A Scoping Review of the Barriers and Prerequisites for MaaS Implementation in Low-Demand Contexts

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A Scoping Review of the Barriers and Prerequisites for MaaS Implementation in Low-demand Contexts

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Abstract.

MaaS, the acronym for Mobility as a Service, denotes the emerging mobility paradigm whose widespread development involves many different countries. It is a user-oriented travel planning solution that combines multiple mobility systems from both public and private operators into one digital platform. The platform supports the user at all stages of the journey: planning, booking, and payment, and promotes the integration of different transport systems according to principles of efficiency and sustainability. To date, MaaS deployments have mainly been in densely populated urban areas, where higher travel demand, infrastructure connectivity, and service provision make this solution more cost and performance-efficient. In regions characterised by low population density, inadequate infrastructure and network coverage, and poor transport services, MaaS solutions are much less likely to be adopted. Despite low passenger numbers and poor financial performance, the highly personalised and adaptable nature of the service, facilitated by the support of the latest technologies, suggests such a formula for improving the mobility of specific groups of users (inhabitants of low-density areas, people with special needs such as the disabled and the elderly). With this assumption, the paper aims to investigate the feasibility of MaaS systems as a solution for passenger transport in low-demand areas, starting with a scoping review of the literature focusing on the prerequisites and limitations of its practical implementation. The selected studies have shown the complexity of the issue and the need to adopt a multi-level perspective due to the very diverse and variable nature of the factors involved. However, such an approach is still rarely used in favour of sectoral studies focusing on specific technical aspects, mainly related to operational performance, efficiency, and economic viability. Much less attention is paid to the social impact of MaaS solutions, i.e. their potential to contribute to territorial rebalancing and the inclusion of vulnerable groups. Further research is needed to develop a practical model that can be used in low-demand situations and that combines cost-effectiveness with environmental, social, and governance principles.

Keywords: Mobility as a Service, Scoping Review, low-demand contexts

1 Introduction

The research aims to define favourable conditions for the implementation of Mobility as a Service (MaaS) in low-demand contexts. MaaS refers to the emerging mobility paradigm that is being widely developed across several countries. It is a user-oriented travel organisation solution that is focused on meeting the needs of users. It combines a telematic platform with multiple transport systems, including both public and private operators, all within the same environment. The system provides combined transport solutions for users, assisting them in planning, booking, and paying for the services required to travel between the place of origin and destination [1, 2].

This solution is mostly feasible in highly populated urban contexts because of its infrastructure, cost-effectiveness and performance efficiency. In contrast, MaaS solutions are less widely accepted in marginal realities characterised by lower demand levels and weaknesses in infrastructure and service supply. However, the highly customised and adaptable nature of the service to a variety of needs suggests this formula for improving mobility in marginal contexts. Starting from these assumptions, this paper aims to investigate the possibility of implementing a MaaS system even in structurally weak contexts. It will begin by exploring the needs, challenges, and barriers to implementation.

The increasing need for daily travel for a variety of reasons has compelled the average user to consider the costs of getting to a destination first when selecting a mode of transport. Therefore, the possibility of choosing alternative solutions has become critical. However, the mobility sector has recently suffered a setback due to the Covid-19 pandemic. The implementation of social distancing measures has resulted in a decrease in demand for transport [3] and a decline in the use of collective modes for longer distances.

The Covid pandemic and the increasing use of ICTs have also highlighted the usefulness of mobility planning information and support services for both end-users and transport managers, as well as the need to ensure equality of access to basic services for all urban and suburban citizens.

Therefore, an in-depth review of the existing studies on Mobility as a Service (MaaS) solutions in low-demand situations was conducted. To achieve this goal, the paper is organised as follows: Section 2 illustrates the methodology adopted, Section 3 presents results, Section 4 reports the discussion of results and the Section 5 presents the conclusions.

2 Method

The selection and further analysis of scientific contributions were conducted using the method proposed by Arksey and O'Malley [4] and the most recent updates to the process proposed by Peters et al in 2020 [5]. The methodological process was divided into five stages as shown in Figure 1:

Fig. 1. Methodological process diagram

2.1 Research Question and Study Design

The definition of the research question is a central part of the methodological process. It guides the research strategy by specifying the topic, the scope of the investigation and the objectives that the study sets for itself [4].

The broader concept examined here is the implementation of MaaS solutions in low-demand contexts. We are interested in investigating the feasibility of such a model of mobility in these specific situations, focusing on the drivers and barriers to its implementation.

The following sub-questions helped to articulate better the main question:

1. What are the main drivers and barriers to MaaS implementation in low-demand contexts?
2. Is there evidence, success/failure experiences to take as case studies?
3. What conditions or structural features of contexts influence the feasibility of MaaS solutions in low-demand situations?
4. How can we measure and evaluate the maturity level of implementation contexts?
5. What planning strategies or policies have been introduced to make MaaS effective in low-demand areas?

These specific questions directly guided the definition of the inclusion criteria to be considered.

The purpose of the study is to summarise the available literature on this topic, by considering time, source, authors' fields of expertise and country, context of application, study designs and research methods, and study outcomes. In this way, the authors aim to provide an overview of the scientific debate on the topic, which may be useful for future research and, in particular, for informing planning practice.

2.2 Identification of Relevant Studies

It should be noted that the term MaaS has lately been integrated into the disciplinary lexicon, both in theory and practice. As a consequence, the search has been limited to scientific production in the last ten years including peer-reviewed studies, grey literature, and literature reviews.

The search strategy is based on the use of a set of keywords representative of the new mobility paradigm (seamless trips using multimodal transport options via a single digital interface) and of context intended as environments with low or seasonally variable transport demand (Table 1).

Table 1. Search settings.

Search themes	Keywords
Mobility	MaaS, Mobility as a Service, Demand Responsive Transport, Combined Mobility, Seamless Mobility Flexible Mobility, Share Mobility, On-demand transit, Inclusive Mobility, Paratransit
Context	Weak demand area(s), rural area(s), low demand area(s)

The concept of low mobility demand is generally associated with low population density contexts, such as rural areas. To broaden the range of contexts to consider in the analysis, the authors added "low demand area", "weak demand area", "inland area", and "marginal context" among the keywords. The next stages of the process will define additional factors to characterise the contexts.

The selected keywords, combined with Boolean operators, resulted in the following string text used for the search: Mobility as a service OR Demand Responsive Transport OR Flexible Mobility OR On-demand transit OR Seamless Mobility OR Combined Mobility AND Inclusive Mobility OR Paratransit AND Weak demand area(s) OR Rural area(s) OR Low demand area(s).

The search for relevant contributions was conducted using two databases, Scopus and Web of Science, resulting in the identification of a total of 337 articles.

2.3 The Search Decision Process: Inclusion and Exclusion Criteria

The third step is to define the criteria for inclusion and exclusion, as outlined in Table 2, to screen the studies.

The two main eligibility criteria included the identification and discussion of conditions that hinder or facilitate the implementation of MaaS solutions, with a focus on marginal contexts. Excluded from consideration were articles that examined the use of MaaS solutions in densely populated contexts, such as cities, or dealt with paratransit systems (in urban contexts). Sector-specific contributions that had a technical focus, such as architecture or mathematical models of applications or service schemes, were also excluded. These were developed in disciplinary areas unrelated to and far removed from urban, spatial, and transport planning, which is the focus of this contribution. Even if their content is innovative and noteworthy, they do not provide knowledge relevant to the research question. For example, papers that discuss highly specialised aspects of ICT and require advanced knowledge and skills to read were excluded. Additionally, papers that discuss public transport during and after the Covid-19 pandemic were excluded.

The included contributions provide indications of several aspects, such as technical, functional, organisational, management, financial, and regulatory issues. These elements either facilitate or limit the implementation of MaaS solutions and flexible on-demand mobility services, such as Demand Responsive Transport or Flexible Transport

Service in marginal contexts. Finally, of the studies that analysed the influence of individual factors on the uptake of MaaS solutions, only those that looked at the whole population, with no restrictions on specific groups (by age, gender, socio-economic characteristics, household composition, etc.), were included.

Table 2. Eligibility criteria

Inclusion criteria	Exclusion criteria
The consulted papers consist of peer-reviewed studies and grey literature. They provide insights into MaaS systems, flexible mobility services and on-demand transportation such as DDRT in low demand or rural areas. The papers address enablers and barriers to MaaS implementation.	Articles that did not fit the research topic were removed based on title and abstract checks. Articles with very specific technical focus requiring a high level of expertise in disciplinary areas far removed from urban and transport planning, were excluded.

The authors completed the screening process in two steps, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart (Arksey & O'Malley, 2005). During the first step, the title and abstract were checked to gather a preliminary selection of articles that aligned with the research question. These contributions were then subjected to a second step of checking by reading the full texts.

Out of the 337 contributions, n=12 were excluded as duplicates, while n=259 were excluded for not meeting the eligibility criteria, as summarised in Table 2. Some of the papers discussed MaaS or DDRT systems but were not included as they did not fully answer the research question, did not refer to low-demand or marginal context or did not discuss requirements and barriers for MaaS implementation.

The included articles provide empirical and theoretical insights into various factors that positively or negatively influence the implementation of MaaS and dynamic DRT systems in spatially or socially marginalised situations.

The 66 papers included after the first screening, can be divided into two subgroups: the first group (n=8) deals with MaaS or DRT in 'weak demand' or 'low density' contexts. The second group (n=58) focuses on 'rural contexts'. Following the second screening, only 14 contributions met the eligibility criteria.

Specifically, for 19 contributions, it was not possible to find the full texts, a second group (n=31) was eliminated as they do not report a clear or comprehensive description of the elements that are useful for the implementation of MaaS systems in marginal contexts, and a third group (n=2) was eliminated as the focus is more on the effects produced by the adoption of MaaS systems rather than on the aspects that influence their implementation. Despite the significant number of papers that qualified for the second screening step of the full-text reading, only a small number were relevant to the study as they fully and comprehensively explored the topic of facilitating or hindering factors for the implementation of MaaS solutions in low-demand mobility contexts (papers where the topic was a minimal part of the proposed study were omitted).

The review decision process is presented in the flowchart below (fig. 2).

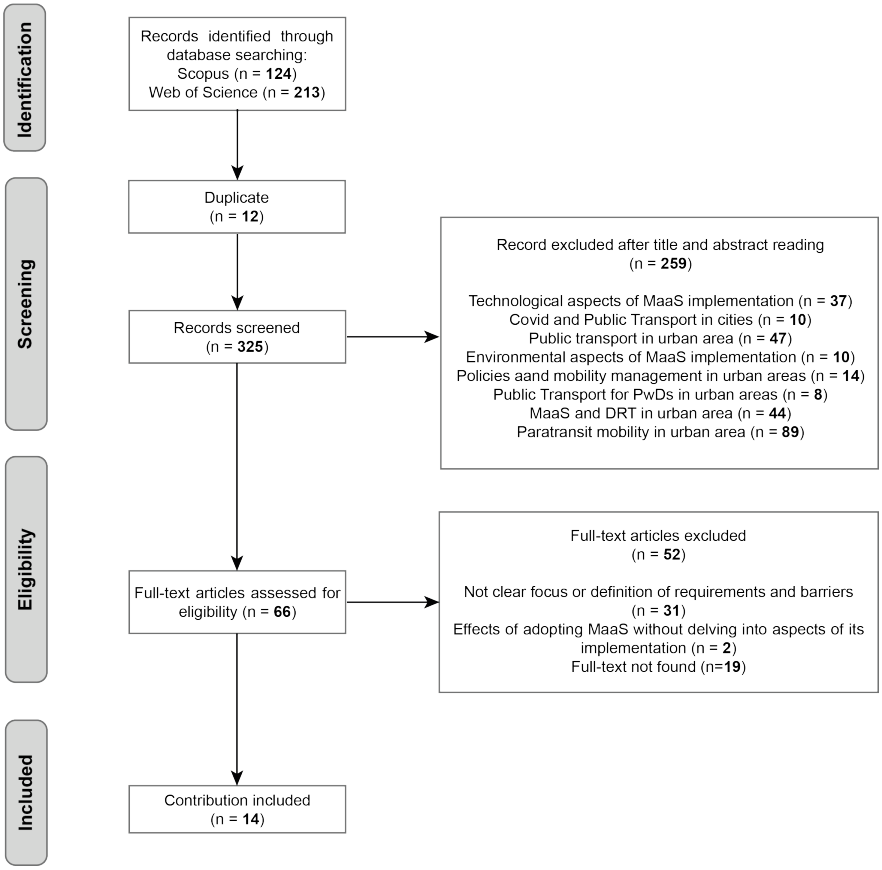

Fig. 2. Flowchart PRISMA [6]

2.4 Extracting and Data charting Process

The full-text screening stage consisted of the extraction and systematisation of data through the development of a data extraction table based on the data charting model proposed by the Joanna Briggs Institute [5, 7].

Supplementary Table 1, reports the following data: main study features (authors, year of publication, sector/disciplinary area, geographical context of application; type of study (empirical or theoretical); population involved (age, gender, number of participants); purpose of the study; data collection methods; characteristics of study context; study outcomes, and finally the most important column containing the key findings of this review: the elements facilitating or hindering the implementation of MaaS solutions.

2.5 Collating, Summarising and Reporting Data

The last part of the analysis involved the organisation of enablers and barriers of MaaS solutions into categories of recurring themes and issues. These categories sometimes present partial overlaps. The contents that emerged are described in the discussion section.

3 Results

Although the research aimed to investigate the ten-year period from 2010 to 2023, all the included studies were published between 2020 and 2023. This is likely due to the recent emergence of the MaaS concept, which was first popularised in 2014 [1, 8]. MaaS is a recent concept and its applicability has been limited to recent years and pilot studies rather than established experiences.

Of the relevant literature, n=13 are journal articles and n=1 conference paper.

As previously mentioned, the majority of MaaS solution trials have been conducted in densely populated urban areas, with less attention given to peripheral or dispersed settlements.

Most of the studies were conducted in Europe. A first group of articles consists of individual specific experiences carried out in Italy (n=3), the UK (n=2), Greece (n=1), Sweden (n=1), Estonia (n=1), and Finland (n=1). Another group of 3 studies provides examples of mobility solutions in European rural areas by reporting a review of several case studies based on Demand-Responsive Transport (DRT) services. Lastly, a third group comprises 2 studies in rural settings in Japan.

3.1 Study Design and Approach

The study included can be divided into two categories: papers describing single experimental research taken as a case study [3, 9-15] and papers that explore more case study and, by comparison, seek to advance more general hypotheses of the phenomenon investigated, in the case of our review, factors that facilitate or hinder MaaS solutions.

From a methodological point of view, the articles are divided into: empirical study [3, 9, 10, 13-19] and literature reviews and study based on literature research [11, 12, 20, 21].

The prevalent method of data collection and management was the administration of questionnaires, also online, and focus groups [3, 9, 10, 15] and conducting semi-structured interviews [13, 16, 17].

As for the type of population involved in the studies, survey activities typically involved stakeholders such as local authorities, mobility service providers, and transport planning experts. Additionally, some studies included populations that commute to the study areas, such as inhabitants, commuters, students, and workers.

3.2 Criteria for Defining Low-demand Contexts

The authors of this scoping review consider it crucial to identify the criteria used in the examined studies to define the study context. In general, contexts with weak transport demand are characterised as sparsely populated territorial areas with dispersed settlements that are distant and poorly connected to main urban centres due to infrastructural deficiencies and a limited variety and frequency of connection services. They are highly dependent on private cars. Most authors associate these situations with rural areas. In particular, to better characterise the contexts, authors used indicators of population structure such as age, gender, ethnicity, and health status, as well as socio-economic status including household composition, employment status, income level, car ownership, … [9, 16]. It is important to note that the classification is objective and based on empirical evidence.

The article cites several sources [10-13, 15, 17-20] to define the degree of peripherality of the context based on daily trips to the nearest urban centres of essential services and their distances [3, 11].

Vitale Brovarone & Cotella [21] investigate rural and coastal areas, while Papaioannou et al. [14] include islands due to the low number of permanent residents and resulting low density and transport demand for extended periods of the year. Finally, only one article named "weak demand areas" [3], territories with high spatial dispersion, few inhabitants, and transport lines with many stops and many different routes. The identified areas include mountain, rural, and lowland settlements.

3.3 Studies Outcome

Although the search for scientific contributions spanned a wide time frame, the included studies were published only between 2020 and 2023. This suggests that the topic is new and gaining relevance.

Most of the studies describe requirements, recommendations, and elements that hinder the implementation of MaaS in rural settings [11, 14, 16-21]. In some studies, the authors extracted information from the papers without changing their meaning [3, 9, 10, 12, 13, 15].

4 Discussion

The included studies provide insights into the organisation of MaaS in low-demand areas. They discuss both factors that facilitate and constrain the implementation. More precisely, enablers and barriers include all factors (conditions, circumstances, qualities, attitudes, and criteria) - related to both the application context and the actors involved - that respectively act as drivers or limits for the transition to MaaS. In other words, enabling factors and barriers address the operationalisation of the concept and shed light on requirements and recommendations for the implementation of a MaaS solution.

Some studies draw useful insights for implementing Mobility as a Service in rural areas from successful experiences supported by survey and data analysis highlighting

useful and effective strategies for MaaS adoption [3, 10, 12, 13, 15-17, 19]. Other articles, however, focus on different types of barriers by outlining the main challenges to be faced in these contexts [9, 11, 14, 18, 20, 21].

The analysed studies show that multiple dimensions act as facilitators and limiting factors, highlighting the complexity of the issue and the need for a multi-sectoral and multi-scalar perspective. Table 3 proposes a categorisation of recurring themes to which drivers and barriers refer: 1. Transportation planning and management; 2. Governance; 3. Policies and regulations; 4. Technological aspects; 5. Characteristics of the context.

Table 3. Systematisation of data collected: enablers and barriers of MaaS implementation in low-demand contexts

Categories	Enablers	Barriers	References
Transport Planning and management	— Densifying the network of multimodal mobility opportunities — Building sustainable operations using private-sector innovations — Using local transport operators' resources and avoiding duplication with existing PT — Integration of DDRT and flexible transport solutions — Mandate timetable coordination between different transport service providers — Active travel and green infrastructures connecting rural areas with PT nodes — Physical infrastructure to support interchanges (intermodal hubs) — Integrated, multimodal, and multi-operator ticketing system — Identify demand to design and operate a commercially viable on-demand service	— Unsuitable infrastructure — Service availability limited in terms of fleet capacity and hours of operation — Fragmentation of local public transport services — Cost of installing and operating DRT systems — Long journey times, lack of timetable coordination, and reliability of public transport — Difficult access to public transport networks.	[3, 9, 10, 14-21]

	— Agreement on the role of different actors involved		
Governance	— Public stakeholder involvement and coordination — Cross-sectoral collaboration Cooperation between local authorities and transport sector to reduce the dependence on public subsidies — Local Civic organisations and commercial mobility service involvement in the design of rural MaaS — Legislative studies to address liability issues and market regulations.	— Issues in collaborating with various transport modes — Lack of directives, strategic policy-making and planning — Unwillingness to collaborate and cooperate among transport providers — Liability of operators in case of disruptions	[10, 11, 13, 15-17, 19-21]
Policies and regulation	— Harmonisation of rules and procedures — Establishment of a regulatory framework to ensure fair competition and non-discrimination — Implement strategic measures and policies to encourage the shift to multimodal transport systems. — Marketing strategies and information campaigns — Support and expertise of regional bodies on administrative and legislative issues — Implementation of appropriate mobility packages, work policies and incentives — Availability of financial resources from various stakeholders	— Lack of administrative expertise — Regulatory constraints and framework challenges — Lack of adequate policies, business practices and official regulations — Lack of planned policies for transition to novel mobility solutions — Lack of planned policies for transition to novel mobility solutions — Lack of directives, strategic policy making and planning	[3, 9, 11, 12, 14, 16-18, 20-22]

Technological aspects	— Digital infrastructure and connectivity to exchange the necessary information — Availability of big data — Expertise in digital technologies to support transportation (i.e., booking and ride management software) — Deploying systems suitable for underpopulated areas.	— Lack of ICT infrastructure (data network coverage in rural areas) — Lack of digital literacy (not everyone has the possibility or knowledge to use apps) — Lack of digital skills and infrastructure — Lack of standardised data formats and APIs — Unavailability of technological assets	[3, 9, 11, 12, 14, 16, 17, 19, 21]
Context characteristics (geographical, social, …)	— Improving the operability of systems in order to increase user-friendliness and utilisation rate — Understand the critical mass required to enable community-based services — Educational/Information interventions focusing on revealing the true cost of car ownership — Digital education for users — Accessible, available for people with different digital competency levels, easily understandable information on routing, booking, and ticketing systems — Active involvement of the future users (community engagement)	— Accessibility challenges (digital divide, lack of accessible information system for vulnerable people by rural citizens and one-time users – tourists…) — Unwillingness to accept the system by the public — Lack of user demand — Operating Costs implementation and stacking of costs (of multiple services)	[3, 12, 13, 15-21]

Transport Planning and Management

The first thematic area covers aspects related to transport planning and management such as infrastructure equipment and transportation supply characteristics. The quality of the public transport service offered is a critical factor in the effectiveness of a MaaS in low-demand areas. It is considered the backbone of the system [23] and a central

factor in the maturity index of contexts regarding the implementation of such an approach [24]. However, the MaaS maturity index proposed by Goulding and Kamargianni, is not applicable in rural settings as the context conditions and transport supply differ greatly from urban settings [25].

The analysed studies identify basic transport requirements such as the importance of multimodal supply, availability of diverse and integrated travel options provided by both public or private operators including publicly subsidised transportation such as school, social and health services transportation [16, 20] but also the integrations among transport services: complementarity and coordination in mode, time and space and the flexibility of services (DDRT and similar).

In terms of barriers unsuitable infrastructure and fragmentation of local public transport services and the limited service availability in terms of fleet capacity and hours of operation may be a concern.

Also, based on the analysis of several case studies, some authors claim that the cost of installing and operating DDRT system is a major barrier. Although these services can provide mobility according to the needs of passengers and represent a valid alternative to the shortcomings of existing public transport systems, DDRTs are more expensive to implement and therefore not economically sustainable and must necessarily rely on alternative financing systems, such as public-private partnerships and public subsidies [3, 16-18, 20].

Governance

The second thematic field focuses on the factors that enable the MaaS ecosystem to function in an integrated manner.

The key governance requirements may concern the collaboration and cooperation among all parties involved at different levels, including public transport operators, private mobility service providers, infrastructure and digital service providers (i.e. electronic ticketing providers, payment service providers), policy and regulatory authorities, and finally, end-users who provide data and information on habits and preferences useful for defining the operational scenario in which the services are used [10, 11, 13, 14, 16, 17, 19]. Public authorities play a crucial role in the implementation of MaaS, setting out policy objectives serving their community and giving guidance or defining mandatory standards for the provision and quality of transport services.

The barriers may concern the lack of directives, strategic policy-making and planning [11, 19] and the transport providers unwillingness to collaborate and cooperate.

Policies and regulation

The third category concerns strategic measures and policies to encourage the transition from private cars to multimodal transport systems as well as the legal and regulatory aspects that support service integration. On the side of policies, it is recommended to use incentives and subsidies such as combined ticket packages and reduced prices for frequent users, the introduction of inter-service ticketing (i.e. unification) with price caps (including subsidies) [16, 18, 20]. Some authors recommend the implementation of work policies in low-demand contexts: accept as productive travel time on public transport [18]. On the regulatory side, legislative studies at various levels are needed to

address liability issues and market regulations for the development of appropriate business models [14].

The main obstacles refer to the lack of administrative expertise [9, 11] and the presence of regulatory constraints [3] (long and complex authorisation procedures to obtain necessary permits or to adapt existing transport facilities).

Technological aspects

The fourth thematic area discusses the technology, infrastructure and data availability required for the implementation of MaaS. The availability of data is crucial to its development and implementation [12] and its management and use require advanced skills in digital technologies. An efficient technological infrastructure is also necessary to enable real-time exchange of information, communications, and alerts between operators and users. An essential condition for the development of Mobility as a Service (MaaS) is the availability of static and dynamic data on the demand and supply of transport services in an open, secure, protected, and non-discriminatory form [26]. Therefore, it is important to ensure a collaborative and non-competitive climate among operators and an ethical relationship with users.

Among the requirements, the most important elements are the technological availability for the implementation of MaaS, including the implementation of complex digital infrastructures to support booking operations and ticketing [19]; the management and use of which require advanced skills in digital technologies, and new opportunities to meet the demand for mobility.

As for barriers, should be considered the lack of ICT infrastructure and data network coverage in rural areas [14], as well as the lack of digital literacy [11], not everyone has the ability or knowledge to use apps. This is particularly relevant for the elderly population who often inhabit the marginal contexts examined in this paper.

Context characteristics

The final thematic area investigates the territorial and social conditions of the MaaS adoption context.

The authors propose social requirements that interested the understanding of the critical mass needs to enable community-based services increasing social acceptance of the proposed system in marginalised contexts and, at the same time, the importance of ensuring accessible information about routing, booking, and ticketing systems and easily understandable by people with different levels of digital competence [20].

On the other hand, from a social point of view, the authors insisted on the importance of educational interventions focusing on revealing the true cost of car ownership in order to trigger travel behavioural change.

Among the barriers some of which already mentioned in the category concerning technological aspects, the authors indicate the lack of digital literacy for the older population, related for example, to accessibility issues, where users need to be able to physically book the journey and meet the bus [21] and the lack of an accessible information system for vulnerable rural citizens [20] and a lack of demand due to the dispersed characteristics of the territorial context [12]. The authors also highlight the reluctance of residents of low-density areas to accept the system because of higher prices and

longer travel times. These shortcomings limit the competitiveness of MaaS solutions and the willingness to give up private cars [15, 20]. Therefore, the higher operating costs of MaaS systems may limit access for weaker population groups [18]. In fact, in small communities with low demand, the operating costs outweigh the accessibility benefits [16].

This study has limitations. Firstly, the topic addressed is very topical and constantly evolving which means that further research is needed to update and advance knowledge. A potential limitation may relate to the methodology, specifically, the selection of inclusion and exclusion criteria may involve some subjectivity. Additionally, the identification of several unavailable articles due to not exclusively selecting open-access articles ultimately reduced the number of included articles.

5 Conclusion

This scoping review provides a cognitive overview of the enablers and barriers to MaaS solution implementation in low-demand transport contexts.

The framework outlined offers many insights for transport planning research and practice, but it is fluid as the subject is new and constantly evolving, especially in relation to implementation cases. This limits considerations of feasibility to a few examples and to pilot studies or experiments that are still in progress, rather than to long-established experiences. A helpful source of knowledge can be the many examples of DRT systems in rural and peripheral areas, which can look back on a longer tradition and offer interesting evidence.

In addition, most of the experimentation with MaaS solutions has been in densely populated urban contexts, rather than in peripheral or dispersed settlements. However, many of the obstacles encountered in dense urban areas are also found in low-demand contexts. At the same time, marginal situations sometimes offer interesting solutions that could also be proposed in larger contexts, for example in terms of combined organisation of services [3, 12, 16], also with innovative bottom-up solutions, in terms of operational and business model as well as governance (distribution of responsibilities, competencies, economic commitments).

According to the studies analysed, financial unsustainability, lack of effective partnership between actors and extreme land use patterns are the most problematic factors to be addressed in low demand areas. There is a need for a strong and well-structured strategic planning action, taking into account several key elements, ranging from the role of the different stakeholders, among whom strong and committed cooperation is fundamental, to a thorough understanding of the context and the market, as well as communication of the potential benefits for operators, users and territories. In this sense, it is possible to identify two distinct but complementary emerging lines of action: (i) a focus on the management and organisational aspects of the ecosystem, firstly governance and business model, with the aim of optimising resources and achieving sustainable goals for communities. Following this line, all authors agree on the importance

of coordination and cooperation between actors involved at different levels; (ii) an emphasis on user behaviour and mode choice, with the idea that understanding travel patterns, user preferences and the drivers of the travel decision process is paramount for any demand-driven transport system, and even more so in low-demand areas.

When it comes to technological and operational challenges, the authors seem more optimistic and confident that new and effective solutions will be easily found.

A pivotal point concerns the value attributed to DRT, regardless of the mode in which it is operated. Authors widely recognise that the perceived barriers to this transport mode are linked to the uneven distribution of demand and the characteristics of the territorial context (dispersed population, inadequate physical and digital connection infrastructures, digital illiteracy, ...). At the same time, the integration of DTR into a more comprehensive MaaS system including peri-urban and rural areas would represent a real paradigm shift in terms of equal access to territorial opportunities, especially for specific categories of users with special needs, such as the elderly, people with disabilities or children.

Although all these aspects are often highlighted by the scientific community, the adoption of MaaS especially in marginal contexts remains a big challenge. This is because often, although the importance of accessibility and inclusiveness is recognised, considerations of economic feasibility or the more technological aspects of MaaS in these contexts prevail. This observation suggests the need for further research and study so that the social value associated with MaaS solutions can acquire greater importance in decision-making processes. In this respect, the framework of enablers and barriers depicted with this scoping review can contribute to increase knowledge and can address the formulation of innovative policies that support the development of MaaS, even in areas with low transport demand.

A clear starting point is the general agreement on the opportunity to adopt a context-specific and user-centric approach.

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Supplementary Table 1 - Data of included studies

Author(s), Year	Subject area/Journal	Study Country	Study design	Approach	Population	Studies outcome	Context under study	Requirements and Barriers
Agriesti, S. A. M., Soe, R. M., & Saif, M. A. (2022)	European Transport Research Review	Estonia	Survey	Surveys and focus groups (STEEP approach) (n=16 municipalities responded to the survey)	Head or deputy head of local government Experts in strategic planning, urban planning, transport, IT or international projects	Identify mobility challenges across the region and what hindering factors are preventing envisioned solutions	Rural area	**Requirements:** • Technological advances • Policy about safety and economical incentives for MaaS **Barriers:** • Unsuitable infrastruc-ture • Lack of administrative expertise
Bauchinger, L., Reichenberger, A., Goodwin-Hawkins, B., Kobal, J., Hrabar, M., & Oedl-Wieser, T. (2021)	Sustainability Switzerland	Europe (Austria, Slovenia, Galles)	Mixed- methods case study design (Desk-based appraisal and documentary analysis -Small-scale empirical research)	Semi-structured interviews	Stakeholders	Explore the benefit of well-established multi-level governance arrangements when introducing smaller-scale mobility solutions to improve rural–urban accessibility.	Rural areas	**Requirements:** • Improve the operability of systems in order to increase user-friendliness and utilisation rate • Create incentives, such as bundled price ticket packages and reduced prices for regular users • Densifying the network of multimodal mobility opportunities • Governance and coordination between stakeholders • Technological advances • Support and expertise of regional bodies • Marketing strategies and information campaigns **Barriers:** • Service availability limited in terms of fleet capacity and hours of operation • Accessibility challenges as users need to be able to physically book a journey and meet the bus • Pre-registration poses an entry barrier for one-time users such as tourists, and may be perceived as too time consuming for infrequent local users • Financial unsustainability of DRT operation
Caballini, C., Olivari, E., Gasparini, C., & Dalla Chiara, B. (2023)	Sustainability Switzerland - Social science/environmental science	Italy (Piedmont region)	Mixed methods: 1. Survey of the literature 2. Multi-criteria analysis	1. Focus group (mobility experts involved) 2. Survey	(n=3428; 59% male; 41% female)	Present the BIPforMaaS (project in Italy that aims to develop the MaaS system at a high level of integration in a regional perimeter with public governance).	Regional scale: from the urban to rural context	**Requirements:** • Establishment of a regulatory framework that ensures fair competition and non-discrimination • Governance and coordination between stakeholders • Coordination among operators offering public transport services • Appropriate mobility packages **Barriers:** • Fragmentation of local public transport services
Campisi, T., Canale, A., Ticali, D., & Tesoriere, G. (2021)	AIP Conference Proceedings	Enna, Italy	Survey	Questionnaire	(n=300 inhabitants; 300 commuters; 150 university students; 150 workers)	Description of what influences whether or not this DRT system works well, e.g. how much it costs, whether people are familiar with it and whether it is easy for them to use	Weak demand areas	**Requirements:** • Need for complex technologies, such as booking and ride management software **Barriers:** • Cost of installing and operating a DRT system • Acceptance by the public • Regulatory constraints (such as obtaining the necessary permits or adapting to existing transport facilities)
Eckhardt, J., Lauhkonen, A., & Aapaoja, A. (2020)	European Transport Research Review	Eastern Uusimaa and Tempere, Finlandia	Overview of case studies	N.A.	N.A.	Requirements to improve accessibility of transport services in rural areas	Rural area	**Requirements:** • Collaboration between Public-Private sector • Public stakeholder involvement • Harmonization of rules and procedures **Barriers:** • Lack of administrative expertise • Lack of policies • Lack of ICT infrastructure (data network coverage in rural areas) • Lack of digital literacy (not everyone has the possibility or knowledge to use apps)
Franco, P., Kaba, D., Close, S., & Jundi, S. (2023)	IET Intelligent Transport Systems	UK	1. Literature review 2. Overviews of case studies	N.A.	N.A.	Recommendations for NMS for passengers and goods for the NMS proposed for a rural area	Rural area	**Requirements:** • Availability of big data • Identify demand to design and operate a commercially viable on-demand service • Understand the critical mass required to enable community-based services **Barriers:** • Lack of user demand • Data availability
Fujisaki, K., Yasuda, T., Ishigami, T., Makimura, K., & Ishida, H. (2022)	Asian Transport Studies	Japan	Empirical study (Multiple case studies research)	Interviews with stakeholders	N.D.	Recommendation for mobility planners to consider several perspectives (management, connecting private-sector invention and local public transport operators' resources, technology, and user needs) for sustainable rural mobility.	Rural areas	**Requirements** • Governance and coordination between stakeholders (Public-private partnerships) • Building sustainable operations using private-sector innovations • Collaboration with other sectors, mitigating dependence on public subsidies • Using local transport operators' resources and avoiding duplication with existing • Integration of DRT into the wider PT network • Designing systems that match area scale and user needs • Deploying systems suitable for underpopulated areas • Increasing social acceptance **Barriers:** • Business practices and official regulations • Sustainable implementation of innovative mobility services. • Operating Costs (mobility financing should also be considered by other sectors of the economy, such as the education, health, and welfare sectors, which rely on mobility.) • Issues in collaborating with various transport modes
Hult, Å., Perjo, L., & Smith, G. (2021)	Sustainability Switzerland	Sweden	Empirical study	Semi-structured interviews online (n=27)	Local civic organizations, local businesses, technology providers, municipalities, mobility service providers, and regional PTAs,	Give insights on how rural MaaS has been, and can be, organized.	Rural area	**Requirements:** • Active involvement of the future users • Cooperation between local authorities and transport leades • Local Civic organizations and commercial mobility service involvement in the design phase of rural MaaS **Barriers:** • Unwillingness to collaborate/ cooperate
McIlroy, R. C. (2023)	Transportation Research Part F: Traffic Psychology and Behaviour 2023	UK	Empircal study	1. Qualitative approach: Asynchronous Online 2. Focus Groups	n=146 in total (1. urban: male n=15; female n=18; mixed n=16; 2. peri-urban: male n=19; female n=26; mixed n=25; 3. rural: male n=6; female n=11; mixed n=10)	Shed light on the primary challenges involved in (and therefore barriers to greater uptake of) multi-modal journeys made by people living in the three location types	Rural area	**Requirements:** • Mandate timetable coordination between different transport service providers • Implement work policies to accept travel time on • Public transport as productive • Implement cross-service ticketing (i.e., unification) with price caps (including • Educational / information interventions focussing on revealing the true cost of car ownership • Improve active travel infrastructure connecting rural areas with public transport **Barriers:** • Interacting issues of journey time, timetable coordination, and reliability of multi-modal transport system • The stacking of costs (of multiple services) • Difficulties accessing public transport networks hinder non-car travel.
Mounce, R., Beecroft, M., & Nelson, J. D. (2020)	Research in Transportation Economics	Europe	Cluster analysis	N.S.	N.S.	Define the role of governments in institutional, organisational, regulatory and financial frameworks in supporting rural transport services at a level that enables this access.	Rural area	**Requirements:** • Active involvement of the future users (community engagement is useful in order to better understandcusers' needs) • Partnerships and community engagement, particularly in the cases of community transport (CT) organisations • Presence of transport services capable of being integrated; • Physical infrastructure to support interchanges; • Digital infrastructure and connectivity to exchange the necessary information, e.g. about service delays. • The willingness of stakeholders to exchange information and to make compromises if necessary **Barriers:** • Digital divide • Lack of directives, strategic policy making and planning • Lack of digital skills and infrastructure
Papaioannou, G., Polydoropoulou, A., Tsirimpa, A., & Pagoni, I. (2023)	European Transport Research Review	Greece	Mixed method: 1. Literature review; 2. Empirical study	Focus gruop	8 representatives from both industry and academia	Assess how the MaaS concept can work in intercity travel and rural/island areas	Island and Rural areas	**Requirements:** • Legislative studies at a pan-European level to address liability issues and market regulations. • Development of adequate business models • Analysis of the Intercity/Rural MaaS Ecosystem to understand the role of different actors • Technological readiness for MaaS implementation • Collaboration and cooperation among transport providers • Digital education for users **Barriers:** • Unwillingness to collaborate and cooperate among transport providers • Liability of operators in case of disruptions • Lack of standardized data formats and APIs • Regulatory framework challenges • Unavailability of technological assets
Poltimäe, H., Rehema, M., Raun, J., & Poom, A. (2022)	European Transport Research Review	Europe	Literature review	N.A.	N.A.	Study the social inclusivity, economic viability, and environmental impacts of novel mobility solutions in rural contexts based on published scholarly literature	Rural area	**Requirements:** • Flexible transport solutions supply • Collaboration between stakeholders • Easily understandable information on scheduling and routing available for people with different digital competency levels • Integrated, multimodal, and multi-operator ticketing system offers convenience and flexibility for all user groups • Availability of financial resources from various stakeholders is a crucial success • Accessible and easily understandable information on routing, booking, and ticketing systems is universally important for all user groups **Barriers:** • Lack of accessible information system for vulnerable people by rural citizens • Distance to the nearest stop and the need to change vehicles have the greatest effect on perceived accessibility • Lack of planned policies for transition to novel mobility solutions
Stephen, A. O. (2023).	Civil Engineering and Architecture	Japan, Kyoto	1. Literature review 2. Data analysis and estimation model (empirical study)	Questionnaire	n=560 people from rural suburban areas	Give insights useful for the implementation of MaaS in suburbs/rural areas and for the development of a sustainable community for all	Rural and suburban areas	**Requirements:** • Integration and flexibility of transport • Strategic measures and policies should be adopted to encourage a shift away from private car to sustainable travel modes. • Inclusion of public transport in the MaaS package • Competitve price of the MaaS plans and incentives for senior citizens to give up **Barriers:** • Unwillingness to accept the system
Vitale Brovarone, E., & Cotella, G. (2020)	Sustainability Switzerland	Italy	Literature based research	N.A.	N.A.	Sheds light on this issue, exploring the accessibility challenges of rural areas and proposing a multilayer policy approach aimed at supporting decision-makers in improving rural accessibility across Europe.	Rural and coastal areas	**Requirements:** • Targeted policies (various users), to draw up policies that directly respond to the needs of targeted groups. • Careful analysis of users' need, in order to avoid spending resources on inadequate services and to understand key priorities • Strengthen a public transport-friendly culture, addressing the main issues that today make public transport unappealing and underused • Mixed use of transport services, widening the number of user groups allowed to use services (i.e., school bus open to other user groups than students) and possibly combining passenger and freight transport (where adequate) • Strengthen local skills and roles, training and up-skilling key staff • Information and involvement, to favor the diffusion of information **Barriers:** • Physical and social barriers linked to digitalization

N.A. = Not available N.S. = Not Specified