolving cities (ICEC 2022)* (p. 23). University of Southampton.

Dadashzadeh, N., Larimian, T., Levifve, U., & Marsetič, R. (2022). Travel behavior of vulnerable social groups: Pre, during, and post COVID-19 pandemic. *International Journal of Environmental Research and Public Health, 19*(16), 10065. https://doi.org/10.3390/ijerph191610065

Dadashzadeh, N., Woods, L., Ouelhadj, D., Thomopoulos, N., Kamargianni, M., & Antoniou, C. (2022). Mobility as a service inclusion index (MaaSINI): Evaluation of inclusivity in MaaS systems and policy recommendations. *Transport Policy, 127* (February), 191–202.

DfT. (2023). UK Department for Transport: Local authority transport: sharing data. Available at: https://www.gov.uk/government/collections/local-authority-transport-sharing-data.

Durand, A., Zijlstra, T., Hamersma, M., van Oort, N., Hoogendoorn-Lanser, S., & Hoogendoorn, S. (2023). "Who can I ask for help?": Mechanisms behind digital inequality in public transport. *Cities, 137*, Article 104335.

Durand, A., Zijlstra, T., van Oort, N., Hoogendoorn-Lanser, S., & Hoogendoorn, S. (2022). Access denied? Digital inequality in transport services. *Transport Reviews, 42*(1), 32–57.

Eckhardt, J., Lauhkonen, A., & Aapaoja, A. (2020). Impact assessment of rural PPP MaaS pilots. *European Transport Research Review, 12*, 1–14.

Eren, E., & Katanalp, B. Y. (2022). Fuzzy-based GIS approach with new MCDM method for bike-sharing station site selection according to land-use types. *Sustainable Cities and Society, 76*(October 2021). https://doi.org/10.1016/j.scs.2021.103434

FIA. (2021). Accessibility: A changing paradigm towards "Mobility for All.". Available at: https://www.fia.com/file/54300/download?token=3wDIGKUT.

Future Transport Forum. https://www.futuretransportforum.uk/.

Gogus, O., & Boucher, T. O. (1998). Strong transitivity, rationality and weak monotonicity in fuzzy pairwise comparisons. *Fuzzy Sets and Systems, 94*(1), 133–144.

Goulding, R., & Kamargiannia, M. (2018). The mobility as a service maturity index: Preparing the cities for the mobility as a service era. *In Transport Research Arena, 7*.

Guidon, S., Wicki, M., Bernauer, T., & Axhausen, K. (2020). Transportation service bundling–for whose benefit? Consumer valuation of pure bundling in the passenger transportation market. *Transportation Research Part A: Policy and Practice, 131*, 91–106.

Hansson, J., Pettersson, F., Svensson, H., & Wretstrand, A. (2019). Preferences in regional public transport: A literature review. *European Transport Research Review, 11* (1), 1–16.

ICoMaaS (International Conference on Mobility as a Service). (2022). https://events.tuni.fi/icomaas2022/.

Inviqa. (2020). Digital accessibility challenges (and how to solve them). https://inviqa.com/blog/digital-accessibility-report.

Kamargianni, M., Li, W., Matyas, M., & Schäfer, A. (2016). A critical review of new mobility services for urban transport. *Transportation Research Procedia, 14*, 3294–3303.

Karlsson, I. M., Sochor, J., & Strömberg, H. (2016). Developing the 'Service in Mobility as a Service: Experiences from a field trial of an innovative travel brokerage. *Transportation Research Procedia, 14*, 3265–3273.

Kolotouchkina, O., Barroso, C. L., & Sánchez, J. L. M. (2022). Smart cities, the digital divide, and people with disabilities. *Cities, 123*, Article 103613.

Kriswardhana, W., & Esztergár-Kiss, D. (2023). Exploring the aspects of MaaS adoption based on college students' preferences. *Transport Policy, 136*, 113–125.

Liu, Y., Eckert, C. M., & Earl, C. (2020). A review of fuzzy AHP methods for decision-making with subjective judgements. *Expert Systems with Applications, 161*, Article 113738.

Longman, S., & Hillcoat, C. (2022). Developing the UK's first multi-city MaaS platform. Accessible via https://www.intelligenttransport.com/transport-articles/135891/developing-uk-first-multi-city-maas-platform/.

Lyons, G., Hammond, P., & Mackay, K. (2020). Reprint of: The importance of user perspective in the evolution of MaaS. *Transportation Research Part A: Policy and Practice, 131*, 20–34.

Marsden, G., & Bonsall, P. (2006). Performance targets in transport policy. *Transport Policy, 13*(3), 191–203.

Mattioli, G. (2017). "Forced car ownership" in the UK and Germany: Socio-spatial patterns and potential economic stress impacts. *Social Inclusion, 5*(4), 147–160.

McIlroy, R. C. (2023). "This is where public transport falls down": Place based perspectives of multimodal travel. *Transportation Research Part F: Traffic Psychology and Behavior, 98*, 29–46.

Melis, A., Mirri, S., Prandi, C., Prandini, M., Salomoni, P., & Callegati, F. (2018). *Integrating personalized and accessible itineraries in MaaS ecosystems through microservices* (pp. 167–176).

Merchant Machine. (2021). https://gfmag.com/data/worlds-most-unbanked-countries/.

Molla, A., Duan, S. X., Deng, H., & Tay, R. (2024). The effects of digital platform expectations, information schema congruity and behavioral factors on mobility as a service (MaaS) adoption. *Information Technology & People, 37*(1), 81–109.

Motability. (2022). The transport accessibility gap. Available at: https://www.motability.org.uk/media/iwaidhxk/motability_transport-accessibility-gap-report_march-2022_final.pdf.

Murati, E. (2020). Mobility-as-a-service (MaaS) digital marketplace impact on EU passengers' rights. *European Transport Research Review, 12*(1), 1–14.

Nicklas, J. P., Schluter, N., Winzer, P., & Schnieder, L. (2015). Accessible and inclusive mobility for all with individual travel assistance-Aim4It. In *IEEE conference on intelligent transportation systems, proceedings, ITSC, 2015-October 1569–1574*. https://doi.org/10.1109/ITSC.2015.256

Nikolaidou, A., Papadopoulos, E., Politis, I., & Basbas, S. (2023). An Indicator-based methodological framework for assessing an eMaaS scheme. *World Electric Vehicle Journal, 14*(7), 186.

OnlineOutput. (2023). MCDM software. https://onlineoutput.com/inconsistency-ratio-fuzzy-ahp/.

Pangbourne, K., Mladenović, M. N., Stead, D., & Milakis, D. (2020). Questioning mobility as a service: Unanticipated implications for society and governance. *Transportation Research Part A: Policy and Practice, 131*, 35–49.

Pangbourne, K., Stead, D., Mladenović, M., & Milakis, D. (2018). The case of mobility as a service: A critical reflection on challenges for urban transport and mobility governance. In *Governance of the smart mobility transition* (pp. 33–48). Emerald Publishing Limited.

Pham, H. D., Shimizu, T., & Nguyen, T. V. (2021). A literature review on interactions between stakeholders through accessibility indicators under mobility as a service context. *International Journal of Intelligent Transportation Systems Research, 19*(2), 468–476.

Phillips, J. K. (2004). An application of the balanced scorecard to public transit system performance assessment. *Transportation Journal*, 26–55.

Railnews. (2023). Objections to ticket office closures soar to 315,000 Accessed on 04/08/2023. Available at: https://www.railnews.co.uk/news/2023/08/03-objections-to-ticket-office-closures.html.

Ranchordás, S. (2020). Smart mobility, transport poverty and the legal framework of inclusive mobility. *Smart Urban Mobilit., 61–80*. https://doi.org/10.1007/978-3-662-61920-9_4

Reimagining Transport. https://www.landorlinks.uk/re-imagining-transport.

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega, 53*, 49–57.

Richardson, J., Howarth, H., & Kim, J. (2022). Developing a heuristic tool for evaluation of mobility as a service (MaaS) mobile application interfaces. In *Contemporary ergonomics and human factors*.

Saaty, R. W. (1987). The analytic hierarchy process-what it is and how it is used. *Mathematical Modelling, 9*(3–5), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8

Samek Lodovici, M., & Torchio, N. (2015). Directorate-general for internal policies policy department B: Structural and cohesion policies transport and tourism social inclusion in EU public transport study. Available at: http://www.docutren.com/pdf/boletin/[IIIA%201440].pdf.

Savastano, M., Suciu, M. C., Gorelova, I., & Stativă, G. A. (2023). How smart is mobility in smart cities? An analysis of citizens' value perceptions through ICT applications. *Cities, 132*, Article 104071.

Serebrisky, T., Gómez-Lobo, A., Estupiñán, N., & Muñoz-Raskin, R. (2009). Affordability and subsidies in public urban transport: What do we mean, what can be done? *Transport Reviews, 29*(6), 715–739.

Shi, R., & Yeh, A. G. O. (2023). Do similar social groups have similar mobility in a city? Social areas and mobility in Shenzhen, China. *Cities, 138*, Article 104350.

da Silva, R. R., Santos, G. D., & Setti, D. (2022). A multi-criteria approach for urban mobility project selection in medium-sized cities. *Sustainable Cities and Society, 86*, Article 104096.

Singh, M., & Pant, M. (2021). A review of selected weighing methods in MCDM with a case study. *International Journal of System Assurance Engineering and Management, 12*, 126–144.

Smith, G., & Hensher, D. A. (2020). Towards a framework for mobility-as-a-service policies. *Transport Policy, 89*, 54–65.

Sochor, J., Arby, H., Karlsson, I. M., & Sarasini, S. (2018). A topological approach to mobility as a service: A proposed tool for understanding requirements and effects, and for aiding the integration of societal goals. *Research in Transportation Business & Management, 27*, 3–14.

Spitzer, V., & Wimmer, M. A. (2021). Conception of a digital mobility platform for citizens in rural areas. In *Proceedings of the 14th international conference on theory and practice of electronic governance* (pp. 414–421).

Sustrans. (2023). Disabled citizens' inquiry: Giving disabled people a voice in walking and wheeling policy and practice. Available at: https://www.sustrans.org.uk/media/11708/sustrans-disabled-citizens-inquiry-full-report.pdf.

Tactran. (2023). Integrated mobility partnership. Accessible via https://tactran.gov.uk/integrated-mobility-partnership/.

TfL. (2017a). Accessible bus stop design guidance. Available at: https://content.tfl.gov.uk/bus-stop-design-guidance.pdf.

TfL. (2017b). Healthy street approach. Available at: https://www.healthystreets.com/resource.

Transportfocus. (2023). Train station ticket office consultation Accessed on 04/08/2023. Available at: https://www.transportfocus.org.uk/train-station-ticket-office-consultation/.

UITP. (2019). Ready for MaaS? Easier mobility for citizens and better data for cities. Accessible via https://cms.uitp.org/wp/wp-content/uploads/2020/07/Policy-Brief_MaaS_V3_final_web_0.pdf.

UK KTN. (2023). Accessible and inclusive transport: Innovation in UK transport to enable access and inclusion, successes and opportunities. Available at: https://iuk.ktn-uk.org/wp-content/uploads/2023/03/InnovateUK_Accessible-and-Inclusive-Transport-Report_Screen_9-3-23.pdf.

United Nations. (2015). *UN SDGs no. 11: Inclusive, safe, resilient, and sustainable transport*. In the United Nations. Available at: https://sdgs.un.org/topics/sustainable-transport.

Wang, X., Yan, X., Zhao, X., & Cao, Z. (2022). Identifying latent shared mobility preference segments in low-income communities: Ride-hailing, fixed-route bus, and mobility-on-demand transit. *Travel Behavior and Society, 26*, 134–142.

Ye, J., & Zheng, J. (2024). How stakeholders influence MaaS implementation? An analysis based on evolutionary game theory. *Transport Policy, 149*, 198–210.