Barriers to the adoption of the mobility-as-a-service concept: the case of Istanbul, a large emerging metropolis

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Barriers to the adoption of the mobility-as-a-service concept: The case of Istanbul, a large emerging metropolis

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ABSTRACT

Megatrends such as urbanization, digitalization, and decarbonization have created the necessity for new and creative approaches to the urban transportation system. As a solution to the problems of the increasingly digitalized urban transportation environment, "Mobility-as-a-Service" (MaaS) was proposed as a new sustainable transportation concept in Helsinki in 2014. With the use of the MaaS concept, residents of a large emerging metropolis, such as Istanbul, Turkey, can be offered a fast, efficient, environment-friendly, and inexpensive way of travel. However, despite the significant benefits of MaaS, there are several factors that can hinder the adoption of MaaS. This paper aims to analyze these barriers and their contextual relationships with each other using Total Interpretive Structural Modeling (TISM) and Matrix-based-Multiplication-Applied-to-a-Classification (MICMAC) methods. The case study has been conducted on an expert group to explore which significant barriers might be encountered during the adoption of a MaaS system in Istanbul. This study also addresses how these barriers should be overcome, and the MaaS concept should be adopted in Istanbul. The results showed that the most significant barrier to adopting the MaaS concept in Istanbul are Laws, Regulations, and Guidelines that primarily include the legal nature of this mobility service. The least important barriers are found to be Customer Acceptance and Labor Shortage. Therefore, the case study results provided a unique perspective for emerging countries in terms of barriers to successful MaaS implementations and revealed significant differences from the developed countries.

1. Introduction

Urbanization has increased significantly since the beginning of the first industrial revolution, but most of this social process has occurred within the past decade (Li and Lin, 2019). According to the United Nations (UN) World Urbanization Prospects report (UN, 2018), by 2050, two-thirds of the world's population (almost 68 percent) is estimated to be living in cities, and by 2030 there will be 43 megacities in the world with more than 10 million inhabitants. Urbanization has been more significantly increasing in developing and emerging countries where significant improvements in transportation infrastructure will inevitably be needed because of the economic, environmental, and social challenges caused by this rapid urbanization. For example, as the urban population increases, the demand for private cars increases, but the average utilization of private cars stays very low. According to Ellen Macarthur Foundation (2015), a typical car in Europe is used only 8% of the time, and an average of 1.5 out of 5 seats are occupied when a vehicle is in use. This consequently leads to increased traffic congestion and reduced air quality due to increased greenhouse gas (GHG) emissions. This rapid urbanization may also create many adverse effects on long-term public health and the environment if no initiatives are taken.

There is also a strong correlation between urbanization, transportation infrastructure, information and communication technologies, and economic growth (Pradhan et al., 2021). Digitalization and emerging technologies are shaping the future transportation systems and creating new business models for transportation. One of these new transportation business models is Mobility-as-a-Service (MaaS), a viable alternative for future urban transport. MaaS is a concept that offers

Abbreviations: MICMAC, Matrix-based-Multiplication-Applied-to-a-Classification; TISM, Total Interpretive Structural Modeling; MaaS, Mobility-as-a-Service; API, Application Programming Interface; ICT, Information and Communication Technology; ITS, Intelligent Transportation Systems; GHG, Greenhouse Gas.

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customers comprehensive mobility services in transportation (Jittrapirom et al., 2017). Hensher (2017, p. 87) defined MaaS as "a concept, combining transport services from public and private transport providers through a unified gateway that creates and manages the trip, which users can pay for with a single account." Similarly, Monzon et al. (2019, p. 258) defined MaaS as a "flexible, reliable, personalized and seamless door-to-door service that provides travelers with multimodal transportation solutions via a single digital interface." Focusing on digital services, Hensher et al. (2021b, p. 153) defined MaaS as an integrated transport service that "integrates transport service brokered by an integrator through a digital platform providing information, booking, ticketing, payment (as pay-as-you-go and/or subscription plans), and feedback that improves the travel experience."

In a MaaS ecosystem, not only public transport options (e.g., bus, train, subway, tram, and ferry) but also private transport options for sharing economy can be found. For example, 19% of route solutions in MaaS trials of Brussels, Canton Ticino, Edinburgh, and Ljubljana included carpooling options (Wright et al., 2020). Therefore, MaaS allows the integration of the transportation means of the end-users (e.g., bicycles or scooters that are owned by users) (Campolo et al., 2019). The MaaS system can also support the usage of electric vehicles such as electric cars, e-scooters, and e-bikes (Narupiti, 2019).

The concept of Mobility-as-a-Service was first introduced in 2014 in Helsinki, Finland, as a sustainable, convenient, and inexpensive alternative transport system (Kivimaa and Rogge, 2022). Various projects have been carried out worldwide to develop the MaaS concept in recent years. MaaS is a transportation concept that offers users a fast, inexpensive, environment-friendly, and personalized travel option through a single platform. It can include various functions (e.g., travel planning, payment, booking, ticketing, parking) that can have different levels of integration. As MaaS encourages the use of environment-friendly transportation options, public transport, and autonomous vehicles and promotes the sharing economy, it can help reduce GHG emissions and carbon footprint. According to a recent report on Whim (Ramboll, 2019), the MaaS system in Helsinki, MaaS users ride public transportation more than Helsinki metropolitan area residents, where their public transportation usage shares are 63% and 48%, respectively. Although taxi usage was very low, Whim users have been using taxis more significantly than their counterparts in the Helsinki metropolitan area (modal share of 2.1% and 1%, respectively) because of the free short taxi trips allowed through the MaaS subscription bundles. However, public transport is critical for the MaaS system in Helsinki, where 68% of all trips by Whim users have occurred within areas that are highly accessible by public transport. Besides, it also offers convenient travel options for elderly or disabled citizens. For example, 8% of the Whim users in Helsinki is the senior (66 years old or older) residents (Ramboll, 2019). Therefore, MaaS is a sustainable solution that addresses economic, environmental, and social aspects. In this sense, it is predicted to revolutionize future urban transport systems. However, the implementation of MaaS is not trivial, and many factors can hinder the success of a MaaS implementation.

Despite the vast literature on MaaS implementations and potential factors affecting the success of MaaS implementation, far too little attention has been paid to the holistic view of the barriers to successful MaaS implementations and the interrelationships of these barriers. Research on MaaS barriers has been mostly restricted to either addressing the barriers conceptually without using real survey data or investigating a single barrier or focus area in detail without considering the interactions with other potential barriers. Also, this paper provides an extensive literature survey for potential barriers to MaaS implementation. The main aim of this study is to examine the applicability of the MaaS concept as a sustainable solution for the urban transport system in Istanbul by investigating the importance of these potential barriers and their relationships. Istanbul is the largest and most populated city in Turkey, with a population of 15.5 million and a total area of 5343 km^2. Istanbul is one of the most populous cities in the world (OECD, 2022), and its population density is 2905 inhabitants/km2 (Istanbul Statistics Office, 2022), which causes serious issues such as traffic congestion, commuting delays, accidents, and environmental damage. According to public transportation statistics in Istanbul (Moovit, 2022), the average daily transit time in public transport is 68 min per person, but 69% of these passengers spend more than 2 h on public transportation every day. Also, 41% of the public transportation passengers make at least two transfers on a single one-way trip, and 38% of the passengers wait more than 20 min at a station or stop. Although Turkey is still classified as an emerging country according to MSCI (2022), the urban transport system in Istanbul as a large emerging metropolis is relatively more established than other big cities in Turkey (see Appendix A for Istanbul Railway Network Map) and ready to adapt new innovative technologies and business models including MaaS. Thus, a successful MaaS implementation can significantly reduce these inefficiencies of urban transportation in Istanbul. In this regard, this study addresses the research gap by exploring the following research questions:

- *RQ1:* What are the possible barriers that may hinder the success of MaaS in Istanbul?
- *RQ2:* What are the relationships and interactions among these barriers?

In this study, the potential barriers to successful MaaS implementations are identified with an extensive systematic literature review. Upon identifying these barriers, Total Interpretive Structural Modeling (TISM) is used to analyze and interpret these barriers. As a systems theory-based model, TISM has several advantages over multi-criteria decision methodologies. TISM is a powerful method that reveals contextual relationships among barriers and analyzes their interactions (Mathivathanan et al., 2021). Also, unlike other systems theory-based methods such as Structural Equation Modeling (SEM), TISM reveals the causal relationship between the barriers and classifies barriers in different hierarchy levels. To better understand the relationships between barriers, the Matrix-based-Multiplication-Applied-to-a-Classification (MICMAC) methodology is employed in this study, and the results of the TISM model are verified by classifying these barriers on their strength and dependence.

This paper is organized as follows. An extensive literature review on MaaS implementation barriers is presented in Section 2. The research methodology and the case study results are discussed in Section 3. Section 4 discusses the findings and explains both theoretical and managerial implications. The conclusion and future work are given in Section 5.

2. Literature review

2.1. Systematic literature review

A systematic literature review was conducted using the academic databases of Web of Science, Scopus, Science Direct, Springer, IEEE Xplore, Emerald, and Sage. Due to the technological nature of the MaaS, we also included grey literature (i.e., technical papers, reports, and white papers written by practitioners) in our search to better capture the state-of-the-art applications. The studies are searched from these academic databases as well as Google Scholar by using the following search string in title, abstract, and keywords:

Search strings. TITLE-ABS-KEY {("Mobility-as-a-Service" OR "MaaS" OR "Mobility Service") AND ("barriers" OR "challenges" OR "obstacles" OR "deterrents" OR "inhibitors" OR "constraints" OR "impediments" OR "handicaps")}

The search yielded a total of 1313 studies. The process of the systematic literature review is summarized in Fig. 1.

The search yielded many studies on pilot projects or successful adoption of MaaS. Table 1 summarizes the applied studies on MaaS that

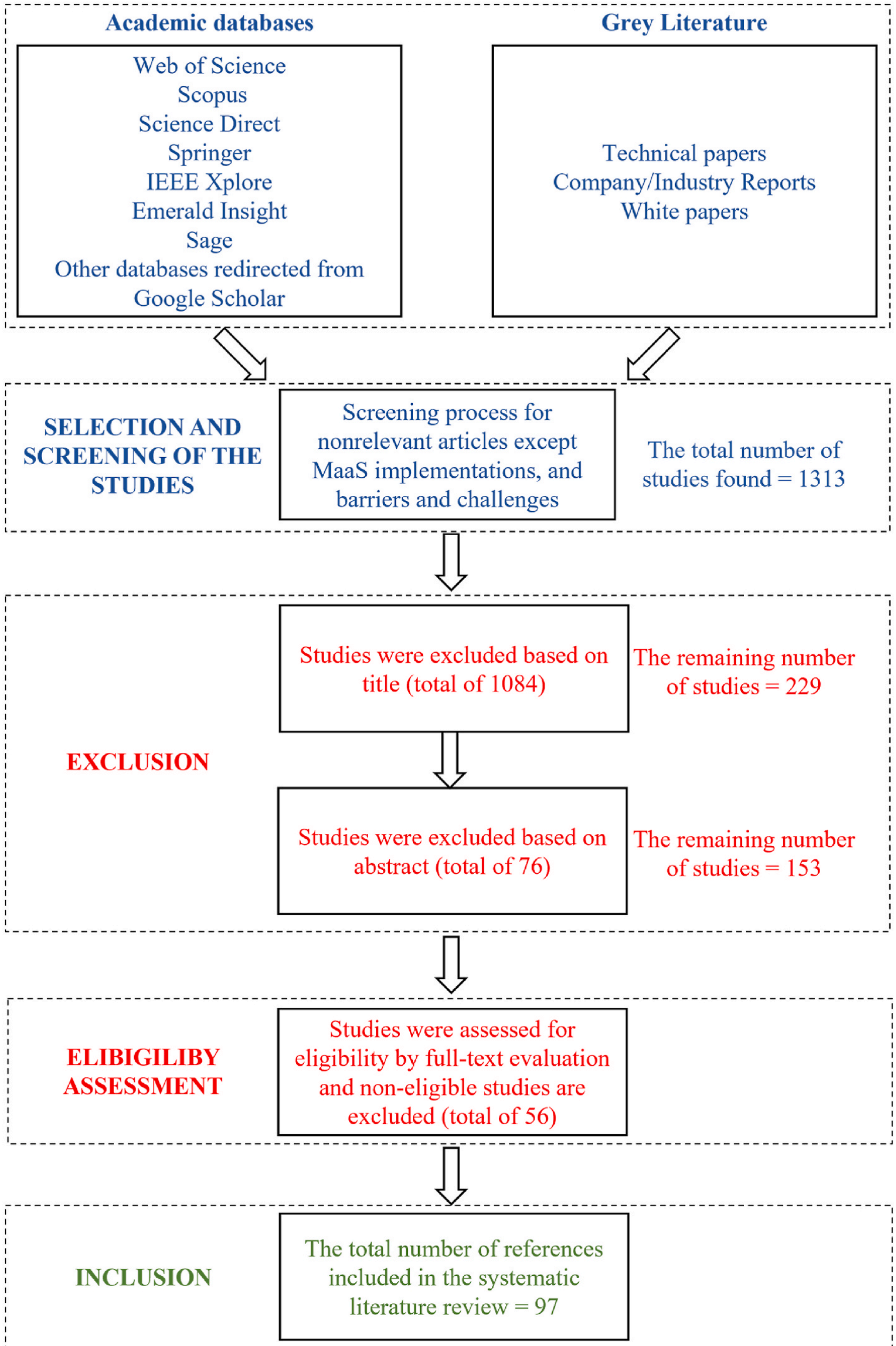

Fig. 1. Systematic literature review process.

focus on different aspects. As seen from the table, most of the attention was paid to the MaaS preferences and customers' willingness to pay as well as MaaS implementations.

However, most of the studies found in the systematic literature search have focused on the barriers to a successful MaaS adoption. As in any innovative technology or concept, MaaS creates many challenges for adoption. These barriers are extensively discussed in the literature and are classified herein under eight groups.

2.2. Collaboration and data sharing

Butler et al. (2021) identified the lack of cooperation among stakeholders as a supply-side barrier and as a possible cause of other problems within the MaaS organization, such as network inefficiencies or monopoly. MaaS is a public-private partnership (PPP) concept in which horizontal and vertical cooperation between public transport authorities and private companies must be significantly strong to have a successful adoption.

Although public-private collaboration is the backbone of the MaaS concept, there are several institutional barriers to achieving effective collaboration. Smith et al. (2020) explained that commercial and non-commercial mobility services may not always have a positive judgment about collaborating with each other. This judgment can be attributed to the fact that data sharing with the public is problematic for private companies as it poses a risk to competitive advantage (He and Chow, 2020). Efficient data sharing and exchange mechanisms should

Table 1
Summary of the applied MaaS studies.

Focus Area	Studies – Country
MaaS preferences, MaaS packages, and willingness to pay for flexible MaaS plans	Hensher et al. (2021a), Ho et al. (2018), Ho et al. (2021), Mulley et al. (2020), Vij et al. (2020) – Australia; Caiati et al. (2020), Durand et al. (2018), Farahmand et al. (2021) – Netherlands; Ho et al. (2020), Matyas and Kamargianni (2019), Matyas and Kamargianni (2021) – United Kingdom; Eckhardt et al. (2018), Liljamo et al. (2020) – Finland; Esztergár-Kiss and Kerényi (2020) – Multiple European Countries
MaaS implementations	Meurs et al. (2020) – Netherlands; Audouin and Finger (2019), Casady (2020), Romanyuk (2018) – Finland; Arias-Molinares and Carlos García-Palomares (2020), Lopez-Carreiro et al. (2020) – Spain; Cerema (2019), Juránková (2021), Koźlak and Pawłowska (2019) – Multiple European Countries; Chang et al. (2019) – Taiwan; Narupiti (2019) – Thailand; Sakai (2020) – Japan; Audouin and Finger (2019) – Austria
Business model	Hurme and Kulkov (2019), Mladenović and Haavisto (2021) – Finland; Polydoropoulou et al. (2020b) – Multiple European Countries

be developed among MaaS partners; however, data sharing does not mean free distribution of all available data (MaaS-Alliance, 2018). Besides, the public and private service providers also see the loss of brand awareness and direct customer relationships as a threat if they participate in a MaaS system (Lund et al., 2017). MaaS providers are also responsible for supporting collaboration between all partners and stakeholders, especially in avoiding the separation between the public and private sectors involved (Narupiti, 2019).

Although the participating parties compete with each other, they must work well together to maximize the profit in the MaaS. Smith et al. (2018) emphasized the need to create an innovative business model for MaaS in which different organizations (public and private) work together for a common goal by combining and distributing their capacities, resources, and expertise. Smith et al. (2020) found that medium-level problems, such as technical integration, customer relationships, and data operations, also lead to collaboration problems due to the uncertainty of the business and governance models.

2.3. Data standardization

The seamless data transfer plays a key role in enabling the MaaS, and the availability of interoperable data is one of the most critical factors for the MaaS concept, which can also prevent potential collaboration problems in MaaS (Smith et al., 2020). However, the data used for MaaS have different open data formats, and there is no standard structure or format for the data, which causes a problem for MaaS adoption (ERTICO, 2019). These non-standardized data and datasets prevent the simple integration of transport services into a MaaS and increase transaction costs. The lack of data standards may result in an inability to use critical data (MaaS-Alliance, 2018).

The Application Programming Interface (API) feeds may also have incompatible data formats for some actors. Using compatible data formats and a standardized API by the transport company participating in the MaaS ecosystem can be potential barriers for MaaS systems. In order to increase the efficiency and effectiveness of the system, data and API feeds must be incorporated simultaneously (Polydoropoulou et al., 2020a). However, some transport companies may not be willing to adapt standardized data formats (Li and Voege, 2017). Therefore, standards for data processing procedures should be established and implemented by policymakers (Lajas and Macário, 2020). To this end, the government or policymakers, and industry can also work together to develop more open standards (Enoch, 2018).

2.4. Labor shortage

According to Smith et al. (2019), the reasons for the barriers to innovations such as MaaS in the public transport sector are the lack of human capital and a suitable workforce. For example, although many small operators in Luxembourg can simply run their services, they do not have the human resources (HR) to carry out innovative projects (Polydoropoulou et al., 2020b). Therefore, insufficient human resources may mean that the potential partners and providers do not want to participate in a MaaS system. Although data is a crucial element for MaaS, data management (data exchange and access) is still a recurring problem in mobility services. In addition to insufficient technical infrastructure, these problems arise from the lack of human resources of public authorities and transport operators (ERTICO, 2019; MaaS-Alliance, 2019).

2.5. Financial resources

Financial resources need to be identified, and financial capacities should be assessed when planning the MaaS adoption (ERTICO, 2019). Companies may not have the financial resources to run a MaaS project, which causes companies to be unwilling to participate in a MaaS project, even though it can increase their market share and profits (Polydoropoulou et al., 2020b). Financial support may also be needed to adapt and implement Information and Communication Technology (ICT) infrastructures (ERTICO, 2019), where the lack of financial resources is also a reason for data management problems (MaaS-Alliance, 2019).

In order to overcome the financial barrier to MaaS, national and local governments should provide economic incentives, subsidies, or financial support for early MaaS providers. As an example of this financial barrier for MaaS, the development of Swedish UbiGo from a prototype to a professional service required more funds, but the project ended due to the lack of financial support (Karlsson et al., 2016; Nikitas et al., 2017).

2.6. Infrastructure and payment services

The necessary infrastructure must be provided in a MaaS system, e.g., high-speed ICT infrastructure and broadband (Woolthuis et al., 2005). The coordination and integration issues, such as information integration, ticketing, planning, and integration through physical infrastructures, may become a barrier to MaaS. In order to cope with these challenges, the necessary physical infrastructure must be established (Lund et al., 2017).

Some products, such as e-tickets, need to be offered electronically to process transactions quickly and simultaneously. This can lead to some infrastructure barriers for a MaaS in Istanbul, Turkey, because its public transport ticketing system is based on paper tickets and does not support electronic tickets. As one of the most important components in a mobility system, data management also plays a key role in MaaS (Smith et al., 2020). Since all these requirements result in high investment costs, it is necessary to increase the capacity and provide the necessary infrastructure for the rapid and simultaneous storage, modification, processing, and sharing of the produced data.

Polydoropoulou et al. (2020b) also identified the availability of APIs as a barrier for a MaaS system because APIs from different vendors may not be available to everyone as only a few operators have their API feeds open. In short, public transport authorities should have infrastructures for flexible ticketing and electronic transactions as they play the key enabler role in a MaaS system. In addition, new infrastructures, such as new charging stations and parking spaces, are required for the sharing economy and autonomous vehicles (Lund et al., 2017). Ticketing and payment technologies, such as Near-Field Communication (NFC) terminals, Wi-Fi, or SMS payment, also offer customers the option to pay for the trip with their mobile devices. To facilitate these alternative payment systems, such as integrated payment platforms (e.g., PayPal, Google Pay), users should be offered a free and good-quality wireless connection. In addition, cellular network coverage and Wi-Fi are also required for simultaneous data transmission between the various actors (ERTICO, 2019).

2.7. Business model

Karlsson et al. (2020) identified the lack of a suitable business model as a key barrier to MaaS adoption. Although various business models for MaaS have been proposed, there is still a need to develop new MaaS business models as they must include new partnerships among both the private and public sectors. Other important challenges to this barrier are how business models need to be adapted or scaled for all stakeholders and how profits (or losses) need to be distributed. If a MaaS system makes a profit from ticket sales, public transport companies might generate less revenue from users, but in this case, more subsidies are needed. Therefore, Li and Voege (2017) suggested that "the government must politically define the MaaS business model." According to Smith et al. (2020), the main reason for problems at the medium level, such as integration, customer relationships, and collaboration problems, is the uncertainty of the business model. For example, the distribution of roles (e.g., which company will act as a service integrator) may not be clear even within an organized MaaS system. In addition, the actors may fear losing control or being dominated by others, which may lead to the collapse of the business model. Therefore, new MaaS business models are needed to satisfy the actors who play different roles within the mobility system (Smith et al., 2019).

2.8. Laws, regulations, and guidelines

Laws, regulations, and guidelines should support MaaS to facilitate a successful MaaS adoption. However, in many countries, MaaS projects are hindered by the lack of regulations in data security, open data standards, ticket sales by third parties, or traffic subsidies (ERTICO, 2019). Smith et al. (2019) defined legislation as an external barrier to MaaS adoption. Karlsson et al. (2020) argued that legislation hinders innovation in the transport sector, as well as the development of MaaS. In addition, there are some efforts to develop the required regulations for MaaS. As an example of centralized regulation, a national MaaS framework has been developed by the Finnish Ministry of Transport and Communications to promote MaaS transportation options (Mulley and Nelson, 2020).

Competition law provisions that do not allow public actors to restrict or distort market competition are cited as barriers. For example, the legal framework for public transport in many countries stipulates that no third-party companies are allowed to sell tickets (Li and Voege, 2017). Also, the determination of the boundaries between the members and their collaborative combination in the MaaS can pose a problem. For example, Lund et al. (2017) argued that the lines between the public transport sector and those involved in the private sector (such as taxi and sharing economy) that work together in MaaS could be blurred. This could lead to uncertainty as to whether transportation, as well as other interested parties, should be subsidized by the government. Similarly, some problems may originate from the business model, such as hierarchical structure or income distribution. For example, Karlsson et al. (2016) noted that UbiGo could not resume services after the initial trials in 2014 because the current regulations do not allow a transport operator to act as a service provider. Therefore, specific regulations are needed for MaaS operators to function between the end-users and MaaS service providers (ERTICO, 2019). In addition, discount tickets, such as students, teachers, or 65+ age tickets, cannot be sold by third parties, which can prevent a MaaS operator from providing competitive prices (Polydoropoulou et al., 2020b).

According to Butler et al. (2021), the lack of a shared vision can be prevented by implementing laws and guidelines in the early stages. Good policies and laws can strengthen strategic direction, reduce inefficiencies, and resolve privacy and competition issues. Therefore, legislation is needed to maintain governance structures and a culture of collaboration between the private and public sectors. Legal regulations are also required for data standards. However, companies might see sharing their data and data management models as a risk to their business. Therefore, "government agencies should promote open data exchange, including open APIs, and implement regulations and guidelines that encourage mobility service providers to do so" (ERTICO, 2019).

2.9. Customer acceptance

The trust and willingness of citizens to use a MaaS system are essential for success because a business cannot survive without the support of its customers. However, there are some barriers to customer acceptance and adoption of a MaaS. For instance, MaaS offers comfortable travel to older generations, who make up the majority of the target audience. However, Butler et al. (2021) and Tsouros et al. (2021) showed a strong correlation between older age groups and reluctance to use MaaS. Although younger generations have greater ability and willingness to adopt new technologies like MaaS (Loubser et al., 2021; Ye et al., 2020; Zijlstra et al., 2020), older people often do not prefer or lack the ability to use a smart device or technologies to use MaaS (Alonso-González et al., 2020; Casadó et al., 2020; Silvestri et al., 2021). To minimize the impact of low technological suitability of senior citizens, alternative options for using MaaS (e.g., SMS correspondence, verbal recognition, or call centers) should be offered for people who do not have internet or smart phone (Alonso-González et al., 2020; Hensher et al., 2021b). Accessing the MaaS system can be even harder for the lower-income population (Golub et al., 2019). Another problem with MaaS-related technologies is the necessity of having a debit or credit card. In order to be able to pay online, the user inevitably needs to have a debit/credit card; however, some citizens may not have this card. Therefore, alternative payment solutions should be offered to ensure everyone has access to MaaS (ERTICO, 2019). Another barrier is the lack of customer trust for the MaaS. For example, Alarcin and Kircova (2020) claimed that people trust ridesharing companies less because they think these companies will charge higher costs for service and damage.

There are also potential internal threats and problems, such as data loss, manipulation, theft of customer data, or sabotage (Lund et al., 2017). Yanocha et al. (2021) noted that there might be serious privacy concerns for the risk of personal data disclosure. Mobility data created, collected, and centralized on a MaaS system include much more sensitive and important information than that created by an individual transportation mode. Cottrill (2020) argued that the risk of data disclosure may also negatively affect the functionality of the mobility service because users may disable location tracking or turn off the device to minimize this risk.

According to Karlsson et al. (2020), not only the willingness and intentions of travelers to use MaaS are unclear but also their willingness to pay the prices for this service is unknown. Various methods of payment are available in MaaS: "monthly payment (subscription)," "pay-as-you-go," and "all-in-one (hybrid)." In the monthly payment (subscription) method, the monthly travel expenses are paid as a monthly invoice. Pay-as-you-go means paying before the trip is taken. In all-in-one, both pay-as-you-go and monthly payment are offered together, and the customers themselves decide which method is selected and used (Aapaoja et al., 2017). Hensher et al. (2021a) investigated the differences between the pay-as-you-go and subscription options in Sydney MaaS trial and revealed that a significant portion of the users are interested in finding financially attractive subscription plans and the subscription to a specific monthly MaaS bundle can significantly reduce the monthly car usage. As an extension, Ho et al. (2021) explored which of the four bundles offered in Sydney MaaS trial were more successful in persuading more MaaS users to use subscriptions instead of the pay-as-you-go option.

While it is often believed that the MaaS sharing economy and public transport could become more attractive and reduce the number of private vehicles, owners of private vehicles are the least likely group to use MaaS and are reluctant to replace their habits of using private vehicles (Lopez-Carreiro et al., 2021; Lyons et al., 2019; Wang et al., 2022). According to a recent study on MaaS adoptions in the Metro Boston area (Basu and Ferreira, 2021), not only ridesharing and public transport options have been negatively affected, but also an increase in car ownership is expected due to the COVID-19 pandemic.

Table 2 summarizes the studies in the literature that focus on the barriers to successful MaaS adoption.

3. Methodology and case study results

In this section, the barriers to the implementation and development of the MaaS system are analyzed with the TISM method. Then, these barriers are classified based on the driving forces and dependencies using the MICMAC analysis. The reason for using these methods in this study is that various studies in the literature use both TISM and MICMAC methods successfully to identify and classify barriers in different application domains, such as barriers to the adoption of blockchain technology (Mathivathanan et al., 2021), strategic thinking enablers (Dhir and Dhir, 2020) and sustainable supply chain performance (Shibin et al., 2017). The TISM and MICMAC methodology used in this study to explore the relationships among barriers to MaaS adoption in Istanbul is presented in Fig. 2.

3.1. *Total Interpretive Structural Modeling (TISM)*

In this study, the TISM method, a qualitative method successfully applied in various disciplines, is used to analyze the barriers to the implementation of MaaS and understand their interactions with each other. Sushil (2012) argued that TISM has the potential to answer questions in conceptualizing research and supporting better decision-making. In TISM, the hierarchical relationships between different elements are analyzed, interpreted, and assessed (Dhir and Dhir, 2020), which are identified with the help of experts' opinions. This allows for the development of a strategic framework and model to explain.

3.1.1. *Identification and definition of barriers*

The first step for TISM is to identify and define the factors to be used in this study. For this, relevant data should be collected. This study was conducted by identifying and defining a total of eight different barriers obtained through a systematic literature review, as discussed in detail in Section 2. These barriers are Collaboration and Data Sharing (B1), Data Standardization (B2), Labour Shortage (B3), Financial Resources (B4), Infrastructure and Payment Services (B5), Business Model (B6), Laws, Regulations, and Guidelines (B7), Customer Acceptance (B8).

In order to analyze the barriers and their relationships with each other, expert opinions about the barriers must be collected. Therefore, experts were selected according to their experience in traffic and mobility systems, logistics, new technologies, and trends or infrastructure required for MaaS. Although 21 experts from different stakeholders in the MaaS ecosystem in Istanbul were identified in this study, only 13 out of them fully responded. The expert group consists of individuals with an average of 15 years of work experience and at least master's degrees. They represent all areas of the transportation sector: specialists from transport authorities of Istanbul Municipal Government and Ministry of Transport and Infrastructure of Turkey (4), professionals from private logistics companies (4) and banks/financial institutions (2), and subject matter experts from academia (3). The detailed profile of the 13 experts is given in Appendix B. Upon giving detailed information about MaaS and the identified barriers to the participants, an online survey

Table 2
The barriers to a successful MaaS adoption.

Barriers	Definition	Main References
Collaboration and data sharing (B1)	Due to competition between partners and insufficient technical conditions, collaboration and data sharing problems may arise between the parties involved. This creates a significant barrier, especially for the private and public sectors in the MaaS ecosystem.	Butler et al. (2021); Eckhardt et al. (2018); Hensher et al. (2020); Jittrapirom et al. (2018); Jittrapirom et al. (2020); Karlsson et al. (2020); Kayikci (2018); König et al. (2016); Lund et al. (2017); Merkert et al. (2020); Narupiti (2019); Polydoropoulou et al. (2020a); Smith et al. (2018); Smith et al. (2019); Smith et al. (2020)
Data standardization (B2)	The different data types and formats received from different sources by different partners and API feeds pose a barrier to seamless integration and simultaneous interoperability.	Chatterjee et al. (2022); Enoch (2018); ERTICO (2019); Jittrapirom et al. (2018); Kostiainen and Tuominen (2019); Lajas and Macário (2020); Li and Voege (2017); Lund et al. (2017); MaaS-Alliance (2018); Smith et al. (2020)
Labor shortage (B3)	The insufficient trained human resources to be occupied in the MaaS ecosystem	ERTICO (2019); Karlsson et al. (2020); MaaS-Alliance (2019); Polydoropoulou et al. (2020b); Smith et al. (2019)
Financial resources (B4)	The limited financial resources (insufficient investment and financial subsidies).	Butler et al. (2021); ERTICO (2019); Karlsson et al. (2016); MaaS-Alliance (2019); Nikitas et al. (2017); Polydoropoulou et al. (2020b); Yanocha et al. (2021)
Infrastructure and payment services (B5)	The lack of infrastructures and payment services required for successful MaaS services, such as ICT infrastructure, for data operations and transactions.	Cottrill (2020); Dzisi et al. (2022); ERTICO (2019); Jittrapirom et al. (2018); Kayikci (2018); Lund et al. (2017); Mladenović and Haavisto (2021); Polydoropoulou et al. (2020b); Smith et al. (2020); Williams (2021); Woolthuis et al. (2005); Ydersbond et al. (2020)
Business model (B6)	The lack of a business model for MaaS leads to operational problems and uncertainty in the distribution of roles and profits (or losses).	Karlsson et al. (2020); Hensher et al. (2020); Jittrapirom et al. (2020); Kostiainen and Tuominen (2019); Li and Voege (2017); Lund et al. (2017); Mladenović and Haavisto (2021); Smith et al. (2018); Smith et al. (2019); Smith et al. (2020)
Laws, Regulations, and Guidelines (B7)	The laws, regulations, and guidelines can be a barrier to successful MaaS adoption, such as ticket sales by third parties, subsidization of traffic, the uncertainty of the role of partners, competition laws, etc. In addition, MaaS should be legally supported on issues such as open data standards and security.	Butler et al. (2021); Chatterjee et al. (2022); ERTICO (2019); Hensher et al. (2020); Hesselgren et al. (2020); Hirschhorn et al. (2019); Karlsson et al. (2016); Karlsson et al. (2020); König et al. (2016); Kostiainen and Tuominen (2019); Li and Voege (2017); Lund et al. (2017); Mladenović and Haavisto (2021); Polydoropoulou et al. (2020b); Shah et al. (2021); Singh (2020); Smith et al. (2019); Williams (2021)

(*continued on next page*)

Table 2 (*continued*)

Barriers	Definition	Main References
Customer acceptance (B8)	There are sociological factors hindering the adoption of MaaS. The older generations have less intention and ability to use new technologies. Personal data without a regulatory standard for processing can lead to trust problems of the customer and negative judgments against MaaS. It is also difficult to change the habits of users with private cars.	Alarcin and Kircova (2020); Alonso-González et al. (2020); Alyavina et al. (2020b); Butler et al. (2021); Casadó et al. (2020); Cottrill (2020); ERTICO (2019); Fioreze et al. (2019); Golub et al. (2019); Hensher et al. (2020); Hensher et al. (2021b); Hoerler et al. (2020); Karlsson et al. (2020); Kayikci (2018); Keller et al. (2018); Kostiainen and Tuominen (2019); Lopez-Carreiro et al. (2021); Loubser et al. (2021); Lund et al. (2017); Lyons et al. (2019); Pangbourne et al. (2020); Silvestri et al. (2021); Storme et al. (2020); Tsouros et al. (2021); Williams (2021); Ye et al. (2020); Zhao et al. (2020); Zijlstra et al. (2020)

was conducted with 56 questions based on paired relationships. The potential users (daily commuters, occasional travelers, business users, elderly people, and so on) were not included in the expert group, as it was difficult to find people who understand MaaS and its implications in developing country context. Note that we assumed that the integration level of MaaS in Istanbul includes various public transportation routes (e.g., rail, bus, metro, ferry, funicular) with various vehicle modes (bus, maritime, railway operators, taxi, minibus, and shuttle operators), multimodal travel planner, book and pay, bundling/subscriptions, contracts among different mobility service providers, which corresponds to the third level of MaaS integration proposed by Sochor et al. (2018).

Although there is currently no real MaaS application in Turkey, there are several working groups to develop MaaS-related business models. A living laboratory for MaaS is being developed in Istanbul Metropolitan Municipality. Besides, there are some initiatives in cooperation with the Union of Municipalities of Turkey and Intelligent Transportation Systems Turkey (ITS Turkey) to disseminate MaaS knowledge and train potential public and private mobility service providers at the Ministry of Transport and Infrastructure of Turkey and increase public awareness. In addition, International Intelligent Transportation Systems Summit (ITS Summit) is held every year to improve knowledge about MaaS and to raise public awareness. To add this, some preliminary ITS applications for integration of public transport routes (e.g., bus, metro, metrobus, marmaray, light rail, funicular, and seabus), development of integrated payment platforms and applications of online route planners have been gradually evolving. Already some mobile phone applications that correspond to the initial levels of Sochor et al. (2018)'s MaaS integration topology can be seen in Turkey, such as Moovit and Google maps for integrated travel planning for all local mobility alternatives (e.g., bus, light rail, metro, train, ferry), Mobiett app for integrated travel planning offering mobility alternatives according to shortest travel time or minimum transfer times, minimum walking distance and so on and "Istanbulkart" app for integrated payment platform by using QR code or NFC. The existing solutions contribute to main mile travel by offering seamless switching between travel modes associated with the fixed routes, whereas the flexible routes for the first mile and last mile travels (e.g., collective taxi, minibus, van, ride-sharing services) are not involved in the travel plan. However, there are some mobile apps such as BiTaksi for Uber-like ride-hailing service and "Martı" app for shared scooters and mopeds. They might have a great potential to be incorporated in the MaaS′ first mile and last mile travel plan.

3.1.2. *Define the contextual relationship*

The next step is to identify the paired contextual relationships between individual barriers with the help of the experts' opinions. These contextual relationships are identified with the pairwise comparisons, such as "B1 influences B2", and there are three possible answers to explain how B1 influences B2: (1) "Agree," (2) "Neither agree nor

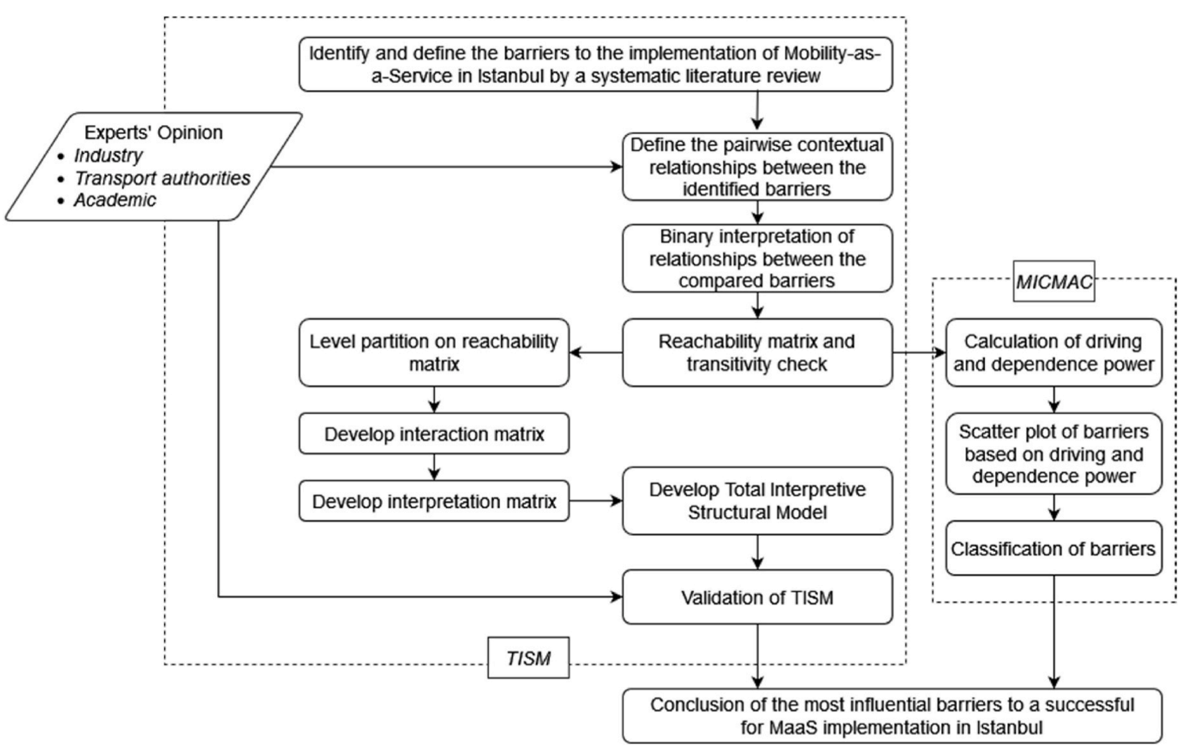

Fig. 2. TISM and MICMAC methodology.

disagree," and (3) "Disagree." As there are eight barriers in total in this study, 8 × 7 = 56 pairwise comparisons were collected from the experts. To develop group consensus, a relationship is regarded as positive only if at least 50% of the expert answers are positive. Otherwise, that relationship is categorized as "no relationship."

3.1.3. Binary interpretation of the pairwise comparison

The interpretation of the relationships among the identified barriers is coded into an "*n* x *n*" matrix, where *n* is the total number of barriers in the study. For each cell, the question "To what extent should/will B_i contribute to reaching B_j?" is answered to clarify the relationship (Jena et al., 2017; Sushil, 2012). Cell (*i, j*) has a value of either '1′ or '0′, depending on the influence of barrier B_i on barrier B_j. '1′ indicates the existence of the relationship between the barriers, while '0′ indicates no relationship (Mathivathanan et al., 2021). Note that diagonal cells are always 1. The initial reachability matrix is created according to the survey results, as presented in Table 3, where all relationships are denoted as 1 (formatted in bold) and highlighted in blue.

3.1.4. Reachability matrix

The reachability matrix is generated by using the pairwise relationships and the transitive relationships. The transitive relationships are obtained with the transitivity rule, i.e., if B_i affects B_j and B_j affects B_k, then B_i also affects B_k (Dubey and Ali, 2014; Mathivathanan et al., 2021). Therefore, although there is no relationship between the two barriers in the initial reachability matrix (Table 3), the TISM model can identify the relationship between these barriers using the transitive relationship. Once these relationships are identified, the final reachability matrix is created in which the transitive relationships are formatted in bold and highlighted in green, as shown in Table 4.

3.1.5. Level partitioning

Level partitioning is performed to group the barriers to ranked levels (Shibin et al., 2017). These levels form the basis of the TISM model and the digraph (Section 3.1.6) (Mathivathanan et al., 2021; Mathiyazhagan et al., 2013). A barrier grouped in a lower level cannot be connected to a barrier at a higher level. A barrier is assigned to the top-level (Level I) if the intersection set is identical to its reachability set, then the barriers in level I are removed from the entire set for the next iteration (Mathivathanan et al., 2021). Note that the intersection set of a barrier is identified as the common barriers in its reachability and antecedent sets. Upon removing the barriers in Level I, the procedure continues with the remaining barriers to identify the barriers to be grouped in Level II. The procedure terminates when all barriers are grouped into a level, and there are no barriers left for the next iteration. In this study, three iterations were sufficient to assign all barriers to their appropriate levels as shown in Table 5.

Table 4
Final reachability matrix.

	B1	B2	B3	B4	B5	B6	B7	B8
B1	1	1	**1**	**1**	1	1	0	**1**
B2	1	1	**1**	**1**	1	1	0	**1**
B3	0	0	1	0	0	0	0	0
B4	**1**	**1**	1	1	1	1	0	**1**
B5	**1**	1	**1**	**1**	1	1	0	1
B6	1	1	1	1	1	1	0	**1**
B7	1	**1**	0	0	**1**	**1**	1	1
B8	0	**1**	0	0	1	**1**	0	1

3.1.6. Development of digraph

The barriers are graphically arranged according to their levels, and the links between the barriers are depicted as arrows according to the relationships shown in the reachability matrix (Mathivathanan et al., 2021; Sushil, 2012). The direct relationships are shown as solid arcs, while the significant transitive relationships are shown by dashed arcs to generate the final TISM model (Fig. 3).

3.1.7. Development of binary interaction matrix

The TISM diagram is then transformed into a binary interaction matrix (Table 6), in which all interactions are represented as "1" (Sushil, 2012). The effective transitive connections are represented as 1 *

Table 5
Level partitioning for all barriers.

Barrier	Reachability set	Antecedent set	Intersection set	Level
B1	B1, B2, B3, B4, B5, B6, B8	B1, B2, B4, B5, B6, B7	B1, B2, B4, B5, B6	**II**
B2	B1, B2, B3, B4, B5, B6, B8	B1, B2, B4, B5, B6, B7, B8	B1, B2, B4, B5, B6, B8	**II**
B3	B3	B1, B2, B3, B4, B5, B6	B3	**I**
B4	B1, B2, B3, B4, B5, B6, B8	B1, B2, B4, B5, B6	B1, B2, B4, B5, B6	**II**
B5	B1, B2, B3, B4, B5, B6, B8	B1, B2, B4, B5, B6, B7, B8	B1, B2, B4, B5, B6, B8	**II**
B6	B1, B2, B3, B4, B5, B6, B8	B1, B2, B4, B5, B6, B7, B8	B1, B2, B4, B5, B6, B8	**II**
B7	B1, B2, B5, B6, B7, B8	B7	B7	**III**
B8	B2, B5, B6, B8	B1, B2, B4, B5, B6, B7, B8	B2, B5, B6, B8	**I**

Table 3
Initial reachability matrix.

Barriers		B1	B2	B3	B4	B5	B6	B7	B8
Collaboration and data sharing	B1	1	**1**	0	0	**1**	**1**	0	0
Data standardization	B2	**1**	1	0	0	**1**	**1**	0	0
Labour shortage	B3	0	0	1	0	0	0	0	0
Financial resources	B4	0	0	**1**	1	**1**	**1**	0	0
Infrastructure and payment services	B5	0	**1**	0	0	1	**1**	0	**1**
Business model	B6	**1**	**1**	**1**	**1**	**1**	1	0	0
Laws, Regulations and Guidelines	B7	**1**	0	0	0	0	0	1	**1**
Customer acceptance	B8	0	0	0	0	**1**	0	0	1

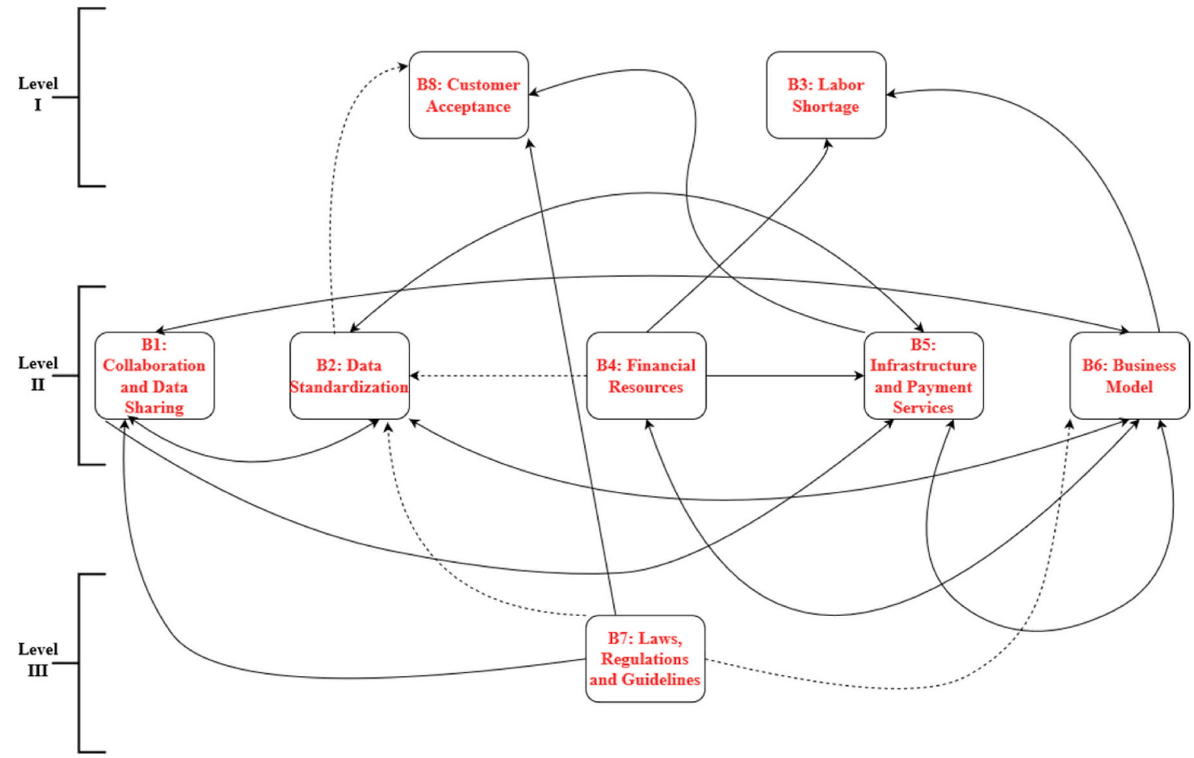

Fig. 3. Digraph showing both direct (solid lines) and transitive (dotted lines) links (Final TISM model).

(Mathivathanan et al., 2021). Note that all interactions and transitive connections are highlighted in blue.

3.1.8. Development of the TISM model

The information contained in the interpretative matrix and the diagram is used to develop the total interpretive structural model (Sushil, 2012). The information in the interpretation matrix is represented by the respective relationships in the digraph, as shown in Fig. 4.

3.1.9. Validation of TISM

The links represented in the initial TISM model should be validated to obtain the final TISM model. To this end, as pointed out by (Jayalakshmi and Pramod, 2015), the same group of experts given their details in Appendix B was contacted to rate the links. A total of 13 experts responded to validate the TISM model. Each of the 23 links between the barriers was asked to be evaluated by each expert based on a Likert scale from "1″ to "5″ with "1″ being "strongly disagree," and "5″ being "strongly agree." Each link that reached or exceeded the average score of three was accepted and kept in the model, and the other links were removed from the model. All links except B1–B6, B6–B2, and B6–B5 were accepted, and the rejected links were removed from the model. The validation assessment of the TISM model is given in Appendix C. The overall score of the model is 3.74, which is above the threshold value of 3. Therefore, we accepted the model as verified. The final validated TISM model is presented in Fig. 5.

3.2. Matrix-based-Multiplication-Applied-to-a-classification (MICMAC)

MICMAC method analyzes the impact of variables/items based on the driving force and dependencies measured by their relationships (Dhir and Dhir, 2020; Mathivathanan et al., 2021). MICMAC analysis was employed in this study to identify the main barriers that hinder the adoption of MaaS. Each barrier's driving and dependence powers are obtained by calculating the row sum and column sum from the final reachability matrix, respectively (Table 7). Then the barriers are plotted as a diagram (Fig. 6), having the driving force and dependence values as

Table 6
Binary interaction matrix.

Barriers		B1	B2	B3	B4	B5	B6	B7	B8
Collaboration and data sharing	B1	-	1	0	0	1	1	0	0
Data standardization	B2	1	-	0	0	1	1	0	*1**
Labour shortage	B3	0	0	-	0	0	0	0	0
Financial resources	B4	0	*1**	1	-	1	1	0	0
Infrastructure and payment services	B5	0	1	0	0	-	1	0	1
Business model	B6	1	1	1	1	1	-	0	0
Laws, Regulations and Guidelines	B7	1	*1**	0	0	0	*1**	-	1
Customer acceptance	B8	0	0	0	0	0	0	0	-

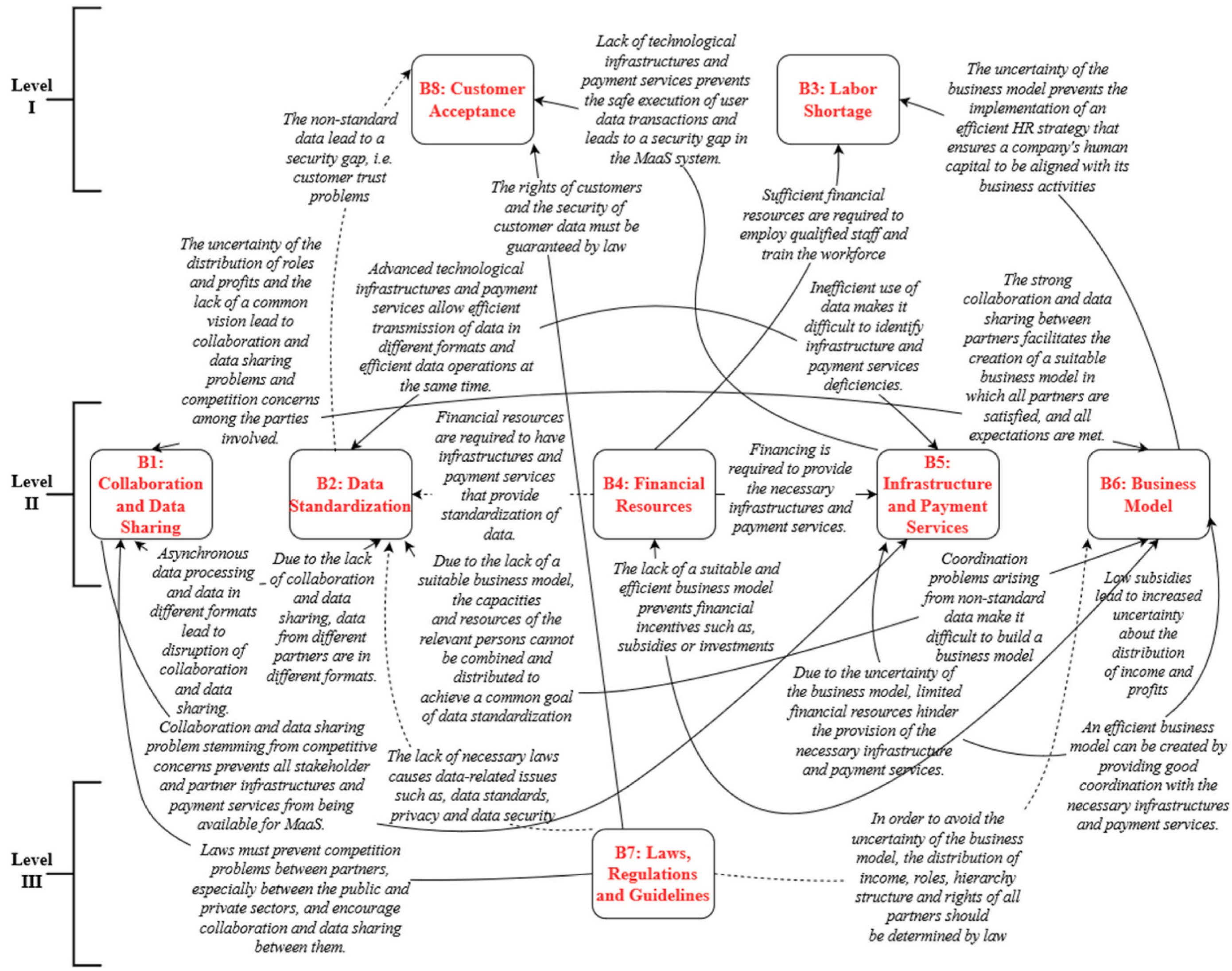

Fig. 4. Total interpretive structural model (solid and dotted lines represent direct and transitive links, respectively).

its x and y axes, respectively. Then, all barriers are classified into four quadrants: (I) autonomous, (II) dependent, (III) linkage, and (IV) driving (Dhir and Dhir, 2020; Mathivathanan et al., 2021).

4. Discussion of findings

The barriers are classified into three levels in the TISM model (Fig. 5). Level 3 consists of the most important barriers and is located at the bottom of the hierarchy. According to the case study results, the third level of the TISM model includes only a single barrier (laws, regulations, and guidelines (B7)). This is the most critical barrier to introducing the MaaS concept in Istanbul because it significantly influences other barriers. While many studies in the developed country context emphasized this barrier (see Table 2 for a detailed analysis), our case study results showed that it is even more important for a large emerging metropolis such as Istanbul. For a successful MaaS implementation, legal and political regulations are required in many areas, e.g., to determine the business model, tax and income distribution, the rights of participants and users, financial support, and subsidies. Therefore, the necessary laws and regulations should be designed first, and then MaaS should be put into operation after establishing a proper legal foundation (Polydoropoulou et al., 2020a). By doing so, some problems (e.g., third-party ticket sales) that are caused by a legal barrier can be eliminated, or their adverse effects on MaaS operations and adaption can be minimized.

The majority of the barriers are located at Level 2: collaboration and data sharing problems (B1), data standardization issues (B2), limited financial resources (B4), lack of technological infrastructures and payment services (B5), and business model (B6). Most studies in the existing literature also emphasized these barriers (see Table 2). In the resulting TISM model (Fig. 4), these barriers connect upper and lower-level barriers and have significant relationships with them. Specifically, the lack of collaboration and data sharing between the partners (B1) and the non-standardization of data (B2) have negative impacts on the system workflow and, therefore, reduce the efficiency of MaaS. Notwithstanding the importance of B1 and B2 in Istanbul, collaboration and data sharing as well as data standardization barriers are less significant in developed countries where the MaaS ecosystem is more mature to collaborate and share the standardized data, although this does not guarantee a willingness to collaborate. The lack of suitable infrastructures and payment services (B5) can create a barrier between the MaaS actors and the customers by preventing the actors from working in a coordinated manner or customers from accessing the system. This barrier (B5) is less relevant in developed countries as they already provide well-developed physical as well as digital infrastructures, including integrated payment systems. Many important issues, such as rights, division of responsibilities, and revenue model among members and stakeholders of the ecosystem, can remain unclear in the absence of

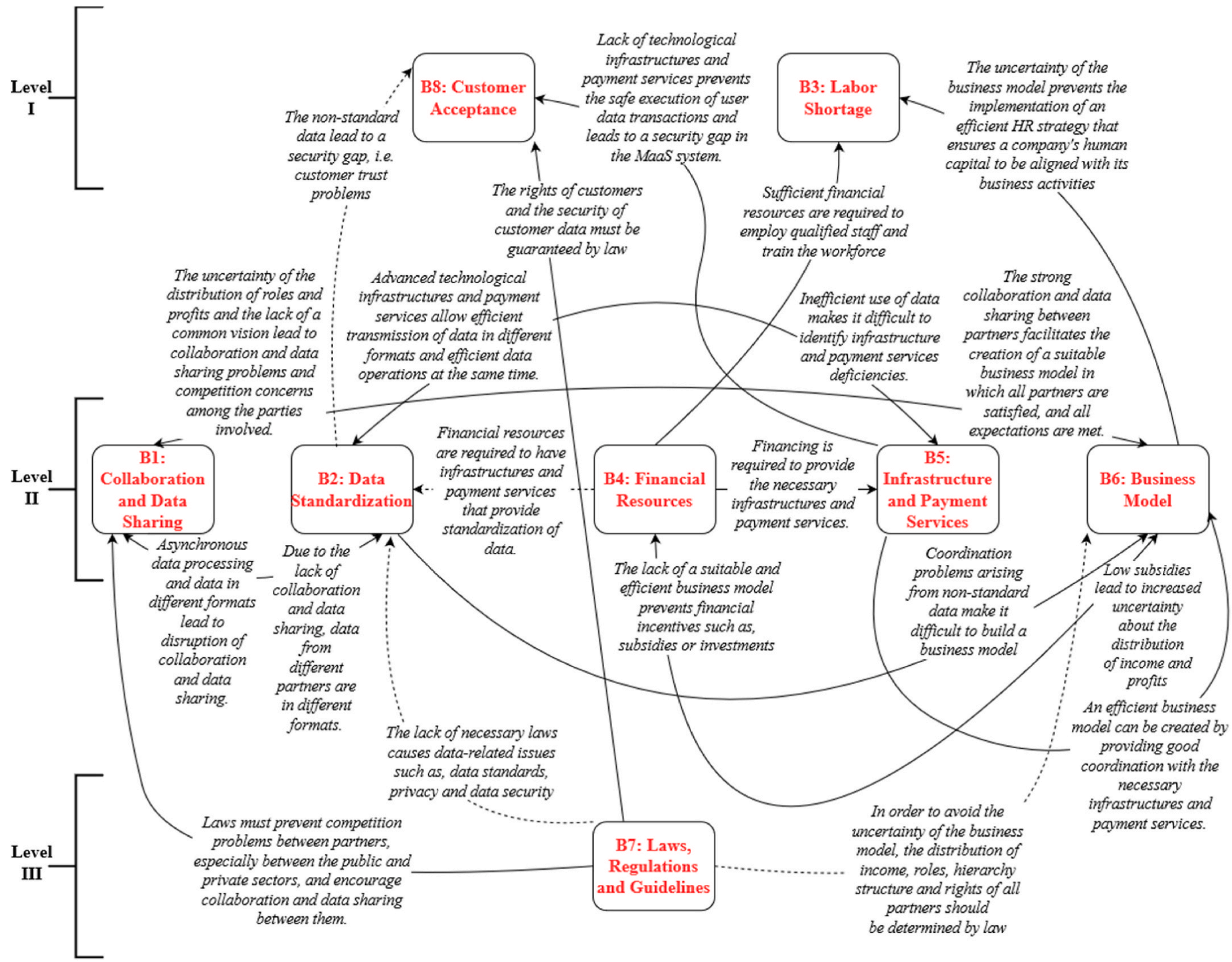

Fig. 5. Validated Final TISM model (solid and dotted lines represent direct and transitive links, respectively).

Table 7
Calculation of driving and dependence powers of the MaaS barriers.

Barriers	B1	B2	B3	B4	B5	B6	B7	B8
Dependence power	6	7	6	5	7	7	1	7
Driving power	7	7	1	7	7	7	6	4

a suitable business model (B6), which can make potential stakeholders reluctant to get involved in the ecosystem. Similar to our findings in Istanbul, this barrier (B6) is also reported as one of the important barriers in developed countries. Financial resources (B4) are one of the essential building blocks for the economic sustainability of this service. As noted in some MaaS initiatives (Karlsson et al., 2016; Nikitas et al., 2017), the lack of adequate financial support and incentives can lead to the termination of the service, no matter how beneficial the MaaS system is. Compared to Istanbul's case, developed countries also require adequate financial resources to implement and operate MaaS systems. Laws, regulations, and guidelines (B7) barrier directly or indirectly affect the barriers of Level 2. Appropriately designed laws and regulations can improve collaboration and data sharing (B1) by preventing competition issues between MaaS partners, especially between the public and private sectors. Similarly, better business models (B6) can be defined by the specific laws and regulations that clarify roles, rights, and distribution of income decisions among MaaS actors. Some issues due to the data Standardization barrier (B2) can be eliminated by designing laws and regulations for data standards, privacy, and data security. Data standardization (B2) also requires interoperability, which requires proper infrastructure and payment services (B5) and an appropriate business model (B6), as well as close collaboration and data sharing (B1) between partners. A sustainable MaaS business model (B6) and required infrastructure and payment services (B5) can only be achieved with sufficient financial resources (B4).

Level 1 is located at the top layer in the hierarchy and includes the least influential barriers (Labor shortage to implement and operate MaaS (B3) and customer acceptance to adopt MaaS in Istanbul (B8)). Although these two barriers have the minimum effect on the other barriers to MaaS adoption in Istanbul, they are found to be significant in the TISM model and still need to be addressed during the MaaS adoption. They are mostly influenced by the other barriers from Levels 2 and 3. Despite the significant literature on the customer acceptance barrier to MaaS implementations in developed countries (Butler et al., 2021; Hensher et al., 2021b; Karlsson et al., 2020), our case study results indicate that this sociological barrier is not as important as the other barriers in Istanbul. This divergence from the findings of the literature on MaaS indicates the difference between developed and developing countries in terms of MaaS adoption issues. Customer acceptance can be negatively affected by the lack of laws and regulations (B7) on the

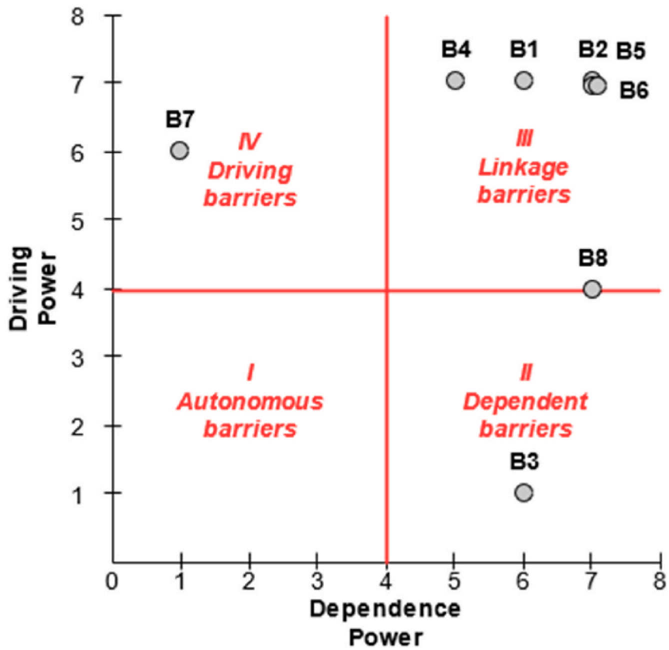

Fig. 6. Driving power and dependence diagram.

privacy of customer data or security issues due to non-standard data (B2). As another important relationship between the MaaS barriers in low-income countries, our case study results of Istanbul showed that insufficient infrastructure and payment services (B5), including access to smart technologies (Golub et al., 2019) or digital payment/banking methods such as digital wallets (ERTICO, 2019) hinder the usage of MaaS technologies and therefore reduces the customer acceptance. Similarly, the labor shortage is not found to be as critical as the higher-level barriers identified in the TISM model. Specifically, the lack of financial resources (B4) affects the labor shortage barrier since qualified staff cannot be hired (or retained) and properly trained for MaaS. Also, the uncertain nature of MaaS as new technology and lack of proper business models (B6) prevent companies from investing in the human capital for MaaS.

Table 8 summarizes the interpretations of these relationships among the barriers in a matrix format where non-empty cells correspond to values of 1 or 1* in the binary interaction matrix (Table 6).

The driving and dependence powers of the barriers are visualized (Fig. 6) using the MICMAC analysis according to the results found in Table 7. The first quadrant is defined as the autonomous barriers with low driving and dependence powers. According to the results of our case study, there is no barrier in this category. The second quadrant consists of the dependent barriers with weak driving power but strong dependency levels. The labor shortage barrier (B3) is the only barrier in this category, which has the weakest driving force, while it is severely affected by other barriers due to its large dependence power. The third quadrant consists of the linkage barriers with strong dependence and driving powers. Therefore, any changes in these barriers affect the entire system. All remaining barriers except B7 are categorized as linkage barriers. Collaboration and data sharing problems (B1), data standardization (B2), limited financial resources (B4), lack of technological infrastructures and payment services (B5), and business model (B6) fall into the category of linkage variables that lie in the third quadrant. Although Customer acceptance (B8) is located at the border of the second and third quadrants, it is also considered to be in the third quadrant because of its high dependence level. These barriers should be considered seriously as they have high driving power and dependency that can affect all other barriers and disrupt the entire MaaS implementation. Note that data standardization (B2), infrastructures and payment services (B5), and business models (B6) have the same drive power and dependency values, and they drive the system most strongly and are most dependent on other variables. The fourth quadrant represents the driving barriers that have a strong influence on other barriers (driving power) but weak dependence power. Only the barrier of laws, regulations, and guidelines (B7) is included in this category. It means that political and legal aspects strongly affect other barriers, but it is significantly not affected by the other barriers. Thus, this is the most influential barrier, and it is the root cause of the other barriers. Therefore, the legal and political dimensions of MaaS should be dealt with first, and the problems that arise from B7 can be reduced or eliminated.

4.1. Theoretical contributions

This study provides several theoretical contributions to the existing MaaS literature. This is the first study to identify significant barriers to the successful adoption of MaaS, especially for developing countries. Also, we provide a comprehensive literature review on these barriers. In addition, this study reveals the structural relationships between the identified barriers using TISM and MICMAC methods. Since previous studies have not dealt with relationships between the barriers, our study uniquely explores how the MaaS barriers are interrelated using a TISM-MICMAC based methodology. To this end, the proposed methodology herein employs the results from both the extensive literature review and MaaS experts' opinions. Using the TISM method, the MaaS barriers are assigned to different hierarchies so that the interrelationships and importance levels of the barriers are clearly identified. Also, using the MICMAC method, these barriers are clustered into different groups (i.e., independent, dependent, autonomous, and linkage barriers) according to their dependence and driving powers using the results of the TISM approach. Therefore, this study provides a novel use of TISM and MICMAC methods to offer some important insights into significant MaaS implementation barriers and their interrelationships.

4.2. Managerial and practical contributions

With the case of Istanbul, this is the first study carried out on a feasibility study for MaaS in Turkey and provides several managerial insights on the successful implementation of MaaS systems by exploring the barriers and their relationships. It also addresses how these barriers can be prevented, and the risk of MaaS failure can be minimized. This study showed that the most important barrier is laws, regulations, and guidelines for MaaS operations. Therefore, before implementing MaaS, the legal framework for this service should be clearly defined. This will also help to build the necessary infrastructure and payment services, define data standards, develop business models, and create a collaborative culture among private companies and public transport authorities. This result also verifies the ongoing efforts of the Ministry of Transport and Infrastructure of Turkey to take some initiatives regarding new laws, regulations and guidelines to support the infrastructures of MaaS ecosystems. Specifically, the MaaS concept was strategically planned at a national level and prioritized for implementation within the frame of the national intelligent transportation systems strategy document and the 2020–2023 action plan of the Ministry of Transport and Infrastructure of Turkey (The Ministry of Transport and Infrastructure of Turkey, 2020). Although a specific roadmap was provided for strategic goals (i.e., Developing the ITS Infrastructure, Providing Sustainable Smart Mobility, Ensuring Road and Driving Safety, Creating a Livable Environment and Conscious Society, and Ensuring Data Sharing and Security) and their action items, the Ministry has not publicly reported any progress regarding the implementation of the plan.

In order to implement a successful MaaS concept in Istanbul, the government, authorities, and industry should work together efficiently. Also, to ensure the economic sustainability of the MaaS implementations, financial incentives should be promoted by the political decision-makers and given by the government authorities. For example, with

Table 8
Interpretive matrix (The cells with 1* are formatted as italic).

	B1	B2	B3	B4	B5	B6	B7	B8
B1	–	Due to the lack of collaboration and data sharing, data from different partners are in different formats.			Collaboration and data sharing problem stemming from competitive concerns prevents all stakeholder and partner infrastructures and payment services from being available for MaaS.	The strong collaboration and data sharing between partners facilitates the creation of a suitable business model in which all partners are satisfied and all expectations are met.		
B2	Asynchronous data processing and data in different formats lead to disruption of collaboration and data sharing.	–			The inefficient use of data makes it difficult to identify infrastructure and payment services deficiencies.	Coordination problems arising from non-standard data make it difficult to build an efficient business model.		*The non-standard data lead to a security gap, i.e., customer trust problems.*
B3			–					
B4		*Financial resources are required to have infrastructures and payment services that provide standardization of data.*	Sufficient financial resources are required to employ qualified staff and train the workforce.	–	Financing is required to provide the necessary infrastructure and payment services.	Low subsidies lead to increased uncertainty about the distribution of income and profits.		
B5		Advanced technological infrastructures and payment services allow efficient transmission of data in different formats and efficient data operations at the same time.			–	An efficient business model can be created by providing good coordination with the necessary infrastructures and payment services.		The lack of technological infrastructures and payment services prevents the safe execution of user data transactions and leads to a security gap in the MaaS system.
B6	The uncertainty of the distribution of roles and profits and the lack of a common vision lead to collaboration and data sharing problems and competition concerns among the parties involved.	Due to the lack of a suitable business model, the capacities and resources of the relevant parties cannot be combined and distributed to achieve a common goal of data standardization.	The uncertainty of the business model prevents the implementation of an efficient HR strategy that ensures a company's human capital is aligned with its business activities.	The lack of a suitable and efficient business model prevents financial incentives such as subsidies or investments.	Due to the uncertainty of the business model, limited financial resources hinder the provision of the necessary infrastructure and payment services.	–		
B7	Laws must prevent competition problems between partners, especially between the public and private sectors, and encourage collaboration and data sharing between them.	*The lack of necessary laws and regulations causes data-related issues such as data standards, privacy, and data security.*				*In order to avoid the uncertainty of the business model, the distribution of income, roles, hierarchy structure, and rights of all partners should be determined by laws and regulations.*	–	The rights of customers and the security and privacy of customer data must be guaranteed by laws.
B8								–

subsidies and financial support, the economic difficulties that many earlier MaaS pilot studies faced can be overcome in the initial implementation stages. Although it has little influence on the other barriers, the customer acceptance barrier should also be taken into account. For this purpose, the targeted customer segment in Istanbul must be clearly identified, and customer demand and preferences must be carefully analyzed. This result also indicates a lack of public awareness about MaaS; therefore, the Istanbul Metropolitan Municipality and some associations like the Union of Municipalities of Turkey and ITS Turkey are offering training programs to increase public awareness. The labor shortage barrier is found to be significant, but it is mainly affected by the other barriers because it can easily be prevented with sufficient financial support, required laws and regulations, and harmoniously working business models. Since there is currently no active MaaS pilot study in Turkey, not many professionals are actively working in this field in Istanbul. However, as a large emerging metropolis, Istanbul is Turkey's most developed and vibrant city with a well-established startup culture and has the most innovative, talented, and diverse human capital in the entire country. According to Drdatastats (2020), Istanbul attracts the highest educated people in Turkey, where 22.90% of the population having an undergraduate or graduate degree live in Istanbul.

This study provides novel implications on MaaS implementations from the point of view of developing countries. Since all MaaS studies in the literature have been conducted on developed countries, this study also provides a unique view of developing countries. The major differences between the barriers emphasized in the literature and the ones identified in the case study of Istanbul. For example, most studies in the literature emphasize the customer acceptance barrier, and it is not as critical as a barrier in Istanbul because the lack of laws and regulations seems to be more critical in a developing country.

5. Conclusion

Mobility-as-a-Service is a transport concept that addresses the transportation needs of the digitized and urbanized world by offering a sustainable transport service. The stakeholders and partners are involved in a profitable, integrated, and environmentally friendly transportation system, providing citizens with fast, cheap, and comfortable end-to-end transportation options. There are many ongoing MaaS pilot studies and operational systems that have been initialized in various countries around the world; however, most of the implementations are from developed countries, and there is a need to investigate the applicability of MaaS in developing countries. Also, the studies investigating barriers to MaaS only identify the barriers observed in the applications. There has been no study on determining significant barriers to successful MaaS implementations and identifying their relationships with each other in a holistic way. The aim of this study is to examine the feasibility of the MaaS implementation in Istanbul, one of the world's most crowded cities located in Turkey, by investigating the possible barriers to successful implementation using the TISM and MICMAC methods and identifying the relationships among these barriers.

Eight possible barriers were identified with an extensive systematic literature review. Various experts from different areas of urban transportation were involved in the analysis to determine the levels of these barriers with the TISM method and identify the relationships among the barriers. The driving power and dependencies of these barriers were analyzed and classified by the MICMAC method. The results of the Istanbul case showed that the most important barrier to adapting the MaaS concept for Istanbul is related to "laws, regulations, and guidelines," which need to be addressed first. Therefore, as a result of this study, the specific legal framework is proposed to be defined by the legislators or the government before starting the MaaS implementations.

This study can help minimize the risk of failure of the possible MaaS system in Istanbul by identifying the main barriers that may arise at the early stages of the MaaS implementation. It explains the potential barriers that transport authorities and managers in the transport sector should consider in this context, as well as the relationships between the barriers and the actions that can be taken. In addition, this work can be guidance for managers and practitioners who will develop and implement MaaS solutions.

This work has several limitations. First, the number of experts who conducted the surveys was limited because of the limited number of MaaS experts in Turkey. However, drawing inspiration from a pioneering study by Mathiyazhagan et al. (2013), the sample size of the experts for TISM and MICMAC was determined similarly for this study and was sufficient to draw conclusions for a MaaS implementation in Istanbul. Second, these barriers are based on the extensive systematic literature review conducted in this study, and most of these barriers were identified for MaaS implementations in developed countries. However, the MaaS experts of this study also verified that these barriers are valid for our case study in Istanbul and did not offer any additional barriers to consider. As the case study was conducted in Istanbul, it may not be possible to generalize these results to developed countries because the level of maturity between countries may be significant. As another limitation, only qualitative data were used in this work, and no quantitative data was collected, such as how many citizens who live in Istanbul are already paying for any mobility services, usage percentages of transportation modes or means, and willingness to use MaaS systems in Istanbul.

As a future study, the maturity level of Istanbul in terms of MaaS, traveler transportation preferences, and subscription choices can be explored with extensive surveys. Also, the developed TISM-MICMAC methodology can be applied to the developed countries in different regions (e.g., Europe, the United States, or Australia), and their results can be compared with the results of this study to identify the similarities and differences in the significance of the barriers among various countries and regions.

CRediT author statement

Yasanur Kayikci: Conceptualization; Data curation, Supervision; Formal analysis; Methodology, Funding acquisition; Resources; Project administration; Roles/Writing - original draft; Writing - review & editing **Ozgur Kabadurmus:** Formal analysis; Investigation; Methodology; Software; Writing - review & editing; Visualisation; Validation.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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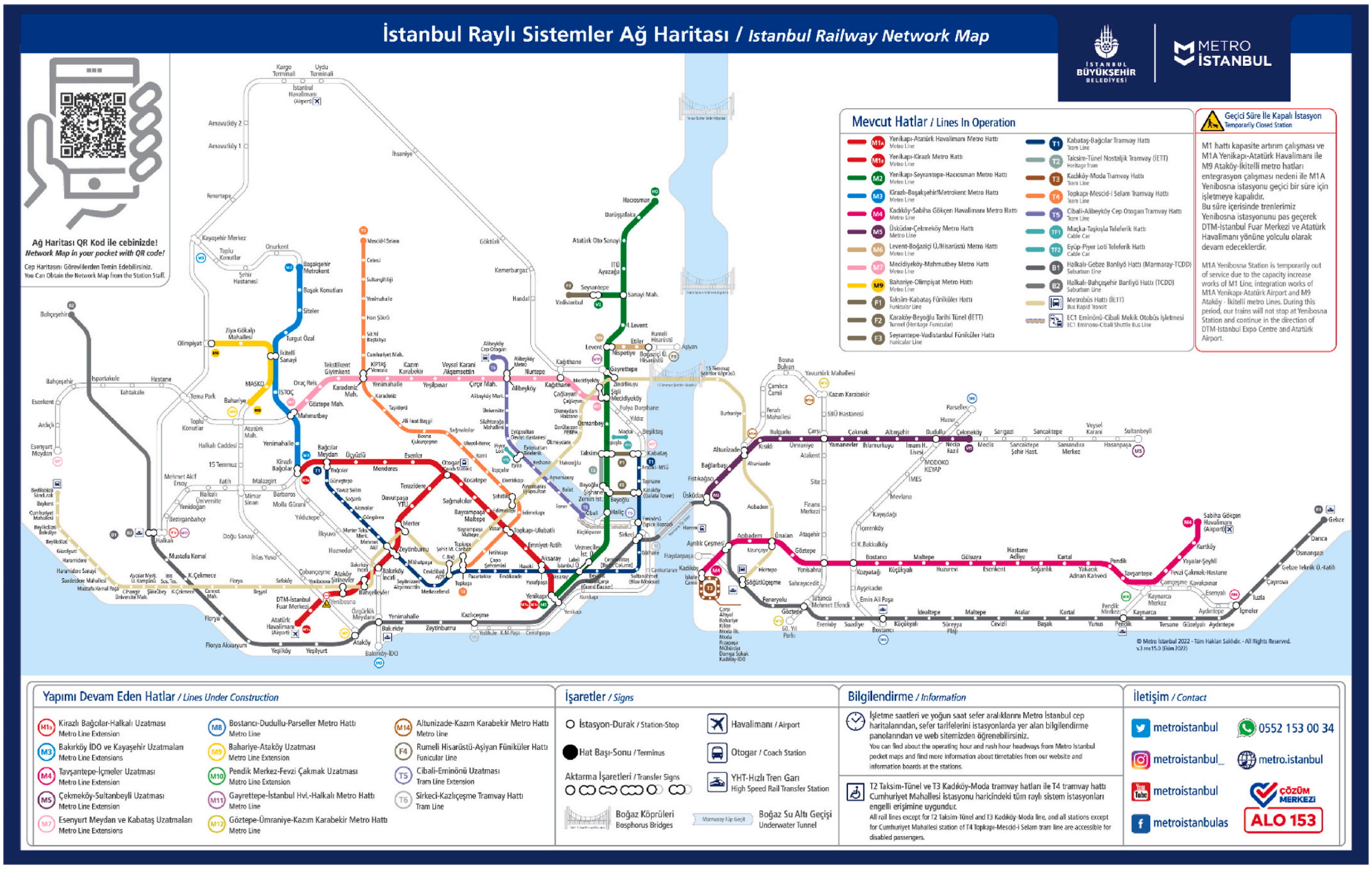
Appendix A. Istanbul Railway Network Map



The illustration was taken from https://www.metro.istanbul/en/YolcuHizmetleri/AgHaritalari.

Appendix B. Profile of the expert group

#	Profile of expert	Degree	Experience	Sector
1	Consultant in Transportation and Mobility	MSc in Operational Research	12 Years	Private Urban Mobility
2	University Professor in Transportation and Mobility	Ph.D. in Transportation	18 Years	Higher Education
3	Head of Department for Digital Technologies	MSc in Computer Science	15 Years	Ministry of Transport and Infrastructure of Turkey
4	Company Owner and Chief Executive Developer	Ph.D. in Operations Research and Transportation Logistics	20 Years	Private Urban Mobility
5	Development Engineer for Mobility Concepts	MSc in Transportation Engineering	10 Years	Ministry of Transport and Infrastructure of Turkey
6	Head of Research and Development	MSc in Transportation and Logistics	22 Years	Private Urban Mobility
7	Head of City Mobility	MSc in Industrial Engineering	24 Years	Istanbul Metropolitan Municipality
8	Head of Digital Banking and OmniChannel	MA in Economics	13 Years	Finance and Banking
9	University Professor in Supply Chain and Logistics	Ph.D. in Supply Chain Management	16 Years	Higher Education
10	Head of Digital Service Transformation	MA in Finance	12 Years	Finance and Banking
11	Head of Research and Development	Ph.D. in Computer Science	9 Years	Public Urban Mobility
12	University Professor in Digital Transformation and Mobility	Ph.D. in Transportation and Logistics	14 Years	Higher Education
13	Head of Smart Mobility	MSc in Industrial Engineering	12 Years	Private Urban Mobility

Appendix C. Validation assessment of the TISM model

#	Paired comparison of barriers	Responses from Experts (E)													Average Response	Accept/ Reject link
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13		
1	The lack of collaboration and data sharing will affect the lack of data standardization.	4	3	4	3	3	5	4	3	4	4	4	4	4	3.77	Accept
2	The lack of collaboration and data sharing will affect the lack of a suitable business model.	3	4	4	3	4	3	4	4	3	4	4	3	4	3.62	Accept
3		2	3	3	3	1	2	3	2	3	4	4	3	3	**2.77**	**Reject**

(*continued on next page*)

(*continued*)

#	Paired comparison of barriers	Responses from Experts (E)													Average Response	Accept/ Reject link
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13		
	The lack of collaboration and data sharing will affect the lack of necessary infrastructure and payment services.															
4	The lack of data standardization will affect the lack of collaboration and data sharing.	5	4	5	4	5	5	5	5	5	5	4	4	5	4.69	Accept
5	The lack of data standardization will affect the lack of necessary infrastructure and payment services.	3	4	4	3	3	3	4	3	3	4	3	4	3	3.38	Accept
6	The lack of data standardization will affect the lack of a suitable business model.	3	4	3	3	4	3	4	2	3	4	4	2	2	3.15	Accept
7	Lack of data standardization will affect poor customer acceptance.	3	4	4	4	3	5	5	4	3	5	4	3	3	3.85	Accept
8	Limited funding will affect the lack of data standardization.	4	3	4	4	4	4	4	4	5	4	3	4	4	3.92	Accept
9	Limited funding will affect labor shortages.	5	5	5	4	5	5	5	4	3	5	4	5	4	4.54	Accept
10	Limited funding will affect the lack of necessary infrastructure and payment services.	4	4	4	5	5	5	5	5	5	5	4	5	4	4.62	Accept
11	Limited funding will affect the lack of a suitable business model.	4	4	4	3	4	3	4	3	3	3	3	3	4	3.46	Accept
12	The lack of necessary infrastructure and payment services will affect the lack of data standardization.	4	5	4	4	4	3	4	4	5	4	4	4	4	4.08	Accept
13	Lack of necessary infrastructure and payment services will affect the lack of a suitable business model.	4	3	4	2	2	3	4	4	3	3	2	4	3	3.15	Accept
14	Lack of necessary infrastructure and payment services will affect poor customer acceptance.	3	3	2	2	4	4	4	3	4	2	3	3	4	3.15	Accept
15	The lack of a suitable business model will affect the lack of collaboration and data sharing.	4	5	4	5	5	5	4	4	4	4	5	5	4	4.46	Accept
16	The lack of a suitable business model will affect the lack of data standardization.	2	3	4	3	2	2	3	2	1	3	1	3	4	**2.54**	**Reject**
17	The absence of a suitable business model will affect labor shortages.	4	4	4	4	4	3	3	3	3	4	3	3	3	3.46	Accept
18	The lack of a suitable business model will affect labor shortages.	2	4	3	3	4	4	3	4	4	4	3	4	4	3.54	Accept
19	The lack of a suitable business model will affect the lack of necessary infrastructure and payment services.	3	3	3	2	0	3	4	3	3	4	2	3	3	**2.77**	**Reject**
20	Laws, regulations, and guidelines will affect the lack of collaboration and data sharing.	3	4	4	4	4	5	5	4	3	2	4	5	5	4.00	Accept
21	Laws, regulations, and guidelines will affect the lack of data standardization.	4	5	3	5	5	4	4	3	5	5	5	4	5	4.38	Accept
22	Laws, regulations and guidelines will affect the lack of a suitable business model	4	5	4	5	5	5	4	4	4	4	5	5	4	4.46	Accept
23	Laws, regulations, and guidelines will influence a lack of customer acceptance.	5	5	4	4	2	5	4	4	5	5	3	4	4	4.15	Accept
	The average score for the model														3.74	Accept

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