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State of the art of electric Mobility as a Service (eMaaS): an overview of ecosystems and system architectures

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Summary

Mobility as a Service (MaaS) is a concept that aligns with both current and future mobility demands of users, namely intermodal, personalized, on-demand and seamless. Although the number of shared mobility, electric mobility and multimodal passenger transport users is rapidly growing, until now, the list of MaaS and electric Mobility as Service (eMaaS) providers is quite short. This could partly be explained by the lack of a common architecture that facilitates the complex integration of all actors involved in the (e)MaaS ecosystem. In this paper we first review the state of the art of (e)MaaS ecosystems and architectures. Secondly, we propose an eMaaS ecosystem and an innovative eMaaS architecture that focuses on the integration of MaaS and electric mobility systems. With this work, we aim to support the further development of eMaaS.

Keywords: MaaS (mobility as a service), mobility system, research

1 Introduction

In recent years, the concept of Mobility as a Service (MaaS) has been gaining popularity within the field of passenger transport systems. MaaS is an innovative mobility concept that combines different transport modes to offer consumers the possibility to get from A to B in a flexible, personalized, on-demand and seamless way, through a single interface [1], [2].

Likewise, an increasing number of organizations, companies, policy makers, and the general public are focusing their attention on the subject of electric mobility. Moreover, several cities and nations are adopting regulations that encourage the usage of electric modes of transport. For example, in the medium-term future, the Netherlands (by 2030), Norway (by 2035), and France & Great Britain (by 2040), intend to apply bans to sales of passenger cars with internal combustion engines (ICE) [3].

With both the growing adoption of electric mobility and the expanding development of MaaS, electric Mobility as a Service (eMaaS) has the perfect opportunity to become one of the foremost solutions for today's mobility challenges. eMaaS expands on the MaaS concept having as a complementary goal to provide users the possibility to go from A to B not only in a multimodal and seamless way but also in an even more eco-friendly way than just reducing car ownership as intended by MaaS.

In this context, with the aim to increase the adoption of electric vehicles (EVs) by combining highly innovative technology and new business models, the "eMaaS project" has started in the beginning of 2018. The project is an initiative of a group of European mobility SME's which are already working towards making eco-friendly mobility more accessible [4] and are supported by the University of Twente.

The eMaaS concept is built upon the MaaS model. Its proposition is that to achieve multimodal, seamless and eco-friendly mobility, MaaS should be combined with Electric Mobility Systems (EMS) and Shared Electric Mobility Services (SEMS). Connecting these three concepts leads to our working definition of eMaaS:

> electric Mobility as a Service (eMaaS) refers to the integration of multiple forms of (electric) transportation modes –including public transport– and shared electric mobility services (e.g. e-car sharing, e-bike sharing, e-scooter sharing, e-bus, e-taxi) into a single mobility service that allows travelers to plan and go from A to B (and/or from B to C and/or vice versa) in an eco-friendly and seamless way. The service is offered through a single customer-centred interface and it also involves the prearrangement of electric mobility technologies and infrastructure (e.g. charging stations, energy contracts).

1.1 Goal and research question

The goal of this publication is to give an overview of the state of the art regarding (e)MaaS' ecosystems and architectures. Moreover, it aims to support the further development of eMaaS by proposing a novel system architecture. The research questions that lead this paper are:

1. What are existing (e)MaaS ecosystems and architectures?
2. What elements and functions should an eMaaS architecture include to facilitate the integration and interaction of all actors within the eMaaS ecosystem?
3. How does a system architecture support the further development of eMaaS?

2 MaaS ecosystems

In this section we present the state of the art of the MaaS ecosystem. The MaaS ecosystem has already been described by some transport specialists, researchers and MaaS developers. However, most of the first (e)MaaS ventures are still under development or at a pilot phase. On a high-level, the MaaS ecosystem consists of: transport infrastructure, transportation services, transport information and payment services [1]. Within the ecosystem, all different modes of transport and actors share the common objective of delivering a seamless mobility experience [5] and aim at improving the transportation network by exploiting the benefits of each service. Moreover, other actors such as local authorities or data management companies can also cooperate to enable the operation of the services and improve their efficiency [6], [7].

An example of the MaaS ecosystem is presented by the Siemens Mobility Division in [8]. There, the authors describe an ecosystem composed of 4 main elements: 1) service providers; 2) a business to business (B2B) platform; 3) mobility retailers; and 4) the travellers. This ecosystem was presented in the context of a MaaS project for the region of Tampere, Finland in 2016. The goal of the project was to integrate the existing and upcoming transport services with the operations of the local paratransit services [8]. Figure A1, in the appendix of this paper, shows the MaaS ecosystem as conceived by [8].

Another example of the MaaS ecosystem, also at a general high-level, is presented by König et al. [9] in the context of the 'Mobility As A Service for Linking Europe' (MAASiFiE) project. The authors argue that MaaS ecosystems consists of four different levels: 1) the public and regulatory level, 2) the transport and logistics service providers level, 3) the mobility service level, and 4) the end-user level. In the ecosystem, the transport and logistics service providers level corresponds to the supply side whereas the user interface corresponds to the demand side. On the other hand, the mobility service level and the public and regulatory level bring into play the most relevant actors in the ecosystem, that is, the local and national authorities (e.g. transport ministries and agencies, city planning department, safety and road agencies) and the MaaS operator, transport service providers. An overview of the MaaS ecosystem proposed by König et al. can be found in Figure A3 in the appendix of this paper.

Also depicting the MaaS ecosystem, Fig. 1 below shows one of the most used (and probably the first) examples of the MaaS framework [10]. The framework was presented by the Finish Ministry of Transport and Communications in December 2014 as an overview of the envisioned scenario for MaaS operators. A remarkable observation given by the MaaS-Alliance on the MaaS framework is that, although the framework includes the main services of the MaaS ecosystem, in a mature ecosystem some of the services could, and most probably be, non-mobility related [5].

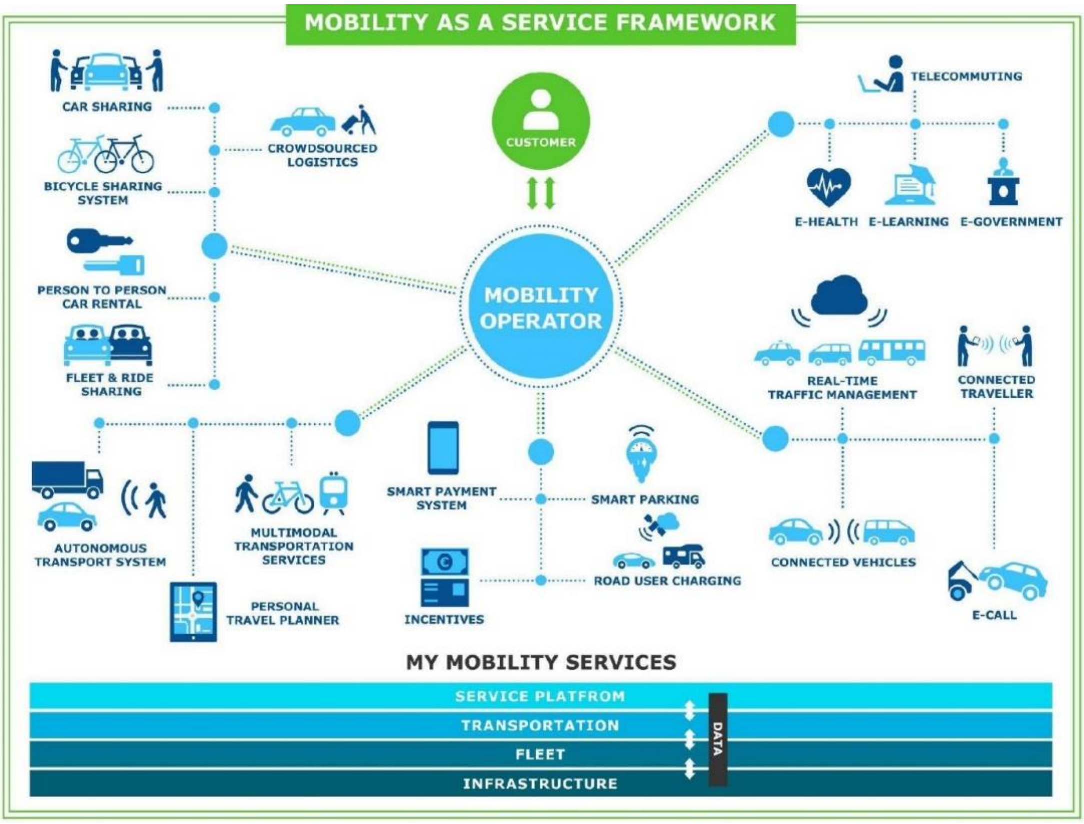

Figure 1: The Mobility as a Service framework. Source: [10]

An additional perspective of the MaaS ecosystem is the MaaS "business" ecosystem. The business ecosystem of MaaS is explained by Kamargianni and Matyas as "the wider network of firms that influences how a focal firm, in this case the MaaS provider, creates and capture value" [11] (p.6). The business ecosystem proposed by [11] is composed of several layers starting from the core business layer, which includes the MaaS provider as the focal firm; the extended enterprise layer which widens the view of the business supply chain to include the complementors and second-layer suppliers; and the outermost layer which corresponds to the business ecosystem and adds regulators, unions, universities and other research bodies, investors, and stakeholders to the business ecosystem [11]. Fig. 2 below shows the layers of which the business ecosystem is composed.

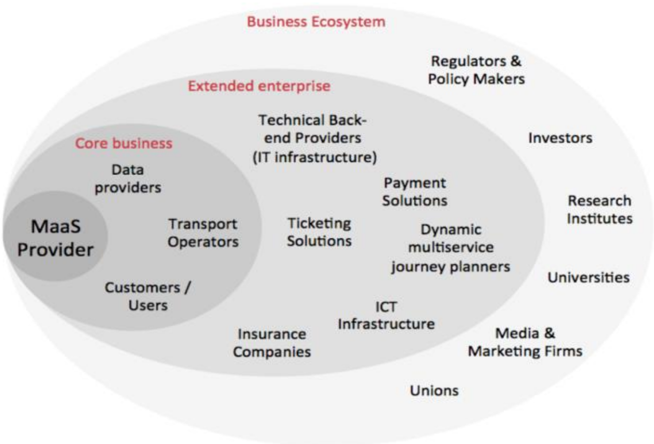

Figure 2: The Mobility as a Service business ecosystem. Source: [11]

2.1 The eMaaS ecosystem

All in all, the MaaS ecosystems found in the literature seem to take all relevant factors into account to guarantee the mobility of users from A to B in a seamless way. However, as explained before, the proposition of eMaaS is to offer users the possibility to travel in an eco-friendly way. Therefore, the eMaaS ecosystem is composed of the combination of Mobility as a Service (MaaS), Electric Mobility Systems (EMS) and Shared Electric Mobility Services (SEMS) as shown in Fig. 3.

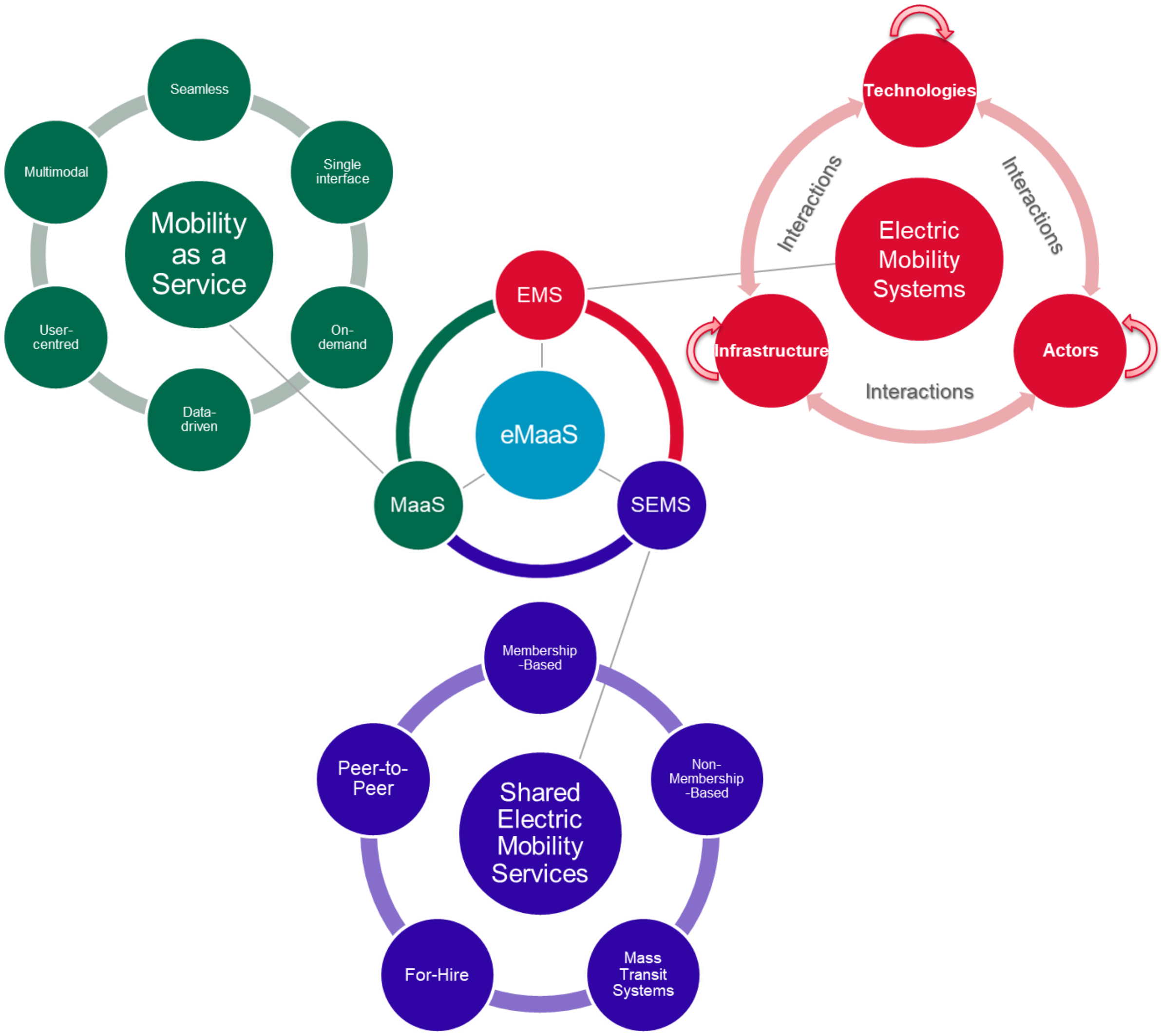

Figure 3: The electric Mobility as a Service (eMaaS) ecosystem.[1]

Within the eMaaS ecosystem all three modules (MaaS, EMS and SEMS) are complementary. This means that, even when each of the modules offer mobility options for the user, eMaaS cannot be achieved by means of only one or two modules. An important reminder here is that eMaaS is built upon the MaaS model, therefore the actors taking place in the MaaS ecosystem are also playing a role in the eMaaS ecosystem.

Firstly, the MaaS module is represented by the main mobility characteristics offered by MaaS namely multimodal, seamless, user-centred, data-driven, on-demand and with a single interface. This module also includes all the components involved in the MaaS ecosystem as described in the previous section and shown in Fig. 1 and Fig. A1 and A3 in the appendix. The main difference is now that the focal firm within the eMaaS ecosystem is, evidently, the eMaaS provider. Moreover, in this case the transport operators and transport

[1] The top-right side of Fig. 3 is an adaptation from the EMS model by Abdelkafi et al. [12].

service providers must offer electric mobility solutions and the infrastructure is focused on electric mobility as well. Besides, regulations and policies should also be adapted to electric mobility.

Secondly, the Electric Mobility Systems' (EMS) module brings the first part of the eco-friendly component of eMaaS. EMS "denote the interaction of actors, technologies, and infrastructures that aims to achieve sustainable transportation by means of electricity" [12] (p.4). Thus, the three main elements of the EMS module are 1) Technologies, 2) Actors and 3) Infrastructure. On the one hand, technologies play a central role in achieving electric mobility and therefore in reaching eMaaS. Technologies that take part in the EMS module are, for example, batteries, charging technologies, drivetrains, and of course electric vehicles (EVs). On the other hand, eMaaS highly depends on how actors deal with the challenges of enabling, developing, using and boosting the usage of electric mobility. The main actors involved in the EMS module are manufacturers, suppliers, customers/users, service providers, governments and substitutes [12] (p.7). Finally, infrastructure refers to the basic physical and organizational structure that enables the use of technologies by actors and makes electric mobility possible. The electric mobility infrastructure builds upon existing infrastructure in the sectors of transportation and energy. Examples of electric mobility infrastructure are charging stations, electricity grid, information and communication technology (ICT) and (EV-)roads.

Lastly, the Shared Electric Mobility Services' (SEMS) module brings the second part of the eco-friendly component of eMaaS. Shared mobility is an innovative transportation strategy that enables users to gain short-term access to transportation modes on an as-needed basis [13], is characterised by the sharing of a vehicle instead of ownership, and the use of technology to connect users and providers [14]. SEMS refers to the utilisation of EVs when providing shared mobility. SEMS adds up to the environmental, social, financial and transportation-related benefits that had already been associated to the usage of electric mobility and shared mobility simply by combining both. Examples of SEMS are e-car sharing, e-bike sharing and e-scooter sharing. Within the eMaaS ecosystem, SEMS can be classified in different models as presented by [13] or [14]. In this paper we adopted the five models as proposed in [13] namely 1) Membership-based (e.g. e-bike sharing, e-car sharing, e-ridesharing, e-ride hailing, e-scooter sharing, e-bus sharing), 2) Peer-to-Peer (e.g. e-car sharing, e-bike sharing, e-scooter sharing), 3) Non-membership-based (e.g. e-car rental, e-limousine rental), 4) For-hire (e.g. e-car/bike/scooter sharing, e-ridesharing e-carpooling), and 5) Mass transit systems (e.g. e-Public Transport, airport autonomous shuttles). Therefore, by offering these models in combination with the previous two modules (i.e. MaaS and EMS), users will be enabled to travel in a way that not only reduces CO_2 emissions and traffic congestion but also gives them multiple possibilities of transportation and allows them to save money by not owning a vehicle.

With the eMaaS ecosystem presented in this section all elements playing a role in the enablement of eco-friendly mobility are presumably covered, though the achievement of eMaaS is only possible if accompanied by a well-designed system architecture. Such an architecture must ensure the smooth integration of all elements in the ecosystem and should allow for effective interaction between them. In the next section we present the state of the art of MaaS architectures and an propose an innovative system architecture that aims at supporting the development of eMaaS.

3 MaaS architectures

As with MaaS ecosystems, some MaaS architectures have already been proposed by MaaS practitioners and researchers. A system architecture "defines the parts constituting a system and allocates the system's functions and performance over its parts, its user, its super system and the environment in order to meet system requirements" [15] (p.5). MaaS system architectures such as the ones presented by Siemens [8], König et al. [16], Datson [17], García Hernández [18], Ambrosino et al. [19], or Pflügler et al. [20] are useful conceptual references to describe the requirements, functions and capabilities of the components within the MaaS ecosystem. In the remainder of this section a few examples of MaaS' system architectures found in the literature will be briefly described.

One of the most common examples referred in literature of a successful MaaS pilot is the SMILE project run in Austria. The goal of the project was to create a mobility platform that not only allowed users to be informed about all available means of transport but to let them book, pay and use them [21]. Fig. A2, in the appendix of this paper, shows the architecture blueprint for the MaaS solution developed for this project. The goal of this architecture was to provide standardized and easy to integrate connectors that enable even smaller partners to use the full range of high quality services offered in the MaaS environment [22]. For the users, the data was selected and combined to provide the most suitable options for the requested trip (including the actual price) and then users had the chance to choose an option to book the entire trip – even with several mobility providers – without changing between different apps [21].

On a more technical level, Fig. A4 in the appendix of this paper, shows the technical MaaS system architecture proposed by König et al in [16]. The focus of this architecture is based on the use of web technologies, as those technologies show a profound basis for establishing new combined and integrated digital mobility services [16] (p.20). The architecture is composed of four main levels, namely 1) the data provider level, 2) the individual service level, 3) the common MaaS service level, and 4) the MaaS interface level. Moreover, processes and technologies required for final MaaS service provision are highlighted in this system architecture, whereas the roles and responsibilities are assigned to the business and operation models as depicted in the MaaS ecosystem developed by the same authors (see Fig. A3 in the appendix).

Another example of a conceptual system architecture for MaaS is presented by Pflügler et al. [20] in the context of digital mobility services for the smart city. The main objective of their work was to design a concept for the architecture of an open mobility services platform. The platform consists of four main layers, namely 1) data sources, 2) modular services, 3) integration layer, and 4) solutions layer. The driving idea behind this platform was to make data available that already exists in many smart cities and create a mobility ecosystem that fosters the development of innovative mobility solutions based on the offered modular services. The concept for the architecture of an open platform for modular mobility services is depicted in Fig. A5 in the appendix of this paper.

Although the existing conceptual architecture references offer an overview of the elements in a system architecture, there is not yet an open architecture that can be used as a base for the further development of (e)MaaS [5], [23], [24]. Taking this into account, in the coming section we present an innovative system architecture that aims to be a supporting pillar for the further development of (e)MaaS.

3.1 The eMaaS architecture

The system architecture proposed here is composed of functional blocks and elements that cover all elements within the eMaaS ecosystem. As shown in Fig. 4, the architecture can be explained by dividing it in three main blocks, namely (1) Shared e-mobility, (2) Data & Analytics extension, and (3) Other mobility & 3rd Party Systems. One of the distinctive characteristics of this architecture is that it is more extensive than the ones intended for MaaS systems. It not only covers electric mobility requirements such as charging points management and EV fleet management, but also combines elements that not all architectures take into account (e.g. smart data brokers integration and advanced analytics). In the following subsections each of the blocks presented in this architecture and their components are explained.

3.1.1 Shared e-Mobility

eMaaS enables the transition from vehicle ownership to vehicle usage. Shared mobility facilitates this transition and electrifying all transportation modes supports sustainability. In this context, the eMaaS architecture needs to enable the sharing of a variety of electric transportation vehicles (cars, bikes, shuttles, scooters) both in standard car sharing as well as in ride sharing approaches.

Furthermore, the integration of these different services into a single, seamless trip -planning, -booking, -execution, and -payment service, needs to be supported. In addition, as most of personal and private vehicle ownership is replaced by fleet ownership, these fleets need to be monitored (via telematics), managed and maintained by the service provider. Similarly, the specific charging infrastructure required for EVs also needs to be monitored and managed. In both cases, the architecture needs to be flexible enough to accommodate multiple vendors, systems and technologies. All those elements, as presented in the shared e-mobility block in the middle of the eMaaS system architecture depicted in Fig. 4, are further explained in Table 1.

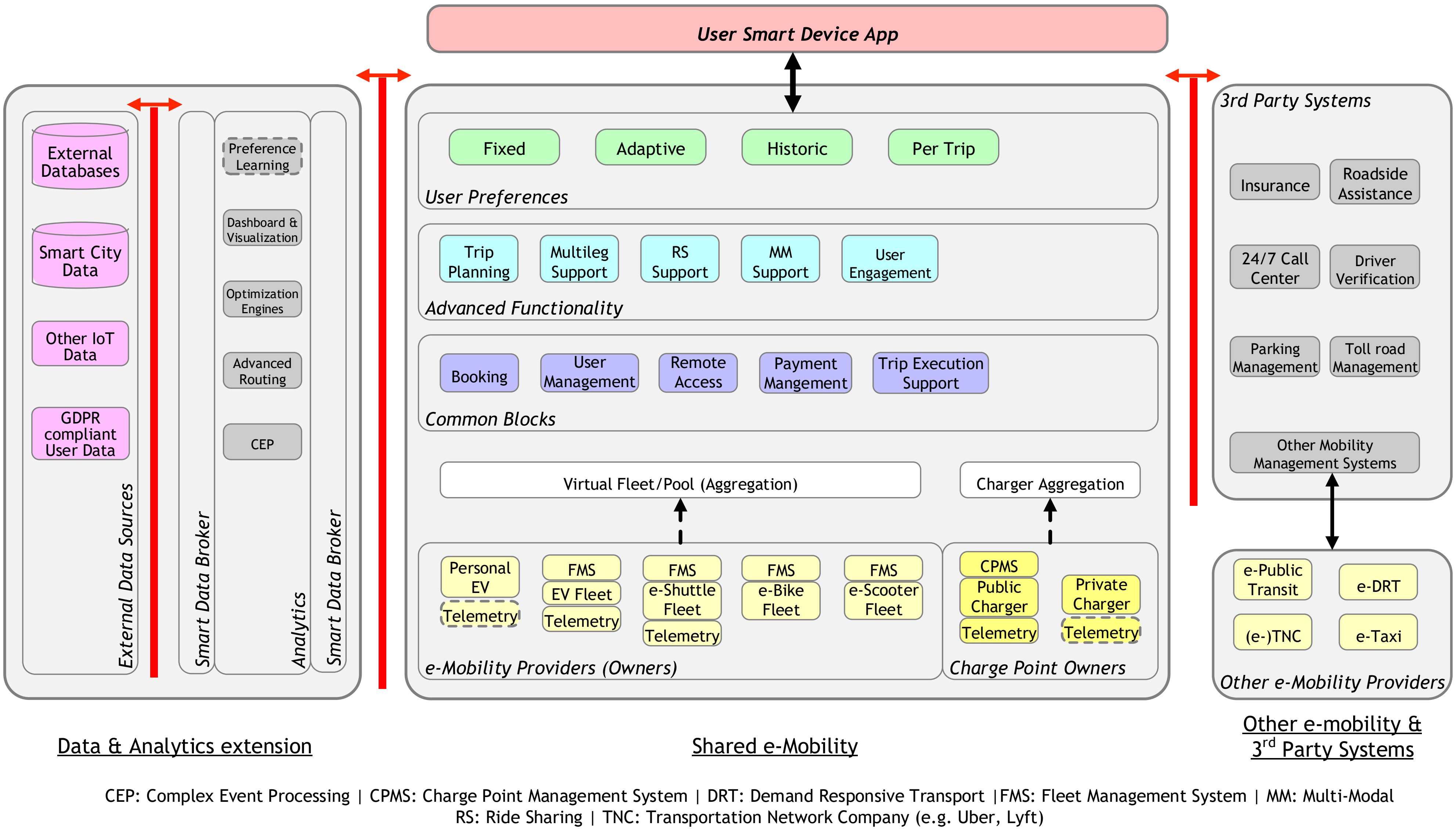

Figure 4: The eMaaS system architecture.

Table1: Elements of the Shared e-Mobility block in the eMaaS system architecture

Element	Description
Mobility Providers	Owners of the vehicles.
Personal EV	Private EVs used in shared schemes such as peer-to-peer or ride sharing.
EV Fleets	Fleets (i.e. non-personal vehicles) include Fleet Management Systems (FMS), covering functions like maintenance and cleaning.
Telemetry	EV (and e-shuttle/bike/scooter) fleets include telemetry hardware; personal EVs have optional telemetry hardware.
Virtual Fleet	For vehicles this is the pooling of multiple physical fleets into one virtual fleet for use by operators.
Charge Point	Owners of the charge points.
Private charger	Own (and optionally operated) charging infrastructure – public or private (e.g. home, building).
Public charger	Public infrastructure includes Charge Point Management System (CPMS) with telemetry (charger related data).
Telemetry	Private chargers include optional telemetry.
Aggregation	Facilitates seamless (vendor independent) charging (potentially with a single "charge card"), and future Virtual Power Plants (VPP) or Vehicle-to-Grid (V2G) scenarios.
Common Blocks	Functional blocks that are common across all (or almost all) shared mobility solutions
Booking	Handling of user reservations (including user preferences).
User Management	Includes enrollment; access to user preferences; user data management; incentive programs; optional gaming.
Remote Access	Based on hardware installed in vehicles to enable smart phone lock/unlock access (may be managed by third party telemetry operator). Telemetry hardware also enables collection of vehicle (or charger) data.
Payment Management	All billing related functions; based on mileage, time or combination; including services such as repeating fees, insurance, roadside assistance, etc.
Matching	Assignment and scheduling of vehicles based on reservations and availability. Optionally based on advanced optimization and advanced analytics.
Advanced Functionality	Functional blocks that enhance baseline shared mobility solutions.
Trip Planning	Navigation; time estimates and optional advanced analytics based features (e.g. real time congestion, low pollution route choices.
Multi-leg Support	Enabling (and scheduling) multi-segment trip with multiple vehicles – for example, first leg with e-bike, second leg with shared car.
Ride Sharing Support	Enabling trips with multiple riders – public shuttles (with dynamic route changes) and private, ad hoc carpooling.
Multi-Modal Support	Interfaces and inclusion of additional transportation and mobility modes – public transit, taxis, etc.
User Preferences	Per user preferences including fixed and changing.
Fixed	Long term (rarely changing) preferences possibly entered during enrollment.
Adaptive	Automatically changing preferences (e.g. based on season).
Historic	Enabling predictive capabilities based on past choices.
Per Trip	At a minimum, preferences on time, range/distance and price.
User Smart Device App	Single app to all user eMaaS features and capabilities. Including all preferences; bills; real time status. Optionally, data sharing (GDPR compliant) for enhanced capabilities based on advanced analytics (e.g. preference learning).

3.1.2 Data & Analytics Extension

eMaaS, like many other domains, is data rich and data driven – data originating from vehicles, chargers, operational systems (e.g., car sharing platforms) and users who opt in, give the ability to enhance and improve the services offered to users. The architecture therefore requires the capability to collect, process and manage the data (both real time and offline batch based) from all data producing parts at all levels of the overall system. Adding advanced analytics opens paths to prediction, optimization, recommendations, etc. All data-driven functionalities, as presented in the Data & Analytics Extension block in the eMaaS system architecture depicted in Fig. 4, are further explained in Table 2 below.

Table 2: Elements of the Data & Analytics Extension block in the eMaaS system architecture

Element	Description
Smart Data Broker	Brokering between data sources using "adapters" (per data source type).
Analytics	Multiple advanced analytics "engines" that can facilitate enhanced functionalities for baseline systems.
Preference Learning	Future functionality (Optional). Learning user behavior, trends, patterns and using for enhanced predictive capabilities.
Dashboard and Visualization	Simple visualization tools both for operators and (app) users on various data (raw or processed).
Optimization Engines	Optimizers underlying a variety of tasks such as vehicle assignment and scheduling, route planning accounting for charging during trip, etc.
Advanced Routing	Dynamic routing based on multiple constraints and adapting to (near) real time changes
Complex Event Processing	Processing of streaming (real time) data by applying rules/filters/etc.
External Data Sources	External data feeds to the Data Broker and Analytics blocks for delivering advanced data services and enhanced features.
External Databases	Any third-party database with relevant data (mostly relational).
Smart City Data	Available Open Data both historic and near real time; city proprietary data.
Other IoT Data	Third party, accessible IoT devices data (mostly streaming and real time).
GDPR Compliant User Data	Data that can be shared considering both GDPR and user settings, including through app usage

3.1.3 Other Mobility & 3rd Party System

The longer-term goal of eMaaS is a converged solution that also includes additional e-mobility such as public transit (e-buses, electrified light rail), taxis, transportation network companies (e.g., Uber, Lyft) and fleets of autonomous vehicles. Ultimately, the user needs to get from point A to B within some given timeframe and subject to some constraints (i.e. user preferences) with a seamless single payment method and accessible through a single mobile app. The architecture is therefore required to be sufficiently extensible and "future proof". Moreover, complementary services such as roadside assistance or a 24/7 call center ought to be inherently included in the offer for the users but would most likely be integrated by 3rd party systems. This kind of capabilities, as well as more mobility providers, are represented in the right-side part of the eMaaS system architecture depicted in Fig. 4.

4 Conclusion and future work

The current state of the art regarding MaaS ecosystems and systems architectures is fairly limited, although some examples can be found in literature which are useful conceptual references for the understanding of the MaaS model and its context. Moreover, some MaaS architectures have been used in practice and have brought the first examples of functional MaaS models (e.g. SMILE).

eMaaS is a concept that builds upon the MaaS model. As such, the MaaS ecosystem and MaaS system architectures serve as a foundation for the development of eMaaS and its system architecture. The addition of the eMaaS concept over MaaS is that the former guarantees eco-friendly mobility while offering the same benefits as the latter. Furthermore, eMaaS can even mitigate some of the downsides of MaaS, like the underutilisation of public transport, by only offering shared mobility services (including public transport).

Having a clear overview of the elements in the eMaaS ecosystem and in the system architecture helps in the development of eMaaS by identifying the requirements, functions, stakeholders and interfaces that need to be covered when developing the eMaaS services. With the eMaaS architecture proposed in this paper, all the required capabilities of eMaaS are covered. The architecture takes into account the additional elements of

Electric Mobility Systems (such as EV fleets and charging points, etc.) and Shared Electric Mobility Services (such as e-car sharing, e-bike sharing or e-scooter sharing, and even extra mobility modes such as e-public transport or demand responsive transport).

One limitation of the architecture proposed in this paper is that it has not yet been evaluated. This will be subject of near-term future research. This work therefore serves as stepping stone towards a validated architecture design for eMaaS, as is the objective of the eMaaS project. For the development phase a technical integration plan has already been designed. This plan is focused on an initial integration between project's partners existing technologies that supports limited key requirements and enables a minimal viable product (MVP). The first step is planned to be around an integration with an initial one-way-flow of information and then to be used for analytics and visualizations, with future phases extending this state and becoming much more sophisticated (e.g., possibly doing some multi-modal calculations and sending the result back for reservation planning). The integration phase is based on uses cases that are concretely around fleet sharing (initially). Additional integration as well as joint development of new capabilities (currently not part of the partners' product) will take place at a later time (Phase 2).

Acknowledgments

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References

[1] S. Hietanen, "'Mobility as a Service' – the new transport model?," *Eurotransport*, vol. 12, no. 2, pp. 2-4 / 26-28, 2014.

[2] A. Burrows, J. Bradburn, and T. Cohen, "Journeys of the Future - Introducing Mobility as a Service."

[3] F.-J. Van Audenhove *et al.*, "The Future of Mobility 3.0 - Reinventing mobility in the era of disruption and creativity," 2018.

[4] EMaaS, "The eMaaS project." [Online]. Available: http://www.emaas.eu/. [Accessed: 15-Nov-2018].

[5] MaaS Alliance, "Guidelines & Recommendations to create the foundations for a thriving MaaS Ecosystem," 2017.

[6] P. Jittrapirom, V. Caiati, A.-M. Feneri, S. Ebrahimigharehbaghi, M. J. A. González, and J. Narayan, "Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges," *Urban Plan.*, vol. 2, no. 2, pp. 13–25, 2017.

[7] A. Kawasaki, "Fujitsu's Approach to Smart Mobility," *FUJITSU Sci. Tech. J*, vol. 51, no. 4, pp. 3–7, 2015.

[8] SIEMENS, "MaaS operation and integration with demand-responsive transport in Tampere." Siemens Mobility Division, 2016.

[9] D. König, J. Eckhardt, A. Aapaoja, J. Sochor, and M. Karlsson, "MAASiFie: Business and operator models for MaaS (Deliverable nr. 3)," 2016.

[10] M. Kivimäki, "MaaS - Finland on the leading edge," in *Mobility as a Service seminar and networking event* , 2014.

[11] M. Kamargianni and M. Matyas, "The Business Ecosystem of Mobility-as-a-Service," Washington DC, 2017.

[12] N. Abdelkafe, S. Makhotin, and T. Posselt, "BUSINESS MODEL INNOVATIONS FOR ELECTRIC MOBILITY — WHAT CAN BE LEARNED FROM EXISTING BUSINESS MODEL PATTERNS?," *Int. J. Innov. Manag.*, vol. 17, no. 01, Feb. 2013.

[13] S. Shaheen, A. Cohen, and I. Zohdy, "Shared Mobility: Current Practices and Guiding Principles," 2016.

[14] G. Santos, "Sustainability and Shared Mobility Models," *Sustainability*, vol. 10, no. 3194, 2018.

[15] G. M. Bonnema, "FunKey Architecting: an integrated approach to system architecting using functions, key drivers and system budgets," University of Twente, 2008.

[16] D. König, E. Piri, M. Karlsson, J. Sochor, and I. Heino, "MaaSiFiE: Technology for MaaS (Deliverable

nr. 5),” 2017.

[17] J. Datson, “MOBILITY AS A SERVICE EXPLORING THE OPPORTUNITY FOR MOBILITY AS A SERVICE IN THE UK,” Milton Keynes, 2016.

[18] J. García Hernández, Ed., *Holistic Personal public Eco-mobility - Deliverable 2.3 - HoPE Architecture Analysis*. 2014.

[19] G. Ambrosino, J. D. Nelson, M. Boero, and I. Pettinelli, “Enabling intermodal urban transport through complementary services: From Flexible Mobility Services to the Shared Use Mobility Agency: Workshop 4. Developing inter-modal transport systems,” *Res. Transp. Econ.*, vol. 59, pp. 179–184, 2016.

[20] C. Pflügler, M. Schreieck, G. Hernandez, M. Wiesche, and H. Krcmar, “A Concept for the Architecture of an Open Platform for Modular Mobility Services in the Smart City,” *Transp. Res. Procedia*, vol. 19, pp. 199–206, Jan. 2016.

[21] “smile – simply mobile,” 2015. [Online]. Available: http://smile-einfachmobil.at/index_en.html. [Accessed: 20-Feb-2019].

[22] “Smile Projeckt.” [Online]. Available: http://at.nttdata.com/fileadmin/web_data/country/at/Archiv_2013_2014/Downloads/Reinhard_Birke__Wr._Stadtwerke_-_SMILE.pdf. [Accessed: 30-Jan-2019].

[23] W. Goodall, T. Fishman Dovey, J. Bornstein, and B. Bonthron, “The rise of mobility as a service - Reshaping how urbanites get around,” *Deloitte Rev.*, no. 20, p. 20, 2017.

[24] J. Eckhardt, A. Aapaoja, L. Nykänen, J. Sochor, M. Karlsson, and D. König, “The European Roadmap 2025 for Mobility as a Service,” in *Proceedings of 7th Transport Research Arena TRA 2018*, 2018.

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Appendix – Conceptual Architecture references for MaaS

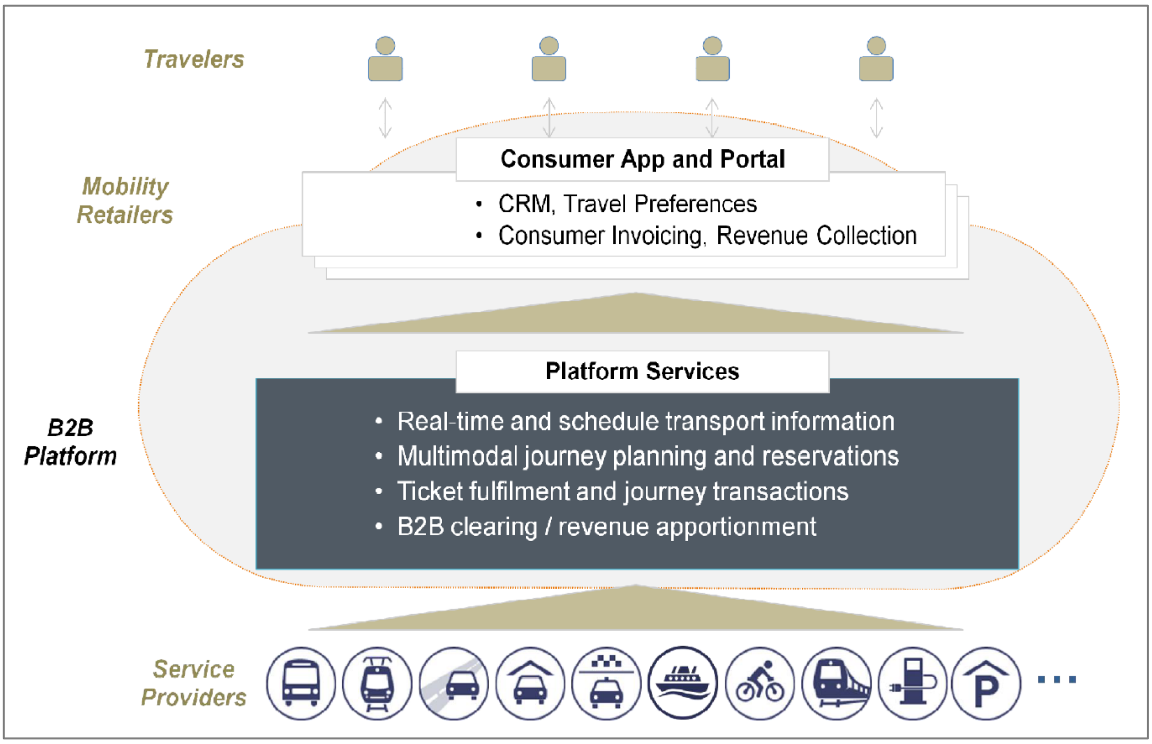

Figure A1: Traditional Mobility as a Service ecosystem by SIEMENS. Source: [8]

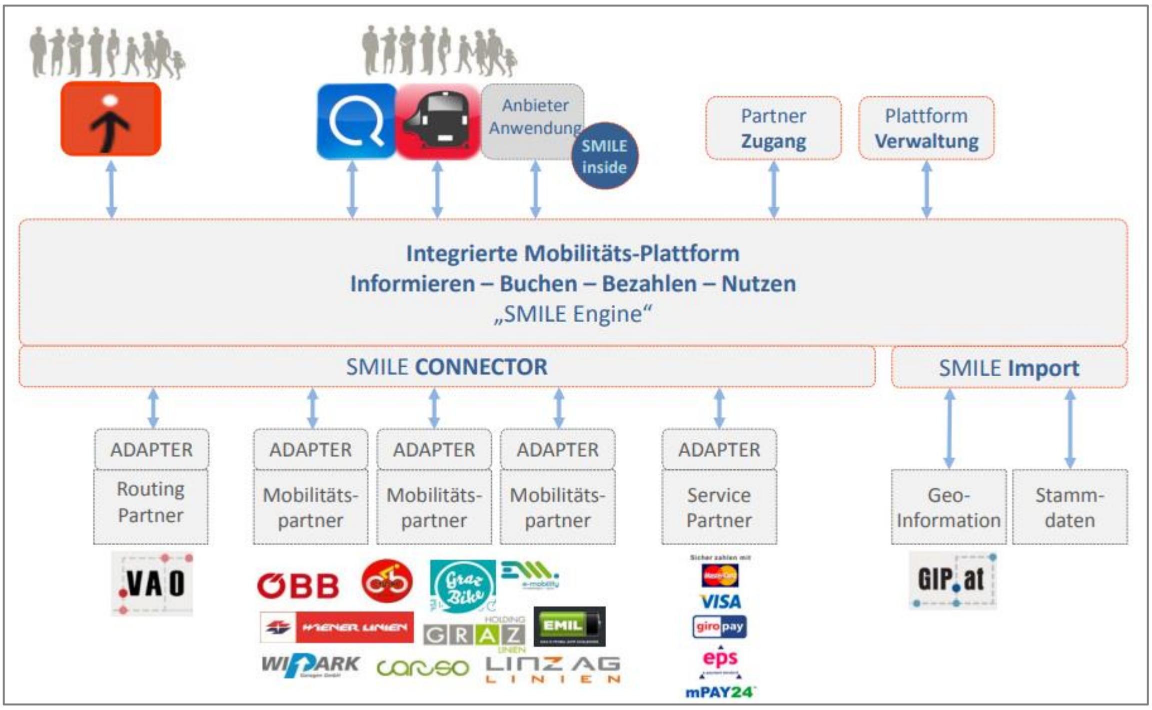

Figure A2: Architecture blueprint for the MaaS project SMILE . Source: [22]

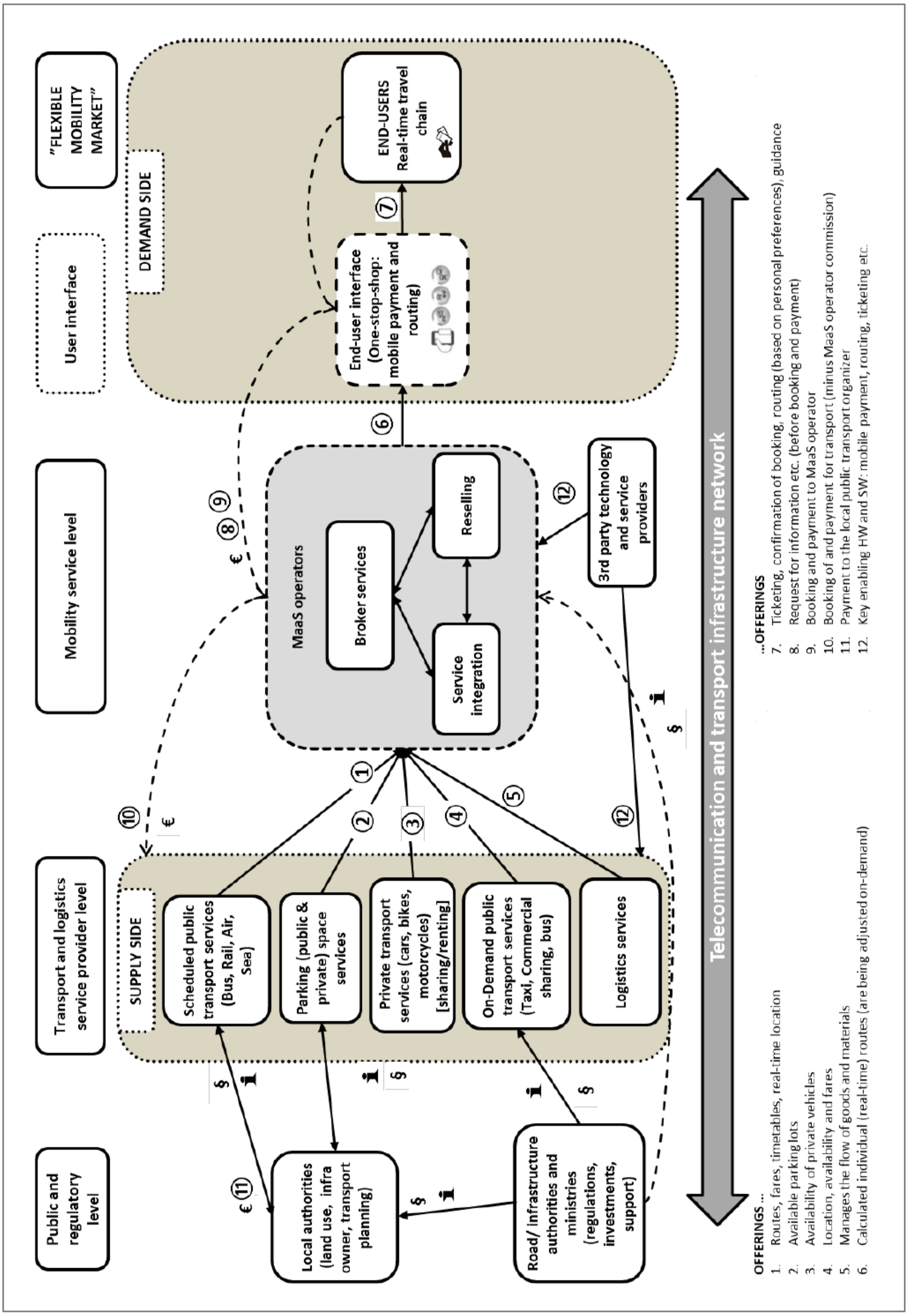

Figure A3: Overview of the MaaS ecosystem by König et al.[‡]

[‡] Source: Aapaoja, A. et al (2016) In: König, D., Eckhardt, J., Aapaoja, A., Sochor, J. & Karlsson, M. (2016). Deliverable 3: Business and operator models for MaaS. MAASiFiE project funded by CEDR

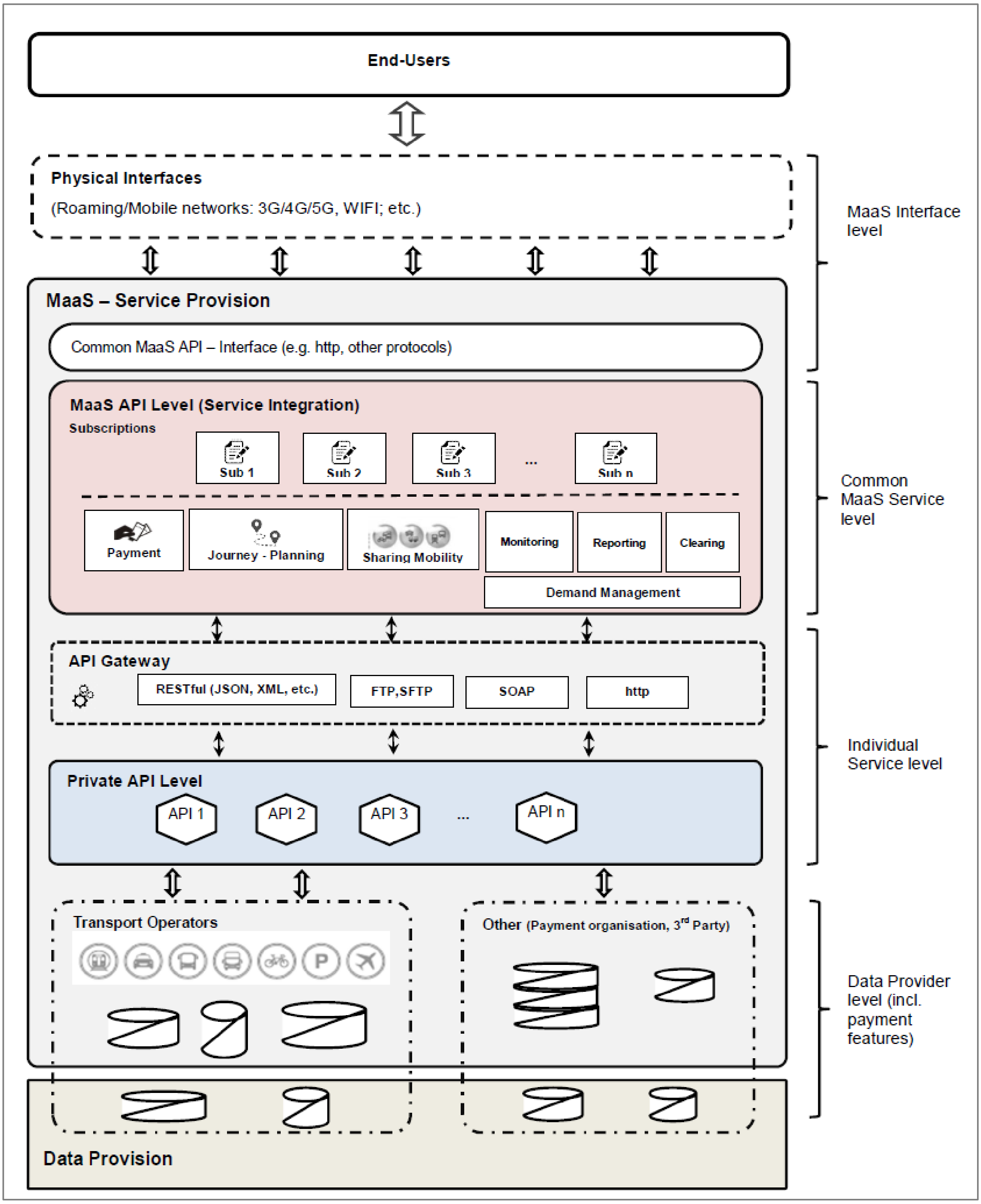

Figure A4: Example of a technical system architecture of MaaS by König et al. Source: [16]

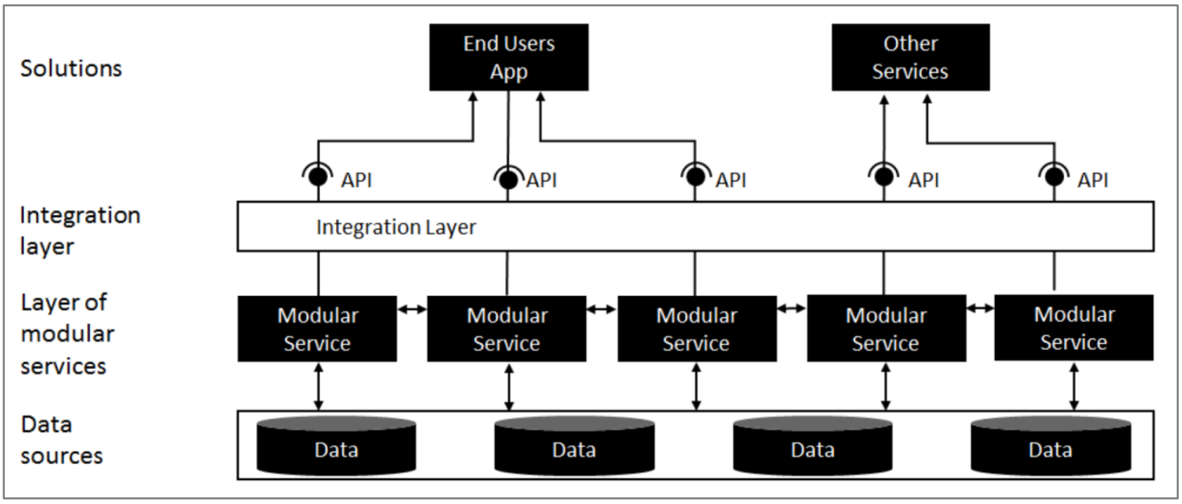

Figure A5: Concept for the architecture of an open platform for modular mobility services by Pflügler et al. Source: [20]