Integration of Road Vehicle Public Charging into Mobility as a Service

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Abstract: The barriers between mobility sub-systems are to be broken. Mobility as a Service (MaaS) is implemented as a platform-based, integrated mobility service, which is open to facilitate further cooperation of mobility related services. The joint operation of smart parking, smart charging, and smart grid services could be expected, as the charging and energy management of road electric vehicle is a supplementary task during parking. Considering this tendency within the MaaS framework, the research question is how the information flow coordinates the smart parking-based charging service. The research objective is to elaborate an information system concept to provide public parking-based charging service in MaaS. The system engineering, process-oriented approach is applied. The information system architecture and its main functions are elaborated, as well as the calculation method of energy power distribution regarding energy management function. Our results intend to support information system planning for such parking-based charging service.

Keywords: *Mobility as a Service, road electric vehicle, parking, charging, energy management*

Introduction

As is one representative of Smart Mobility, Mobility as a Service (MaaS) has been implemented in several cities. The development of MaaS meets its difficulties facing Covid-19. However, as the overall aim of MaaS is the mobility integration, the continuous development of MaaS is still expected. Especially taken the electromobility into consideration in MaaS [1]. MaaS is significantly supported by digitalization regarding the service platform and integrated mobility services, but it is not limited by the digitalization. At current phase, the integration in MaaS is still discussed and implemented in the information, platform, and service level [2, 3]. As is to be a further step, the land use, or the infrastructure integration is to be taken into consideration, as the 15-min or 30-min city concepts are proposed both in Smart City and Smarty Mobility [4, 5]. Service stops or mobility hubs are to be the connection points, where the shared vehicle services, vehicle parking, and electric vehicle charging are located. Regarding the further development tendency, the Jelbi MaaS service implemented in Berlin is a pioneer [6].

Electric cars, bikes, scooters, buses, etc., all are electric road vehicles, the electric road vehicles refer to electric cars (EVs) and electric scooters (e-scooters) in this work. The owners of EVs are not the focusing points in our work; namely, both situations are acceptable, that the EVs either are personally owned or for shared use. As this paper works as an initial service concept from the informatics point of view, we assume the significance is the ability to provide the parking-based charging service. Thus, the discussed parking-based charging space can be used for both purposes: public charging for personal owned vehicles and public charging for electric vehicle sharing services.

Charging is a parallel task along with the parking of electric vehicles. Typically, the candidate location determination for installation of charging-enabled parking lots and, converting existing parking spaces into EV-enabled parking spots, which are the two main research streams in this relatively new parking-based charging services [7]. In addition, the solar-charge EVs in parking lots are also studied by researchers considering longer time parking activities, e.g., the solar charging opportunities in Park and Ride (P + R) facilities [8].

MaaS is implemented as an open digital platform, which provides opportunities to further integrate various services, both mobility related services or non-mobility related services are welcomed.

Regarding mobility related services, charging and parking of vehicles are significant services which are to be included. Furthermore, in a vehicle-to-grid approach, EVs are available to feed the smart grid as well. Simultaneously, the electric vehicle sharing services are strongly proposed in MaaS, as well as the infrastructure integration planning of MaaS are to be taken into consideration. Parking-based charging space and parking lots are such kind of connection facilities are identified as the joint points. Thus, the research niche facilitated by the main research question stands that, from the informatics point of view, how the information flow coordinates the smart parking-based charging service considering the energy management in the smart grid.

Accordingly, research questions are unfolded as follows:

- Why and how to include the parking-based charging service into MaaS?
- What are the main information system functions?
- How to balance the energy distribution in a vehicle network point of view?

To answer research questions, the remaining of the paper is structured as follows. Literature review is summarized in Section 1. In Section 2, the research methodology is described by the steps in the research process. The summarized opportunities in digitalized mobility services are also presented as the research background. In Section 3, the functions in the information system, the parking-based charging service concept in MaaS, as well as the calculation method of energy management considering smart grid, are elaborated. The paper is completed by the concluding remarks including future research directions.

1. Literature review

From the transportation integration point of view, MaaS is neither a new nor innovative mobility service [9]. The origin concept could be the Advanced Traveller Information Systems. Various technology development, especially the information and communication technology (ICT) provides the opportunities, and facilities the integration in transportation field. However, considering the perspective to view mobility services, the service usership, and the shared mobility services, MaaS is new. MaaS is proposed as a new power intending to lead people to a more sustainable and environmental-friendly transport system. The Whim application is developed in Helsinki by MaaS Global this private company, and it is well-recognized as one MaaS representative mobile application [10]. The success of Whilm application is also strongly supported by the public transport sector of Helsinki [11]. In addition, that a personal car may be not needed in Helsinki had been ever discussed [12].

Not so many cities are available to provide such strong public-private cooperation to facilitate transportation. Thus, on the one hand, MaaS speeds its implementation, e.g., launch mobile applications in cities. On the other hand, the willingness to accept and use MaaS service are still blur and not strong [13]. Michal et al. [14] had conducted an online survey intending to investigate the attitude to use MaaS among around 6000 valid respondents in four European cities. Their results indicate significant evidence that the personal opinion counts, regarding shared economy, environmental friendliness, and social influence, which does impact the willingness to use MaaS. Their collected data also shows that people with higher age and the lower income are the average undecided users. Income level and education level do influence the mode choices of transportation, authors of [15] also comment that 'educating citizens is an important path to reduce car dependency'. In addition, this statistical based survey study focuses on respondents in urban area.

What should be and could be the MaaS, or the intelligent passenger transport in rural area has been also discussed [16]. MaaS is proposed as a 'mobility for all' service, people with special mobility needs, as well as mobility in rural areas are to be considered in MaaS planning. Problems such as uncertain and low demand exist, however, neglect problems are not a smart solution. Mobility hubs function as such connecting facilities, the relevancy and opportunities with solar charging and parking of electric vehicles also attracts researchers.

According to a measurement study [17], the energy efficiency of measured EVs is low regarding that, the 55% of the energy taken from the electric socket has not been used for the wheels to be driven. This situation is significantly expected to be improved, it takes time and not easy. Whatever, the charging facilities play a key role in electromobility. The infrastructure, e.g., the availability of charging points influences the purchase and social attitudes towards purchasing and using EVs [18]. Land use planning forms a key question in vehicle parking. Currently, according to various parking behaviours, vehicles still park a lot even in most developed regions [19]. However, regarding the charging is a supplementary task during parking, then the parking lots may have opportunities to convert to the charging enabled-parking lots [7]. Both on-street parking space and the Park and Ride facilities are to be considered for such combination, in order to optimize the utilization of the parking space [8, 20]. In addition, smart parking and smart charging which are available to be managed via mobile applications, is the advantage in the parking-based charging service [21]. Especially considering the information flow interact with the energy flow in the smart grid to optimize the energy management [22, 23].

From the perspective of informatics, MaaS is an open platform to involve digitalized mobility related or non-related services. Based on this assumption and stimulated by above literature, taken the tendency of electromobility into consideration, we identified the research niche. The novelty of our work is that, we include the parking-based charging service concept into MaaS framework taking the smart grid into consideration, from the transport informatics point of view.

2. Methodology

The main applied method is the engineering principle based, process oriented functional modelling approach. In addition, regarding energy consumption calculation, two typical calculation methods are summarized. The steps of the research processes in our work are presented in Figure 1.

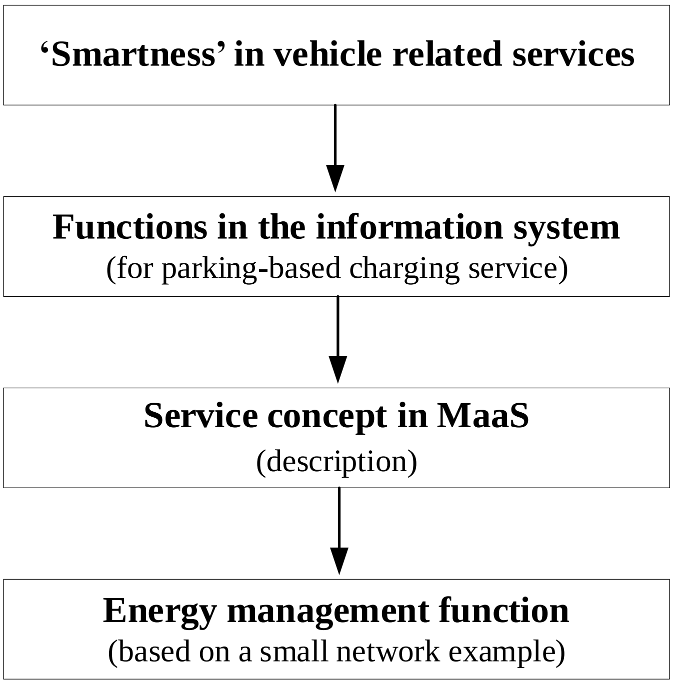

Figure 11. Steps in research processes

First, the opportunities of digitalized mobility services incorporating with MaaS are presented. Then, considering a parking-based charging space as a unit in the charging network, the functions in the information system regarding the charging-parking space provided service are elaborated. The charging of EVs and the e-scooters are considered in the same charging point. Next, regarding the parking-based charging service, how information flow interact with energy flow is interpreted, from the perspective incorporating this service into MaaS. Finally, the energy management function is detailed from the smart grid point of view, taken real-time data interaction and dynamic control into consideration.

Here, we further discuss the relatively fast developed mobility services recent years regarding digitalization, as well as the connected information systems. The opportunities in digitalized mobility services (based on EVs) are summarized in Figure 2. Charging/filling, parking, running, and maintenance are the major activities of vehicles. Since more and more intelligent devices are equipped or installed on the vehicles, especially with the EVs, the smartness or the intelligence is not only from the process of the provided mobility services, but ‘the smart vehicle in the smart service’ as a whole is provided to users.

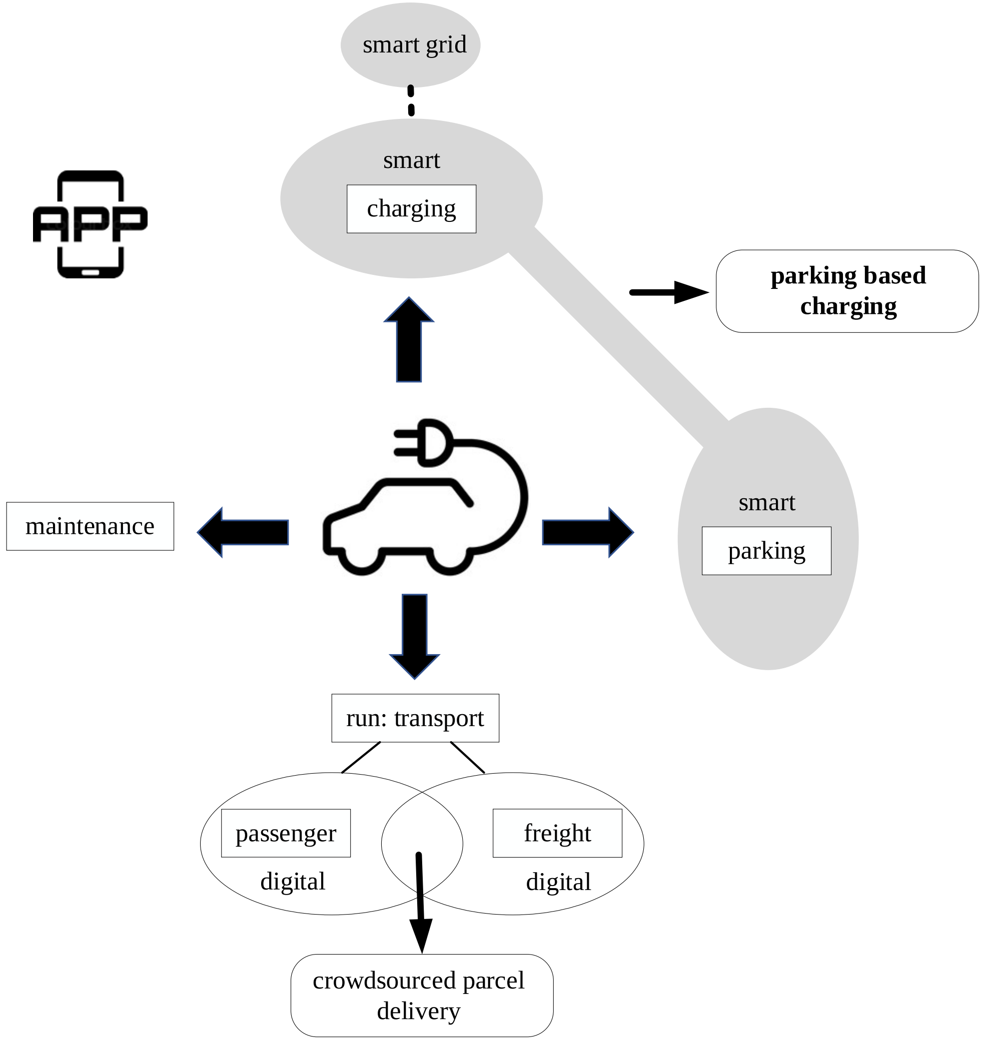

Figure 12. Opportunities in digitalized mobility services

We focus on the new services stimulated by the digitalization. Mobile application is used as the interaction platform by users. Regarding vehicle charging and parking services, the first smartness stands at the digitalized infrastructure management, which means that demand and supply of charging point and parking space could be coordinated with real-time data. Availability and accessibility of charging point are visible on the map of the charging network, supporting the online booking and payment. The appropriate amount of charging points should be provided for people with special mobility needs. In addition, although Vehicle-to-Grid (V2G) approach remains at theoretical level with technology limitation during current phase, e.g., the lifecycle of batteries is decreased by the frequent charging and use, the national grid or the corresponding grid are to be transformed with changes, too. The smart grid concept is to be still promoted and put on effort. Use dynamic price of electricity as the tool to adjust the use period of electricity, it saves and balance the energy consumption in theory.

Similarly, the availability and accessibility of vehicle parking is also with smart solutions. Not only the EVs, taken autonomous vehicles into consideration, charging may still be the big problem. Considering the charging demand and (may) decreased parking demand, balance the land use of parking space and charging point is expected, as charging is the supplementary task during vehicle parking. Thus, this is the reason why the parking-based charging service is proposed by several researchers. Parking based charging service could be both implemented on street parking area and in the Park and Ride facilities. In this work, we discuss the parking-based charging service as a whole in MaaS. Distinguish these two situations are our further work regarding analysis of mobility hubs.

Regarding vehicle running, because of the wide range of mobile phone use, the online connections are more available between users. The connection between passenger and freight (parcel) are possible supported by digitalization. The crowdsourced parcel delivery service is proposed in this situation [24]. It is only earlier than MaaS one or two years. The platform dependency may provide the opportunity that MaaS involves the crowdsourced parcel delivery service. The parking-based charging service is to be also a platform dependent service, it highly related with vehicle activities. In addition, several MaaS applications already included the parking space on their StreetMap. Thus, we propose incorporating the parking-based charging service into MaaS. Taken infrastructure integration into considerations in MaaS, mobility hub development is to be considered in this integration level, the (shared) vehicle parking and charging service are essential to be located in the mobility hubs.

3. Results and Discussion

Based on how to involve the proposed parking-based charging service concept into MaaS, firstly a 'unit' of the information system is presented in sub-section 3.1. How to use this service is interpreted. In sub-section 3.2, how this service is to be in real practice is envisaged, by taken MaaS into consideration. In sub-section 3.3, the energy management function is detailed by providing calculation methods of dynamic electricity power distribution in smart grid, based on a small network example.

3.1 Information system and functions

Considering a parking-charging space as a unit of the information system, the main components are determined as follows:

- **MaaS operator**: service coordinator and platform operator
- **User**: the service is used via mobile application on the smartphone
- **Charging point**: with smartness, connected to the information system and the smart grid
- **Electric vehicle**: either public shared EVs or personal owned EVs
- **Energy provider**: the electricity provider
- **Operator of infrastructure**: operator of charging point and charging network.

The components and main functions in the information system (a unit) are presented in Figure 3.

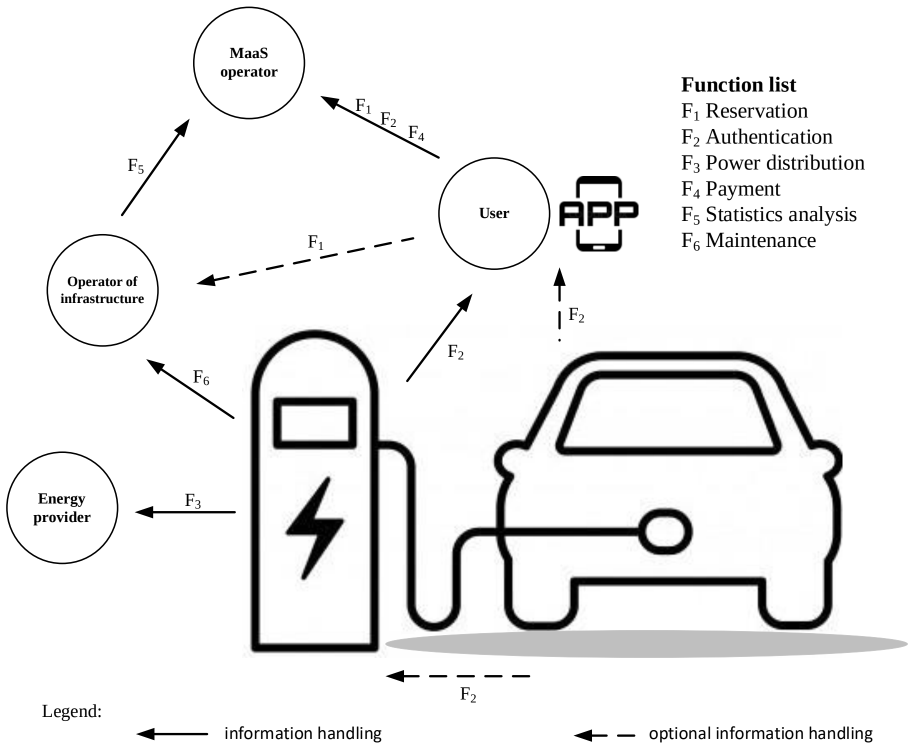

Figure 13. Functions in parking-based charging services

The main functions are listed in Table 1.

Table 6. Functions

Function			
F_1	Reservation	F_2	Authentication
F_3	Power distribution	F_4	Payment
F_5	Statistics analysis	F_6	Maintenance

Since the base assumption is that components are connected in the information network, thus, user uses service via mobile application. By fingertip clicks, the service is to be smoothly experienced. Listed functions are information management related functions.

3.2 Incorporating service concept into MaaS

Taken MaaS into consideration, how the parking-based charging service works is interpretated with determined functions. To visualize the service concept, we provide the following Figure 4. Both EV's charging and e-scooter's charging are considered in a same charging point.

Figure 14. Illustration of the parking-based charging service

We only consider the combination of e-scooter charging and EV charging in this work. E-scooters do not occupy too much electricity, and its size is small. It does not occupy too much physical parking space as well. The e-scooter is shared, public scooters. Personal owned e-scooters are available to be easily charged at home. Thus, the public shared e-scooter is provided with public charging opportunities.

F_1. Reservation: User reserves the charging service via smartphone, either including charging service in a travel chain or only reserves the charging service. In case the charging service is reserved within a travel chain, for example, after using the car-sharing service, the user can charge the vehicle and leave the vehicle at the charging station.

F_2. Authentication: User uses smartphone to start the charging process, via e.g., the quick response (QR) code scanning, the Near Field Communication (NFC) technology, for authentication purpose.

F_3. Power distribution: the real-time information flow influences the energy flow. With the dynamic control, the electricity is to be distributed according to demand in the grid network.

F_4. Payment: the electronic cash flow is the information flow as well. Payment can be involved in the MaaS monthly plan as well.

F_5. Statics analysis: users' data of charging behavior are collected and analysed, for example, the frequent charging time duration (average charging time), the charging point location (where to frequently use the charging service: working place, shopping mall, hospital, etc.), the charging motivation (long time parking, shopping duration, fitness duration), etc. Personalized recommendations could be also provided based on the results of statistics analysis. Such as the nearest charging point with fast charging option, available charging facilities with the entertainment opportunities, etc.

F_6. Maintenance: the maintenance in this context is not the physical vehicle maintenance. It points to the maintenance of the information network and the platform. In order to better handle the data and improve the usability of information system.

3.3 Function of energy management considering the smart grid

According to concept of Vehicle-to-Grid, vehicles are available to charge back the electricity into grid during daily time [23]. And the vehicle is charged during the night period. Theoretically, the combination of these two can share the pressure of electricity usage during daily peak time. This is one of the applications of smart grid concept.

The smartness in parking-based charging service is that, the energy distribution or energy flow can be controlled by the information flow. In other words, the information flow can adjust the energy flow.

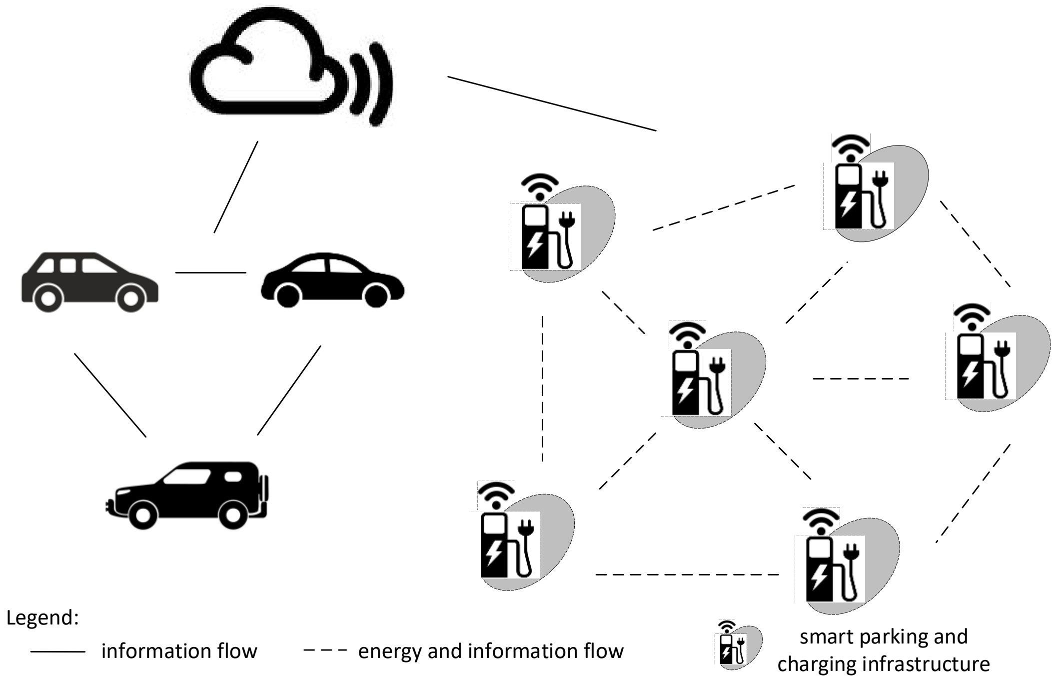

Figure 15. An example of parking-charging network

The information connections between vehicles are still not available at current stage, the connected vehicles or fleets in information systems are expected in the near future with highly automated vehicles or autonomous vehicles. The base equation of energy distribution is shown in Equation (1).

$$E_{p_{ave}} = \frac{E - (n_c \cdot E_c + n_s \cdot E_s) + E_{ba}}{n_{request}} |_t \quad (1)$$

Regarding a specific time point *t*,

- E_{Pave}: the average, available to be distributed power, kwh
- E: available power in all, kwh
- n_c and *Ec*: *n* cars have charged E_c electricity, kwh
- n_s and *Es*: *n* scooters have charged E_s electricity, kwh
- E_{ba}: the electricity which are charged back to the grid, kwh
- $n_{request}$: *n* cars are requested to be charged.

The calculation is based on the real-time data from the energy network. At the time *t*, the available remaining energy is calculated first and then distributed to the requested vehicles which are to be charged. The charging back electricity is considered as 'E_{ba}'. The exact time point *t* is determined in this calculation. Namely, Equation (1) provides the answer to 'the vehicle is to be charged at time *t*, which amount of average energy (electricity) could be distributed to the vehicle?'

In case the peak time charging diagram is available, then, the available charging power is to be calculated with the approximation theory-rectangular approximation. An example is presented in Figure 6. Namely, the available energy of a time duration can be calculated.

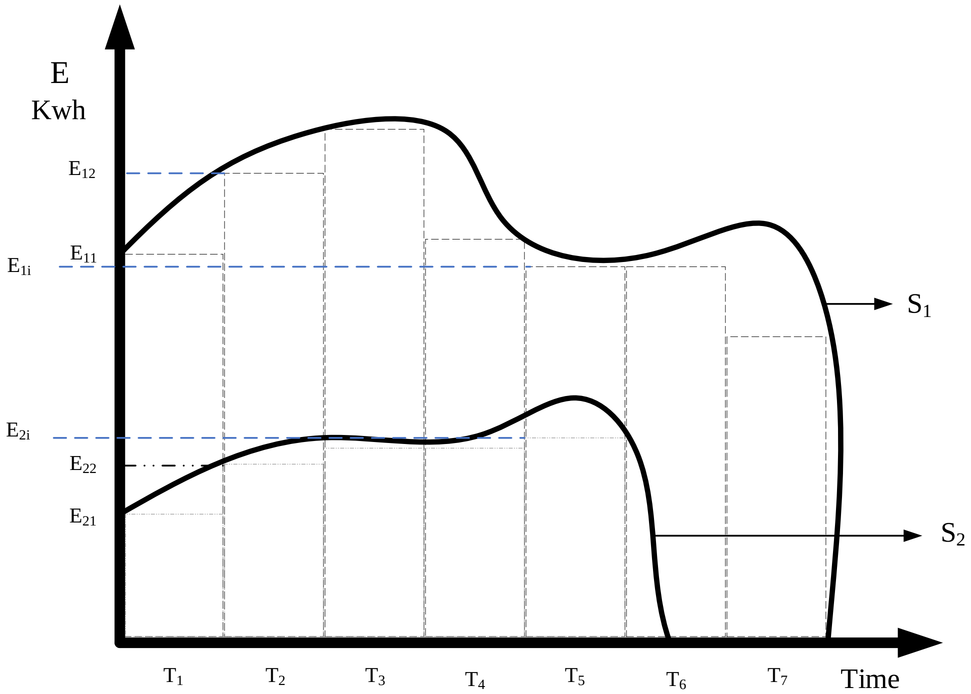

Figure 16. An example of energy management

The available energy is the area between S_1 and S_2, which is expressed in Equation (2).

$$E_{available} = \int_{T_1}^{T_i} (s_1 - s_2) \tag{2}$$

For the further step calculation, the value of available energy is calculated according to Equation (3).

$$E_{available} \approx (T_1 \cdot E_{11} + T_2 \cdot E_{12} + \cdots + T_i \cdot E_{1i}) - (T_1 \cdot E_{21} + T_2 \cdot E_{22} + \cdots + T_i \cdot E_{2i}) \tag{3}$$

Then, the average energy distributed to a vehicle during the time duration [T_1, T_i] is calculated according to Equation (4).

$$E_{p_{ave}} = \frac{E_{available}}{n_{request}} \tag{4}$$

Theoretically, the average distributed electricity of a vehicle at time *t* or during a time duration can be roughly calculated according to Equation (1) and (3), (4), respectively.

Conclusions

The concept of integration of road vehicle public charging into MaaS is elaborated in our work, focusing on EV and e-scooter charging at the same charging point, from the perspective of transport informatics. MaaS provides mobility services based on a digital platform. Considering the MaaS ecosystem, more and more digitalized mobility services are welcomed to join the MaaS. Smart parking, smart charging, smart grid, these smartness-based concepts or implementation require the digital platform as well. Thus, involving smart parking-based charging service into MaaS is a promising step, as well as taken the smart grid into consideration.

The first research question is answered by the summarized opportunities in digitalized mobility services in Figure 2. The second research question is answered by the elaborated information system structure with main functions in Figure 3. To answer the third research question, a small network example is presented in Figure 5, the simplified calculation methods of dynamic energy distribution are provided considering the energy management in smart grid.

One of our further research directions is that, the parking-based charging service management will be distinguished regarding the locations of mobility hubs. The size and functionalities of mobility hubs in urban and suburban are different, even the mobility hubs in rural areas could also be considered. For example, the mobility hubs in city center, the Park and Ride located at the suburban-urban area. Regarding the integration aim of MaaS, the location of mobility hubs in MaaS will be reconsidered. Charging availability plays a key role in mobility hubs, as well as in the further concept of 15- or 30-minute liveable cities planning.

Acknowledgement: *The research reported in this paper was supported by EFOP-3.6.3-VEKOP-16-2017-00001: Talent management in autonomous vehicle control technologies. The project is supported by the Hungarian Government and co-financed by the European Social Fund. It was also supported by project no 2019-2.1.11-TÉT-2020-00176 has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary from the National Research, Development and Innovation Fund, financed under the 2019-2.1.11-TÉT-2020 funding scheme."*

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