Interoperability Concerns for Multidimensional Urban Mobility Within the Frame of MaaS

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Abstract Nowadays, due to urbanization growth, the need for mobility arises around the world. Some cities indeed are seeking for innovative solutions in order to meet the increasing users demand in connectivity, among which mega cities that have introduce air mobility. This latter will increase the mobility externalities and complexify its management. In the past decade, mobility as a service paradigm has been proven as the best approach to address such issues. But the current solutions are provided by autonomous mobility providers. In order to provide policy-makers in cities with a decision support tool allowing them to manage traffic regulation, environmental pollution, safety of the passengers, and services and infrastructures renewal, there is a need to address interoperability issue between the existing mobility systems. This paper is a preliminary study of interoperability concerns in the context of multidimensional urban mobility, which includes land and air modes. To that end, we present and discuss the building blocks of the underlying system and show which kinds of the interoperability occur and provide directions to solve them, within the frame of mobility as a service (MaaS).

Keywords Mobility as a service · Urban air mobility · Multidimensional urban mobility · Interoperability

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1 Introduction

In recent years, we have witnessed a rapid growth of urbanization which poses a major challenge to the cities. An alarming increase in population, economic, social, environmental, and traffic-related problems is becoming more acute across the globe, particularly in mega cities. These latter were looking for a solution to ever-growing needs of the population, developed with hopes of economies of scale, both for the governments and the businesses (construction, manufacturers, suppliers, etc.) that helped build them. Another advantage was vicinity of the public to great resources and occupations that these cities would provide. Industries were welcomed to these cities since they knew the cities could hold their workforce and provide a flourishing environment both for the workers and the enterprises.

The mounting pace of urbanization threatens infrastructure of cities (e.g., it renders transportation system inadequate and ineffective). This creates a number of other problems which prove significantly harmful to the lives of people and to their financial stability. Owing to the fact that the need of urban mobility arises for urban planning decision-makers to solve transportation challenges, such as traffic congestion, safety of the passengers, environmental pollution, and infrastructures renewal. Urban mobility states to the effective movement of people and goods, by well-organized, environmentally good, safe, and reasonable transportation that contributes to improving social fairness, public health, resilience of cities, and efficiency. Two-dimensional transportation and mobility are recognized as central to sustainable development since they increase economic progress, enhance accessibility, and achieve better integration of the economy while regarding the situation. Better transport encourages universal access to social services and therefore can make an important contribution to merging and achieving development advantages in urban areas. In the foreseeable future, decision-makers will introduce an efficient deployment of the new mobility paradigm, which includes the air mode. Urban air mobility (UAM) refers to as a third dimension of the mobility which is a significantly effective solution for the problems of areas where merely increasing two-dimensional capacity cannot tackle enduring traffic problems. It also creates new opportunities for travelers for whom personal comfort and speed are at a premium, as well as for rescue services. Moreover, gradual merger of urban air mobility with existing mobility landscape would pave the path for smooth and safe travel. It would give the passenger tremendous experience at an increasingly low cost [1]. As a matter of fact, there are various private mobility providers who deliver large number of mobility services in the context of multidimensional urban mobility (MUM). In order to facilitate public authorities to enhance services and infrastructures availability and quality, for the future mobility, the systems managing the current mobility services need to be interoperable, so as to manage the underlying complexity.

The rest of the paper is structured as follows: Sect. 2 highlights the related work associated with urban mobility concerns, including a discussion on how MaaS addresses such concerns, while Sect. 3 presents some interoperability concerns at different levels for MaaS. Finally, Sect. 4 concludes the paper and provides directions for future work.

2 Related Work

This section outlines the main studies related to MUM and the associated interoperability issues.

As stated earlier, the rapid growth of urbanization spawns a variety of MUM concerns which must be tackled timely, such as traffic congestion, infrastructure, safety of the passengers, and environmental pollution (as shown in Fig. 1).

- **Traffic congestion**. Urbanization creates a lot of traffic-related problems. Congestion has proved to be a significant issue. Surely, if there is a constant increase in the number of vehicles while the road system and parking areas remain the same, com mute will become difficult. This particularly occurs in the urban areas; however, the problem of congestion cannot be eradicated by merely initiating infrastructure projects, such as bridges, roads, and railway networks. Technology has evolved as a tool to solve human problems and making lives easier, and it is greatly helpful in reducing congestion as well. It is very important to note other factors that are responsible for traffic jams like accidents, maintenance work, ineffective transportation systems, etc., which needs to be tackled as well, both individually and a part of the overall solution [2].
- **Infrastructures**. There is a chain of railway networks, roads, footpaths, airports, and other infrastructure projects which facilitate transportation. These need to be planned according to the projected needs of each community and in places where new projects are not possible, rejuvenation or at the very least up-keep projects, and it can be implemented to make sure that the systems work as expected, helping prepare for increased or decreased flow accordingly [3].

Fig. 1 MUM concerns

- **Safety of the passengers**. Many accidents take place due to increase in traffic. Often, the more congested the traffic in urban areas is, the more the accidents, injuries, and deaths are probable. Some countries have experimented with rules like allowing only a specific segment of cars (e.g., cars with odd or even registration numbers) on roads on certain days, but people bypass these laws by buying multiple cars. There is also a decreased sense of security among the commuters [4].
- **Environmental pollution**. Energy consumption has colossally enhanced due to urban transportation. Therefore, pollution has increased. Coupled with vexing noise, pollution has rendered life of urban people miserable as it is gravely injurious to their health [5].

The aim of city planners is to improve cities' management of natural and municipal resources and in turn the quality of life of their citizens. A city that performs well in the economy, people, governance, mobility, environment, and living, and is built on a clever combination of endowments and activities of self-decisive, independent, and aware citizens [6]. Finding a way to deal with above cited MUM concerns, city planners need some smart urban mobility solutions such as MaaS.

2.1 Mobility as a Service

In the vision of city, MaaS is globally a new way of structuring urban mobility that meets sustainability requirements, since its intended purpose is to prevent individuals from using their own vehicles. As a counterpart, a wide range of services is offered to them. Indeed, it is based on a wide use of digital technologies to guarantee access to information for users and the invoicing of the services used, within the frame of sustainable development. It enables the users to easily find the best route, price, multimodal framework across several end-to-end services (through convenient tools such as recommender systems or routing planners), and real-time information such as traffic condition time of day and demand. MaaS also organizes the relationships of the urban mobility stakeholders and ensures that their respective priorities are met: (i) the end user prioritizes speed and cost for his or her travel, without sacrificing comfort and reliability; (ii) the transport authority must ensure accessibility to the city's various attractions while reducing costs to make the best use of public funds, in a context where environmental concerns and their impact on health (pollution) and climate (carbon footprint) are becoming increasingly important; (iii) mobility operators, public and/or private, highlight the need for profitability of the services they offer in order to be able to invest and pursue the development of services that are increasingly in line with users' expectations [7]. Righteous cycle in relation to these stakeholders' priorities can then occur: (i) services provided to end users motivate them leaving their private cars for public modes; (ii) the city center is then relieved of congestion, which also reduces the carbon footprint, while (iii) users switch to high-performance services whose costs are controlled, taking into consideration this mass modal shift; (iv) operators in turn can continue their development and investments.

According to Jittrapirom et al. [8], the following features can characterize MaaS:

- **Integration of transport modes**. The objective is to encourage the use of public transport services through multimodal transport and to facilitate intermodal travel;
- **Tariff option**. It is composed of two types of fare, "mobility package" and "pay-as-you-go"; the first contains packages of different modes of transport and includes a number of km/minutes/points that can be used in exchange for a monthly payment, while the second charges users according to their actual use of the service;
- **Single platform**. It is based on digitalization of content through which users can easily access (including from their smartphone) various services such as travel planning, booking, ticketing, e-payment, and real-time traffic information;
- **Multiple actors**. Interaction occurs through a digital platform between different stakeholders within MaaS ecosystem, including individual or corporate customers, transport service providers (private or public), platform owners (third parties, public transport providers, or metropolitan authorities), e-payment, e-ticketing, telecommunications, and data management companies;
- **Use of Internet technologies**. It is mainly based on the combination of devices such as smartphones or computers, mobile Internet network (Wi-Fi, 4G, LTE, GPS) e-ticketing and e-payment systems, database management systems, and infrastructure integrated technology (Internet of Things);
- **Obligation to register**. The aim is to enable the end user to join the platform and benefit from access to services, including personalized services;
- **On-demand services**. The purpose is to facilitate the satisfaction of end user requirements and expectations;
- **Personalization**. This allows end users to change service options according to their preferences, hence the possibility of freely composing related trips or building their mobility package, with a different volume of use for certain modes of transport.

It is clear that MaaS is mainly infused by Internet and Communication Technologies (ICT), used in both backward and forward applications, to support the optimization of traffic fluxes, but also to gather citizens' views about livability in cities or quality of local public transport facilities [9]. By using these new technologies, the need arises to introduce new type of services such as car sharing, bike sharing, and ride sharing [8]. Several MaaS-based platforms have been developed: for example, BeMobility at Berlin, EMMA at Montpellier, OptiMod at Lyon, STIB at Brussels, SHIFT at Las Vegas, SMILE at Vienna, UbiGo at Gothenburg, etc. [2, 8, 10]. Although most of them have succeeded in implementing the integration of e-ticketing, e-payment, several mobility modes, and the development of practical solutions for users such as itinerary recommendations, proposal of multimodal solutions, and real-time traffic information, these achievements did not address the complexity induced by the third mobility dimension (i.e., air mode), nor its management, which is required for decision-makers in cities. Within the frame of sustainable development,

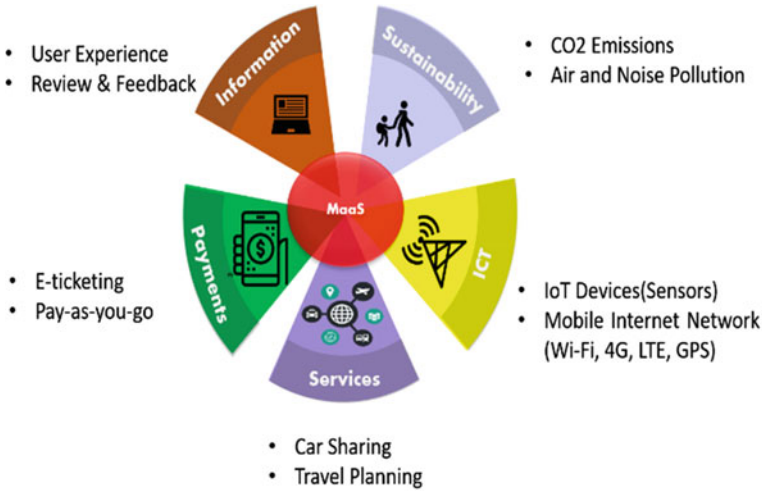

Fig. 2 MaaS ecosystem

air mobility will undoubtedly induce the need for shared poles of exchange between land and air modes, and also the necessity to rethink the pricing schemes (even the underlying business model), which may complexify the overall management of services along with the infrastructure maintenance.

It appears then that five key characteristics should keep in mind to frame a MaaS (as shown in Fig. 2).

- **Information**. To meet users' needs on the basis of in-depth information on the reasoning behind their views and to explain their experiences using the service more systematically. Inspiring participations such as giving away free bus passes [11], often combined with information to increase the success rate, is an example of convenient information service provided.
- **ICT**. ICTs have played a vital role in the transformation process from old technologies to new trends of technologies such as IoT devices, e.g., sensors and actuators to collect real-time data for MaaS providers.
- **Sustainability**. The aim of MaaS is to sensitizing users to relieve their personal cars; carbon footprint reduction be the consequence to provide sustainable environmental model, to manage environmental issues such as air and noise pollution.
- **Smart Services**. MaaS platform should provide several smart services by using single platform such as car sharing, bike sharing, best route suggestion, mix-modal transportation, travel planner, and e-ticketing.
- **Payments**. Pricing and payment would be available in more convenient and an efficient manner, for instance, to provide a single price for the same ticket, and that the payment is digitalized.

The aim of the present work is therefore to develop a decision support system allowing to help policy-makers in cities to efficiently manage the above-mentioned issues, taking into consideration models provided by the existing mobility solutions. This requires to cope with several levels of interoperability within the intended support system.

In an implementation perspective, the above-mentioned MaaS characteristics can finally be seen as different components of the underlying system.

2.2 *Brief Overview of Interoperability Concerns and Approaches*

In order to make MaaS framework components interoperable, it is necessary to consider different interoperability concerns, i.e., data, services, process, and business and different interoperability implementation approaches, i.e., integrated, unified, and federate [12]:

- **The data interoperability**. Generally, consider the main interoperability concern related to data access, aggregation, and reasoning. It is about to find and share information coming from cross-domain sources, i.e., databases, operating systems, and database management systems.
- **Interoperability of services**. It is referred as services that are independently developed by different vendors and running together to solve syntactic and semantic level issues.
- **Interoperability of processes**. It is referred as a combination of the different services that work together. Process defines in which order services will be running according to user needs. Mostly, several processes are functioning collaboratively within an organization to validate certain tasks.
- **Interoperability of business**. The interoperability of business refers to the workflows of the system in a consistent way for business-to-business integration.

Following are approaches to address above concerns.

- **Integrated approach**. Implementing interoperability over an integrated approach means that different models used same template. The common format is not necessarily an international standard but must be agreed by all stakeholders to develop models and build systems.
- **Unified approach**. It means there is a shared format between systems, but it only exists at high level (abstraction). This format is not an executable likewise in integrated approach.
- **Federated approach**. In this approach, there is no shared format between all the systems, to make systems interoperable at run-time. It means federated approach suggests that no partner enforces their models, languages, and methods of work, and they must share an ontology with each other [12].

There are several ontologies in literature dealing with several interoperability concerns in the domain of mobility by using different approaches as mentioned above that includes traffic management, accidents on roads, and transport problems, etc. [13].

The Ontology for Transportation Networks (OTN) was introduced [14] as part of the reasoning on the web with rules and semantics (REWERSE) project. OTN formalizes and extends the Geographic Data Files (GDF) for geographic information and addressing data and service level concerns using integrated approach. The Transport Disruption Ontology is calculated to accumulate data and help merge it so as to identify events which can create disruption in traveling. This ontology was used in Social Journeys in order to unearth in what way social media could be helpful for sharing information to the commuters and only focused data level concerns using integrated approach [15]. Ontology-based management of the traffic on roads was established to help drivers take proper decisions, with the ultimate objective of making the way effectively clear for emergency vehicles and resolve, data and services level concerns by using unified approach [16]. Osmonto ontology is used for OpenStreetMap tags and trying to solve location-based service interoperability concern using unified approach [17]. GenCLOn was built and presented as an ontology that dealt with city logistics. GenCLOn is designed to encourage the sharing and reutilization of the paradigms constructed to guess the behavior of all parties that participate in the area of urban logistics using federated approach to solve data and business level interoperability concerns. Recent work by Benvenuti et al. [18] merges KPIOnto and Trans-model ontologies to strengthen monitoring of system of public transportation. KPIOnto catches generic concepts connected to Key Performance Indicators (KPIs). Trans-model and KPIOnto are connected by linking the basic data classes in Trans-model with indicators from KPIOnto. KPIOnto and Trans-model are part of a suggested frame for a system to buttress the design and dissection of a management system for the systems of public transportation. This work also solves data level interoperability issues using integrated approach.

Above all cited ontologies in literature used different approaches to solve different level of interoperability concerns. In addition, the aim of this research work is to discuss different interoperability concerns for MUM within the frame of MaaS.

3 Interoperability Concerns for MUM Within the Frame of MaaS

In this section, we discussed different building blocks of the MaaS ecosystem and different interoperability concerns associated with these blocks. MaaS building blocks comprise stakeholders, operating infrastructure, and smart services.

- **Stakeholders**. Potential stakeholders of MaaS are users, providers, and public authorities (as shown in Fig. 3). End user used different services that are provided by various mobility providers and public authorities such as government need to make new policies and regulation to address MUM concerns like traffic congestion, infrastructure, safety, and pollution to creating a sustainable green and user-friendly environment [9]. From a stakeholder point of view, they need to exchange and share data by using some services. For instance, public authorities need services data from different mobility providers linked to existing city infrastructure to make policies and regulation to improve quality of existing infrastructures. From a mobility provider perspective, they need to integrate booking and payment processing systems that are built separately by different solution providers. Mobility providers are always looking for an opportunity to generate new business models from the existing model and add a new business model on top of the existing model. For example, the pay-as-you-go model is a new way of payment and it must be interoperable with traditional payment systems.

- **Operating infrastructure**. Contains physical objects such as IoT devices, e.g., sensors and actuators, infrastructure of roads, bridges, railway stations, airports, and vehicles network, i.e., 1D, 2D and 3D, etc. (as shown in Fig. 4), are utilized to analyze the environment in order to collect information with the help of sensors and initiate actions so as to impact the environment and give a response back to systems [19]. In operating infrastructures, we have different IoT devices, i.e., sensors and actuators to collect data from various heterogeneous sources to make them interoperable for analysis and take some appropriate decisions, i.e., infrastructure renewal.
- **Smart services**. The new mobility paradigm is changing the core mobility services like public transport, car rental, parking, taxis, and shuttle into new smart services such as car sharing, bike sharing, integrated mobility, and on-demand mobility (as shown in Fig. 5) [20]. Since these all services are developed by autonomous

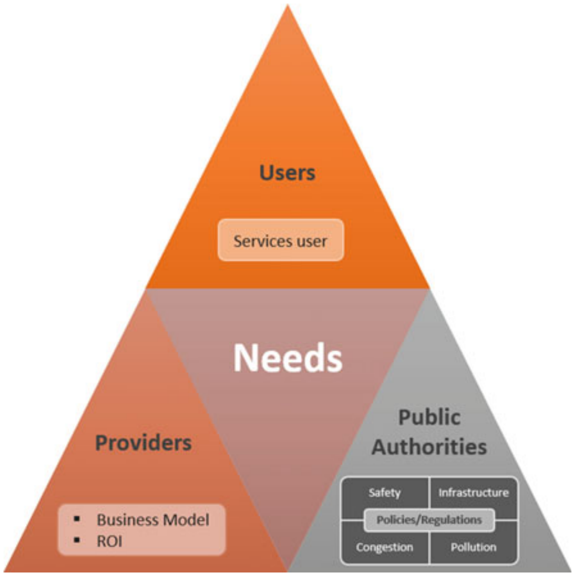

Fig. 3 Stakeholders

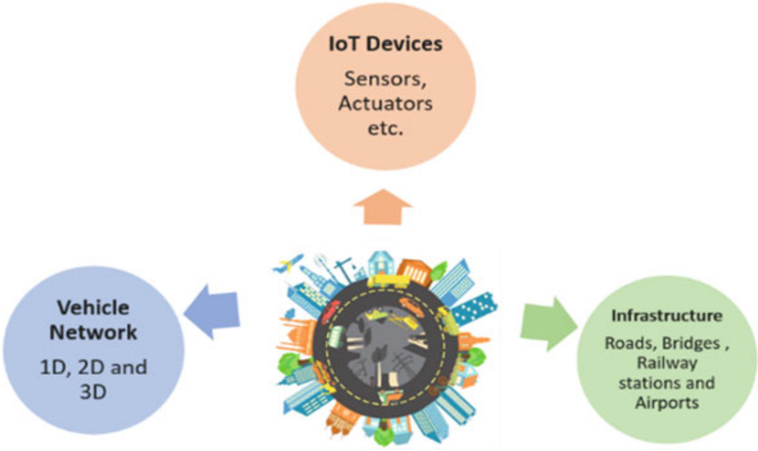

Fig. 4 Operating infrastructure

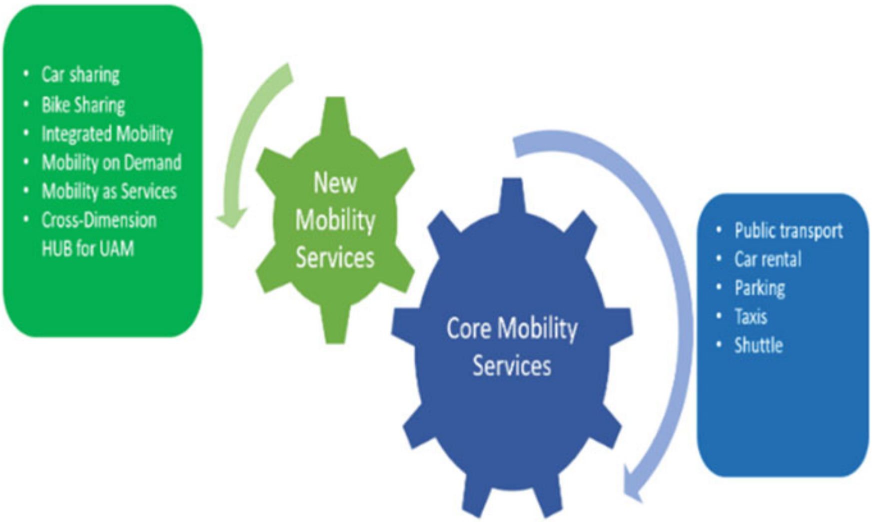

Fig. 5 Smart services

solution providers, to use all these services on a single platform, need to be integrated and interoperable with each other, the user of the services needs to adopt the different processes to use a particular service like first he registers then pay. So, these processes are also interoperable for smooth accessing of the service.

Thus, there is a need to provide standards to make blocks interoperable with each other to ensure that the interfaces, data flows, and message content allow for the open exchange of communications and collaboration among MaaS building blocks.

4 Conclusion and Future Perspectives

This paper has presented a conceptualization of different interoperability concerns such as data, services, business, and organization for MaaS building blocks in the context of MUM. The future perspective of this research is to federate ontology based on available ontologies in literature using semantic model. Build intelligent decision support system for decision-makers to manage traffic regulation, environmental pollution, and safety of the passengers and infrastructures renewal.

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