Linked MaaS: a vision for leveraging Semantic Web Technologies for Mobility as a Service

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Abstract. Mobility as a Service (MaaS) promises to dissolve the boundaries of today's transport network through the integration of transport modes. However, stakeholders such as the operators, public transport authorities, or end-user routing application developers, are facing interoperability barriers in the way of providing a seamless travel experience. To identify, understand, and devise a plan for integration, we must first be able to clearly define the interoperability requirements of MaaS. In this paper, we propose a framework consisting of 6 layers: (i) the Stakeholder layer, (ii) the Data layer, (iii) the Infrastructure layer, (iv) the Ownership layer, (v) the Auth layer, and (vi) the Connection layer. In each layer, we outline the opportunities for Semantic Web technologies. In addition, each layer is equipped with use-cases to illustrate the application of the framework. Through the Linked MaaS framework, we formulate a baseline that extends the research focus of semantics in transportation and builds a guideline for the development of an explicitly defined and understood MaaS.

Keywords: Mobility as a Service · Linked Data · Semantic Web Technologies · Integrated Mobility · Semantics · Knowledge Graphs · Smart Mobility

1 Introduction

Mobility as a Service (MaaS), an emerging concept that promises to dissolve the boundaries of today's transport network, continues to face a manifold of closed doors. The progress towards the seamless vision of MaaS, which provides users with a carefree experience of planning, booking, and payment of transport services, requires integration at multiple levels of the MaaS ecosystem, including data integration for journey planning, ticketing and payment integration, and the integration and alignment of stakeholder's commercial goals. To identify, understand, and devise a plan for integration, we must first be able to clearly define *"What is a MaaS ecosystem and what are its interoperability requirements?"*

In pursuit of finding the answer to this question, a thorough literature review was used in an attempt to provide an unclouded understanding of MaaS. However, there exists over 15 definitions attributed to "Mobility as a Service" in the literature with no agreed-upon definition [4]. Nevertheless, the literature offered a clear view of the building blocks of MaaS out of which we were able to derive a novel framework consisting of 6 intrinsic layers of the MaaS ecosystem. In this paper we propose this framework as a guiding tool for an explicitly defined and understood MaaS ecosystem. In addition, we highlight the opportunities for using Semantic Web technologies as a solution to complications present in each layer.

2 Related Work

When MaaS was first coined by Hietanen [7], he referred to the ecosystem as a combination of transportation services, information, infrastructure, and payment services. Kamargianni and Matyas [8] outlined a business ecosystem for MaaS which consists of the multiple organizations and actors of MaaS. Hensher et al. [6] developed one of the recent MaaS definitions, encapsulating the main elements of MaaS, which includes multimodality, user-centricity, sustainable goals, payment and ticketing integration and more. Spencer [10] characterized *progress* as the shift from homogeneity of structure to heterogeneity of structure in a system which increases the complexity of the structure. With the increase of complexity in ecology, the term *ecosystem* was defined as a network of interconnected organisms and inorganic resources which build their distinct domain of analysis [11]. Analogous to interconnected organisms, are interconnected firms in an economic ecosystem [1]. Presently, Mobility-as-a-Service is inherently a set of densely interconnected and heterogeneous firms and resources that constitute a multilayered ecosystem.

Meadows [9] stated that a system must consist of three kinds of things: *elements*, *interconnections*, and a *function* or *purpose*. We conducted a thorough exploration of the literature on MaaS which encapsulated an in-depth bibliographic analysis of the full record of 347 articles on MaaS, extracted through the query `ALL=("Mobility as a Service")` from Web of Science. Illustrated in Figure 1 is the result of a co-occurrence analysis which showed that all tangible concepts fall under one of three categories: (1) Business, Policy, and Stakeholders, (2) Data and Technology, and (3) Infrastructure (Physical and Digital). We argue that there exists a lot of discrepancies over the semantics of MaaS elements which has lead to a cascade of incompatibilities at various layers of the system. Such incompatibilities gave rise to a major obstacle to MaaS which is the lack of agreement or keenness of different parties of interest to participate in the ecosystem [2]. Through the proposed framework, we aim to provide a guideline that aids in eliminating barriers to MaaS semantic interoperability.

3 The Linked MaaS Framework

To compose a solution that harmonizes the semantics of MaaS, we break down the MaaS ecosystem into its constituent sub-systems. Each sub-system is illustrated as a layer of categorized MaaS elements and their interconnections, with

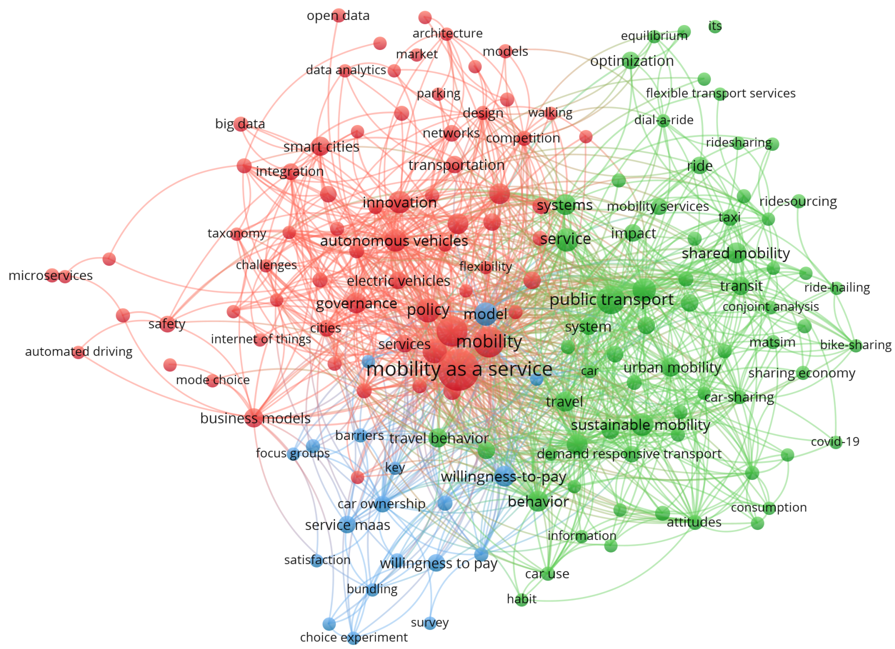

Fig. 1. Illustration of bibliographic co-occurrence analysis of the literature on MaaS

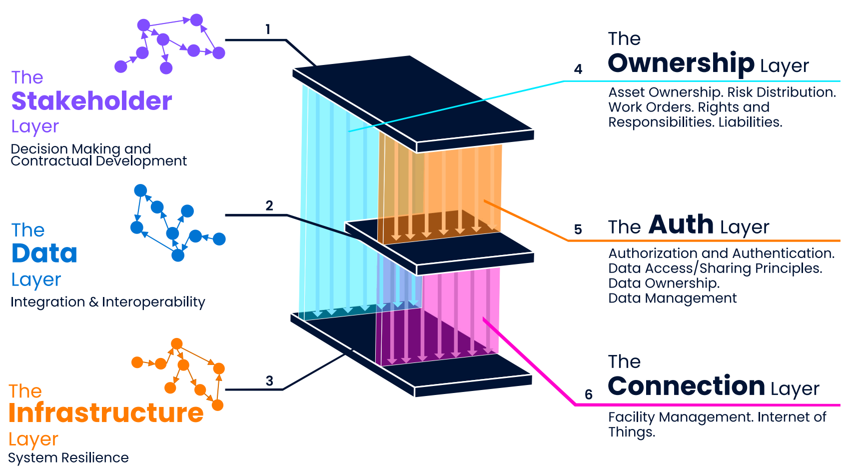

Fig. 2. Proposed structure of the Linked MaaS Framework

a distinct function for each layer. Together, these layers constitute the Linked MaaS framework as summarized in Figure 2. The framework consists of **3 Graph layers** – comprised of both nodes and relationships:

1) The Stakeholder Layer,
2) The Data Layer,
3) The Infrastructure Layer,

The Graph layers can be viewed as an independent domain of analysis. In addition, we define **3 Linking layers** – comprised of relationships only:

4) The Ownership Layer,
5) The Auth Layer,
6) The Connection Layer.

The proposed Linked MaaS framework introduces 6 interlinked layers, that each can benefit from using Semantic Web Technologies (SWT) to model, analyse, and formulate solutions for issues within each layer. Throughout the following subsections, we will discuss the functions of each layer and the reasoning behind its development. Furthermore, we will discuss the recommended Semantic Web technologies for different use-cases in each layer, in addition to, other supplementary technologies.

3.1 Layer 1: The Stakeholder Layer

The first layer of the Linked MaaS framework is **The Stakeholder Layer**. As the name suggests, this layer consists of the stakeholders of MaaS as the elements of focus, whilst also modelling the interconnections between them. In MaaS workflows, it is often the case that a single decision can have direct or indirect effects on any MaaS stakeholder, whether taken collectively or individually. In such a case, delineating the relationships and dependencies between these key players is needed. The main function of this layer is to build an abstract model of the business ecosystem of MaaS. Kamargianni and Matyas [8] provide a suitable starting point for identifying the stakeholders present in today's landscape. For each stakeholder, an explicit definition will be given that delineates their characteristics and roles. An *instance* of any stakeholder *class* shall inherit its *properties* as well as possess a unique ID for their identification on the Web. In addition, an explicit representation of the relationships and dependencies between each stakeholder will be defined. Some of the independent use-cases envisioned for the stakeholder layer are listed below:

- Standard and shared definitions of the different stakeholders can be used for applying policies and conditions for participating in the ecosystem (e.g. A transport operator must have a registration number with a specific authority).
- Convenient retrieval of information on stakeholders and their connections will be enabled (e.g. querying the available MaaS providers in a specific region).

– Analysis of the effects of different decisions and scenarios on the system, perhaps using the Decisions Ontology[3] with the aid of a systems theory approach.
– Analyzing the graph to derive new information and conclusions (e.g. Analyzing the centrality of the nodes to detect how important is a particular stakeholder in a defined region).

3.2 Layer 2: The Data Layer

A main area of concern within emerging transportation technologies is the representation of data, syntactically and semantically. The digitization of transportation data led to the development of multiple standards such as GTFS *static*[4], GTFS *realtime*[5], GBFS[6], MDS[7], The TOMP-API [8], NeTEx[9], SIRI[10], OSLO Mobility[11], and more. When a standard is developed, it is common to define it up to a certain level of granularity, leaving certain issues open [12]. The knowledge of how a system holistically functions is expected to be understood by the standardization community rather than reside within the standard itself. An escalation in interoperability issues, such as incompatibility of protocols, syntax, and other basic building blocks, occurs when the source of the different standards stems from different standards' bodies, each with their own approach to doing things [12]. The data islands, formed through *multi-organizational standardisation*, represents the current situation of data standards in the realm of mobility. This results in: 1) lack of an overview of the system by its implementer, specifically for a MaaS provider that is expected to work with multiple standards, 2) Using standards beyond their original purposes due to the lack of inclusion of particular use cases or newer scenarios in the specification of a certain standard, and 3) Each standard defines its own rules and culture for its implementation, which may significantly vary from those of another standard. For users working with multiple standards, this might be a tricky situation that leads to mistakes and confusion in digesting different concepts [12].

Data, in the MaaS ecosystem, is heterogeneous and present in silos. It is not equipped with the metadata necessary to enable data interoperability. In addition to multiple standards, there still exists a vast amount of data that does not even follow a standard [3], compounding the hindrances in the face of actualising MaaS. For the de-Silo-fication of data and its collective use in decision-making and routing applications, an explicit definition and formalization of the inherent

[3] https://www.w3.org/2005/Incubator/decision/XGR-decision-20120417/Sample_Decision_Ontology.html
[4] https://developers.google.com/transit/gtfs
[5] https://developers.google.com/transit/gtfs-realtime
[6] https://github.com/NABSA/gbfs/blob/v2.2/gbfs.md
[7] https://github.com/openmobilityfoundation/mobility-data-specification
[8] https://github.com/TOMP-WG/TOMP-API
[9] http://netex-cen.eu/
[10] https://www.vdv.de/siri.aspx
[11] https://data.vlaanderen.be/ns/mobiliteit

MaaS data and their relationships is required. Therefore, the main function of this layer is to explicitly model MaaS data with its interconnections. Figure 3 illustrates 6 possible categories of data that fall under the Data Layer of Linked MaaS, noting that these categories are extensible.

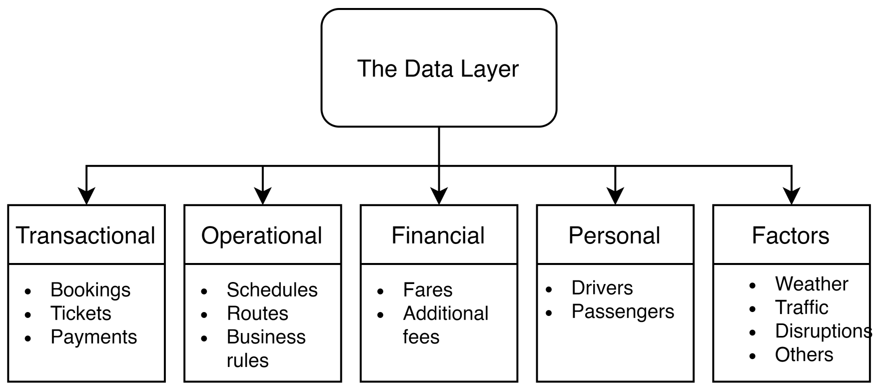

Fig. 3. Illustration of 6 possible data categories under the Data Layer, including examples

Some of the independent use-cases envisioned for the data layer are listed below:

- Automated integration of data from heterogeneous sources through the alignment with existing standards.
- Performing simple and complex queries and algorithms over MaaS data (e.g. querying for availability of bike lanes, running route-optimization algorithms).
- Reasoning over the graph to derive new information and conclusions (e.g. inferring which factors have an effect on which modes of transport).

3.3 Layer 3: The Infrastructure Layer

There is a distinction between servitizing transportation and servitizing other industries, of which some have witnessed successful models disrupting preceding distribution models. The implementation of MaaS relies on the existence of physical infrastructure. Physical transportation infrastructure is a prerequisite for actualizing MaaS. *How can we shift people to more sustainable modes of transport if we are lacking the infrastructure for it?* Promoting bikesharing, for example, requires bike lanes for a safer commute. Shifting to electric cars requires charging stations. Major investments in public transport is needed to set up railways and subways. The significance of infrastructure to MaaS necessitated its inclusion as the third layer of the Linked MaaS framework. Considering the technological advancements in transport, the core elements of the infrastructure layer include both physical and digital infrastructure. The main function of this layer is to provide a digital twin of both physical and digital infrastructure as well as the relationships between them. Some of the independent use-cases envisioned for the infrastructure layer are listed below:

- Through graph theory approaches, various analysis can be performed to determine System Resilience, identifying the weakest links and bottlenecks in the infrastructure. This can aid in deriving multimodal disaster mitigation and recovery plans.
- Analysis of the system to identify missing infrastructure links at different locations, both physical and digital, which require installation. Through such analytics, investments can be directed to the right infrastructure sectors and locations.
- Inter-dependencies between modes and the dynamics of a multi-modal system can be derived from the model for usage in smart city mapping and planning.

After discussing Graph layers 1, 2, and 3, we now look at forming interlinks between these layers. The Linking layers represent relationships between elements from different graph layers. These layers are discussed in the subsequent sections.

3.4 Layer 4: The Ownership Layer

There are relationships between MaaS stakeholders and the Infrastructure layer. These relations can include which infrastructure belongs to a stakeholder's assets, who is responsible for the maintenance or development of specific infrastructure, etc. These questions mainly depend on the ownership of assets. Therefore, the main function of this layer is to model the links between the stakeholders and the infrastructure. A significant use-case that we envision for the Ownership layer is to contribute to the analysis of risk. Through the links between the stakeholders and their assets, an optimum risk distribution model can be determined for a given MaaS ecosystem.

3.5 Layer 5: The Auth Layer

A major debate within MaaS falls under the umbrella of data management. Some of the questions include:

- Who will have the authority over MaaS users data?
- Who is responsible for data maintenance and quality?
- Who is authorized to access a specific type of data?
- How do we authenticate the user/agent accessing the data?
- Will MaaS Providers contribute to the monopolization of data or will there be a decentralised data access?

To resolve this debate, we propose the Auth layer. The main function of this layer is to model the links between stakeholders and data. The incorporation of the Auth layer in Linked MaaS can aid in the following use-cases:

- Explicit identification of read-write access rules to different data entities, perhaps through the Access Control List Ontology.
- Explicit definitions of roles and responsibilities of the stakeholders for data management.
- Examining the effects of different data access distributions on the stakeholders of the ecosystem (e.g. business opportunities through Open Data).
- Incorporation of data pods following the Solid[12] Project for decentralization of user data.
- Enforcing data policies through validation rules.

3.6 Layer 6: The Connection Layer

Although the Data layer and the Infrastructure layer appear to overlap, there is a clear distinction between them. The Infrastructure layer models the physical and digital assets of the ecosystem, whereas a part of the Data layer would consist of data derived from that infrastructure. For instance, the infrastructure layer would model railway tracks whereas data from sensors attached to these tracks are modelled in the data layer. Between these two layers, we propose a relationship layer, **The Connection Layer**, where the main function of the layer is to model the connectivity of the infrastructure. This layer would be used to power the development of Internet of Things in transportation, providing insights on which parts of the infrastructure is connected over the internet, what types of connections do they have, for instance, having vehicle location data for a train but lacking sensor data for facility management.

4 Conclusions and Future Outlook

In this paper, we presented the Linked MaaS framework and discussed 3 Graph Layers and 3 Linking layers, justifying their function in the ecosystem. In alignment with the results of the literature, the layers contain all categories identified which were (1) Business, Policy, and Stakeholders, (2) Data and Technology, and (3) Infrastructure, noting that the inclusion of policy concepts is distributed throughout the layers rather than constituting a layer of its own. We envision the development of Linked MaaS to be a catalyst for actualising MaaS. As part of an ongoing research, we are focusing on works that will contribute to the Stakeholder layer, the Auth layer, and the Data layer. We invite researchers of MaaS and the Semantic Web community to bring the Linked MaaS vision to reality through novel contributions to the 6 layers.

Under the previous subsections of Layers 1 to 6, we provided examples of use-cases that the individual layers are expected to handle as part of their *function*.

[12] `https://solidproject.org/`

From a holistic perspective of Linked MaaS, there is an opportunity for synergistic use-cases which rely on the collective use of the layers. Some examples are:

- Generation of data-driven contracts, based on the analysis of the stakeholders' relationships with infrastructure, with data, and with each other.
- A forecasting engine can be derived to predict the effects of adding, removing, or changing any elements in the system (e.g. a merger between two companies, construction of a new highway, incorporation of a new technology).

We predict the use of Linked MaaS to be a guiding tool for various processes in MaaS. The high-level concepts for all the layers, likely represented as ontologies or vocabularies, can serve as a foundation upon which a Linked MaaS knowledge graph is constructed specific to given geographic regions where MaaS operates. This will set a roadmap for MaaS to achieve an *Adaptive* level of interoperability - highest level in the Enterprise Interoperability Model [5] - where firms are capable of adapting to new environments and accommodating new partners, making interoperability itself a subject of continuous improvement. The extensibility of Semantic Web technologies will serve as a future-proof solution for the continued introduction of novelty into the MaaS ecosystem.

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