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ABSTRACT

This discussion paper revises the government-contracted Mobility-as-a-Service (MaaS) model by Wong et al. (*1*), by making the contracting entity maintaining the mobility system's sustainability, likely to enhance sustainability compared to the current state. The achievement of sustainability objectives is ensured by dynamic transport mode pricing based on the total sum of each trip's internal and external costs. By combining government-contracting and sustainability objectives, MaaS can overcome the most critical regulatory and operational challenges in the implementation process, such as the lack of incentives for active mobility and cooperation between public and private companies. To implement such a system, we propose a four-step approach, with policy mechanisms changing from information-based to mainly regulatory and economic (*2*). The initial goal is a journey planning tool that transparently shows time, distance, emissions, and full costs of a trip for a chosen transport mode and recommends more sustainable alternatives. The full version offers mobility bundles and budget solutions including ticketing, combined with full cost transport pricing that takes into consideration space-time dynamics. However, the proposed approach cannot overcome all the risks involved in a MaaS implementation. Individual user behavior is difficult to predict and part in the evaluation of this concept. The goal of this proposed MaaS model is to improve environmental and social sustainability by changing transport prices in relation to the full costs. This paper contributes to the recently started nine-year MCube mobility research cluster project, which aims to develop and test a MaaS model for the metropolitan region of Munich.

Keywords: Mobility-as-a-Service, sustainability, transportation governance, MCube

INTRODUCTION

Until now, research into Mobility-as-a-Service (MaaS) has focused on its potential positive impacts on the efficiency and sustainability of transport networks in metropolitan regions (*3*–*5*). These positive aspects provide benefits to three distinct stakeholders, as follows:

- *Users*: Access to flexible, personalized, on-demand mobility and seamless door-to-door travel.
- *Public sector*: Improvements in the effectiveness and sustainability of the holistic transport system, growth in employment and gross domestic product generated by new businesses.
- *Businesses*: Creation of profitable markets for new transport services, new opportunities for conventional transport and infrastructure businesses through innovative service concepts and co-operations.

However, recent literature also points out several challenges and unanticipated implications of MaaS, especially when discussion only focuses on its potential benefits rather than taking a more comprehensive approach (*4, 6*–*9*).

In addition to such positive and negative effects, it is also necessary to define the MaaS system's objective and determine what it is supposed to be capable of. The literature provides a variety of standard MaaS definitions, as summarized by Cruz et al. (*10*). This study uses the following definition, as laid down by the House of Commons Transport Committee (*11*):

"MaaS is a term used to describe digital service, often smartphone apps, which people use to access a range of public, shared, and private transport, using a system that integrates the planning, booking and paying for travel"

In this paper, we extend this definition with features of a government-contracted MaaS model that pursues the objective of sustainability. The concept further develops an idea presented by Wong et al. (*1*) that is reproduced in **Figure 1**.

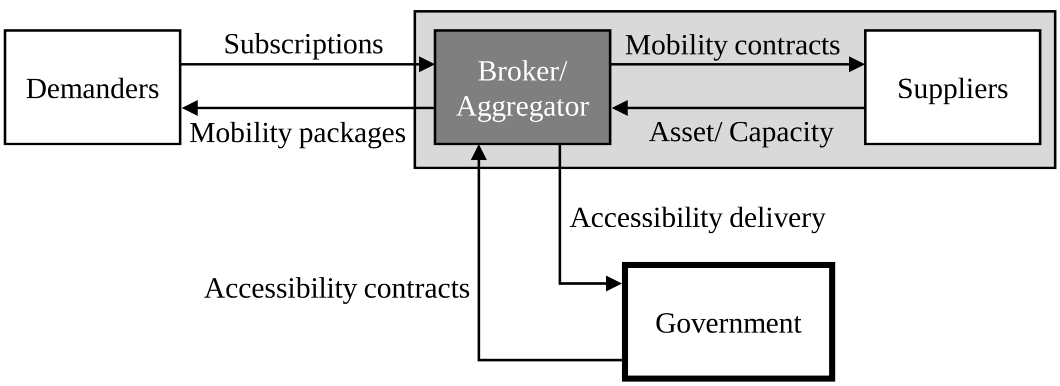

Figure 1 Mobility-as-a-Service under government contracting (*1*)

The figure illustrates a government-contracted MaaS implementation model. Like any MaaS concept, it is intended to supply accessibility using multiple modes of transport. Additionally, the government directly procures a mobility broker. Individual transport mode pricing can be implemented and complemented by internal cross-subsidization or, where necessary, with financial support from the public. It regulates network efficiency by incorporating a road user charge, while general pricing (mobility subscriptions or credit packages) depends on a trip's time of day (real time), geography (location and road type) and modal (both spatial and temporal) properties. Other inputs such as environmental and social considerations can also be included and are considered in this paper. In general, the government-contracted MaaS model is a demand management concept that aims to provide societal benefits.

This paper seeks to continue and expand on the ideas of Wong et al. (*1*) regarding a government-contracted MaaS model, combined with governmental sustainability objectives. It does this by internalizing social and external costs of mobility options to the individual trip level. It discusses the features, implementation steps, and requirements of such a new MaaS concept. The task and research question of this discussion paper is to discuss the key features, implementation steps, and requirements of a government-contracted MaaS model, in which the government pursues the objective of sustainability. The concept is known in its abbreviated form as SuGov-MaaS.

After the introduction, the extensive literature review points out and categorizes the key challenges of the MaaS implementation. The next section describes the features and the implementation process of the presented MaaS model. Finally, the risks and benefits of the model are discussed, and the paper concluded. This is the first paper of a research series focusing on MaaS in combination with full cost-related pricing methods. Subsequent studies will reveal data, results and trials of the presented MaaS model within a larger research cluster with the name of MCube. "MCube – Munich Cluster for the Future of Mobility in Metropolitan Regions" is part of the BMBF (Federal Ministry of Education and Research of Germany) clusters4future initiative and will receive 45 million euros in funding over the next nine years.

CHALLENGES FACING MAAS

After conducting an extensive literature review on the subject of MaaS, we filtered the most relevant papers in terms of the challenges of implementing MaaS and categorized and ranked them. The ranking is based on assessments by well-known MaaS authors and frequency of occurrence. Accordingly, the literature suggests six notable categories of MaaS challenges. The categories are in order of severity: technical, individual, social, economic, operational, and regulatory (see **Figure 2**).

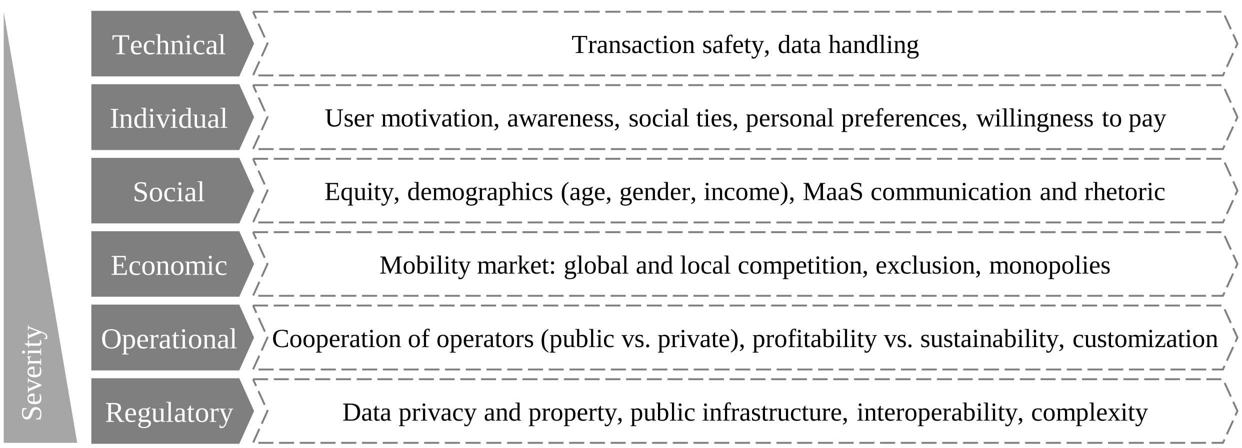

Figure 2 Overview of MaaS challenges

From a technical point of view, MaaS – as defined in the introduction – is already a relevant product for the regional transport market. Safe transactions (*10*), unified data formats, and high data quality (*12*) are all important aspects that need to be taken into consideration when developing a MaaS application.

When it comes to implementing MaaS products, individual user behavior is a crucial element of the system's success. Hensher et al. (*13*) and Jittrapirom et al. (*4*) state that the key challenge for MaaS is to attract users and motivate them beyond the stage of early adopters. It is hard to change the behavior of users who are familiar with current solutions (*14*). This is especially true when insufficient marketing information means that users are not aware of what impact the external and social costs of local transportation options has (*10*). Even though the number of driving licenses among young cohorts in Germany is declining, the rate of private car ownership has recently increased (*15*). Furthermore, most people around the world still want to own a car, according to Mulley (*14*), pointing out that for a MaaS system to be successful, attitudes towards car ownership need to be changed (*14*).

It is not only on the individual but also on the societal level that there are significant challenges to MaaS implementation. For example, Pangbourne et al. (*6*) reported that communication and rhetoric on the subject of MaaS are too positive and that the problems associated with MaaS are not sufficiently addressed. This can lead to unanticipated outcomes, with the result that change is no longer possible (*6*). Problems related to the exclusion of people who do not have a bank account or a smartphone could pose substantial threats to equity in society. This applies in particular to poor and old people (*6*). An understanding of customer needs is related to demographics (age, gender, income) and psychographics (interests, opinions, attitudes, values) (*16*). Equitable MaaS systems need to be able to fulfil the needs of diverse user groups.

On an economic level, it is important to know who has control of the MaaS app (*10*). There will be enormous competition between potential MaaS providers and other travel application providers such as public transport authorities, established companies and local governments and start-ups (*10*). If private companies will be the sole MaaS broker, there will be a risk of a monopoly (*6*). This risk will be even higher (*10*) in the case of a large company that cooperates with global data handlers (Google, Apple, Amazon) and controls mobility pricing (*8*). This could lead to exclusion from the free market due to exclusive data ownership and relationships (*6*), ultimately resulting in a negative impact on competition and a threat to innovation itself (*12*).

An additional challenge lies in the cooperation between transport operators and service providers. Willingness to cooperate can be affected by a lack of trust and an unequal distribution of power between the operators (*1*). In particular, the conflicting objectives of private and public service providers can lead to highly complex partnerships (*4, 10*). Monitoring contract flexibility (*10*), agreement on pricing (*8*) and the allocation of revenue to each transport operator (*14*) are some of the most critical sources of conflict. Partnerships between private and public operators involve a change of identity on both sides. Private companies generally act on a national or global level and impede developments towards open-source standards (*12*) while public transport is controlled by local governments (*1*). With MaaS, public authorities face a dilemma due to decreases in monopoly and economies of scale (*4*).

Not only the cooperation between operators but also the MaaS operation itself creates several challenges. Most operational challenges are related to the commercial success and profitability of the operation, leading to an increase in the volume of trips and traffic rather than the desired reduction (*6*). Additionally, an operation that focuses solely on commercial, monetary success would be unlikely to promote active and healthy transport options (such as cycling and walking), since it does not take social costs into consideration (*6*). Lyons et al. (*8*) determines a distinct conflict of interest between making a profit and offering sustainability and equity. This is why Wong et al. realize that financial support and social cost considerations are needed for a successful MaaS application (*1*). This and other conceptual requirements are discussed in the next section.

The most acute challenges that MaaS faces are of a regulatory nature. The regulations relating to digital platforms, including data privacy and data property, need to be adapted (*10*). At the same time, public infrastructure changes are required and investments have to be made, while a legally compliant third-party ticket selling framework also has to be established (*12*). The necessary interoperability and information sharing between local governments, public transport authorities and private companies render urban mobility governance with MaaS even more complex (*6, 10*). So far, mobility governance in urban areas is highly mode-specific and operator-focused and, thus, not customer-oriented (*6*).

Coping with regulatory issues and generating revenue while being sustainable are key challenges to be addressed by MaaS. It is against this background that Wong et al.'s government-contracted MaaS model (**Figure 1**) will be conceptualized in the next section and further developed with the addition of sustainability objectives.

SUGOV-MAAS CONCEPT

Features

Recent MaaS approaches have proven unsuitable due to the challenges involved. Wong et al. (*1*) took the first step towards a new approach by bringing MaaS under a system of government contracting (**Figure 1**). The features of their adaptation are presented in the introduction to this paper. Given that it is unlikely to achieve the objective of sustainability, this section develops additional features for a government-contracted MaaS with an integrated sustainability objective (SuGov-MaaS), as illustrated in **Figure 3**.

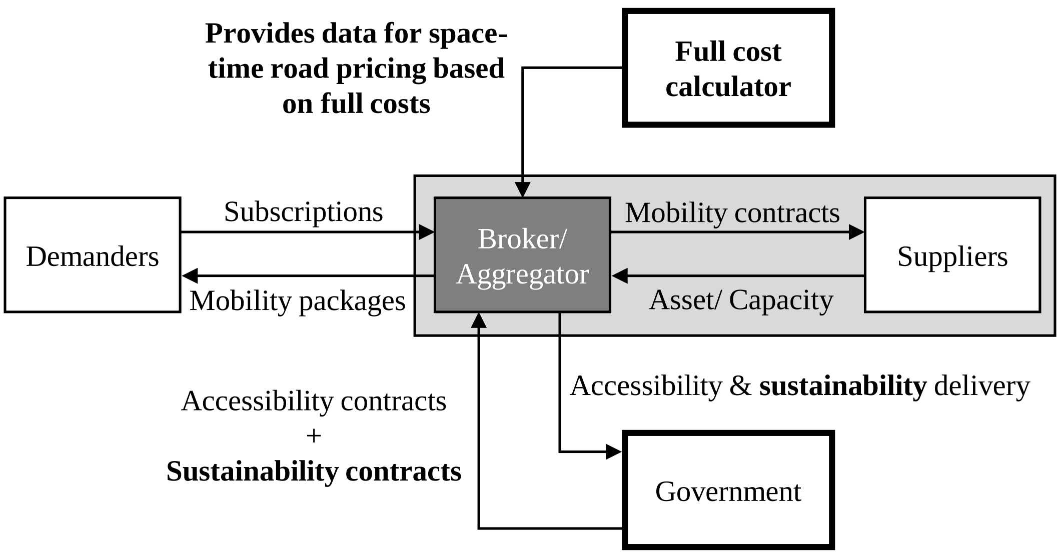

Figure 3 Government-contracted MaaS with a sustainability objective

Figure 3 is an expansion of Figure 1 with additional elements to show the implementation of a sustainability objective. In addition to accessibility standards (*1*), the government sets sustainability standards, which can be defined, for instance, as delivering a certain percentage of low-emission transport in the interest of environmental sustainability. This can be achieved by combining the pricing of the individual modes of transport with the full cost calculations to achieve full cost transport pricing that takes into consideration space-time dynamics.

$$C_{full} = C_{internal} + C_{external} \tag{1}$$

For the purpose of this paper, full costs C_{full} are defined as the total sum of all internal costs $C_{internal}$ and external costs $C_{external}$ incurred by a mode of transport (see Equation 1). External or social costs describe all costs incurred through the use of a certain transport mode that users are not directly aware of and that are not covered by their expenditures. These costs relate to, for example, environmental damage, the health care system due to accidents or noise, land usage and many other factors. Future studies will focus on the detailed definition and determination of external cost parameters, as interpreted for the concept presented here. Internal costs comprise all those costs that the consumer is directly concerned with. The internal costs incurred by most modes of transport have been covered in previous work (*17*).

However, these costs depend greatly on location and time frame as well as on the mode of transport. The full cost calculator is thus a dynamic, multimodal routing application that is able to calculate total costs for each transport mode and recommend routes and transport modes that incur the lowest full costs and thus represent the most sustainable trip. Active modes of travel frequently represent the most sustainable alternative for short trips. This is why the government has to be able to cross-subsidize or incentivize active travel modes such as walking and cycling in the MaaS application. This can be achieved by introducing mobility budgets and limits to the application. Further details of this are presented in the next section.

Governments can use this version of MaaS as a transport management tool and improve transport efficiency and sustainability while considering social equity. Mobility management and pricing should not be left to the open market or private companies. Rather, local governments should be responsible for strategic transport planning and steering activities.

Implementation process

The development of government-contracted MaaS, as presented in the section above, requires a structured framework. The implementation process can be divided into four levels, each representing a step in the development towards the final government-contracted MaaS application, with an integrated sustainability objective (Level 4 = SuGov-MaaS), that can be used as a transport network management tool (**Figure 4**). According to Axsen et al.'s (*2*) categorization of policy mechanisms, the levels evolve from being mainly information-based to mainly regulatory in Level 3 and mainly economic in Level 4. The mechanisms are described in detail in the following.

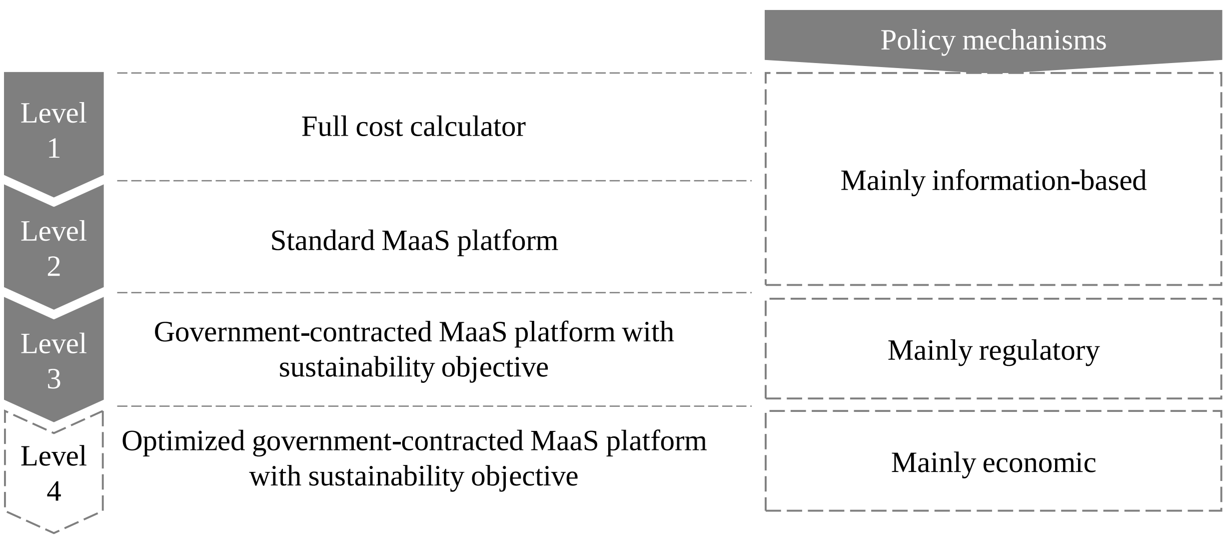

Figure 4 Implementation levels for a government-contracted MaaS with a sustainability objective

In Level 1, a full cost calculator is developed as a web-based implementation. It includes a function for routing from a chosen start point or current location to a chosen destination within a specific region. Travel time, distance, emissions and full costs, including internal and external costs, are calculated for the mode and route chosen, and shown transparently in the application. The user is given information about alternative transport modes and routes, while a routing algorithm recommends more sustainable, faster or lower-emission options. Dynamic routing is based on live data for each transport mode. For this purpose, the web-tool is connected to the relevant operator's interface as well as other application programming interfaces (APIs) for live data (train arrival, shared vehicle locations, congested roads, etc.).

Schröder and Gotzler (*18*) used a similar approach and analyzed routes with randomized origin-destination matrices in the metropolitan region of Munich (**Figure 5**).

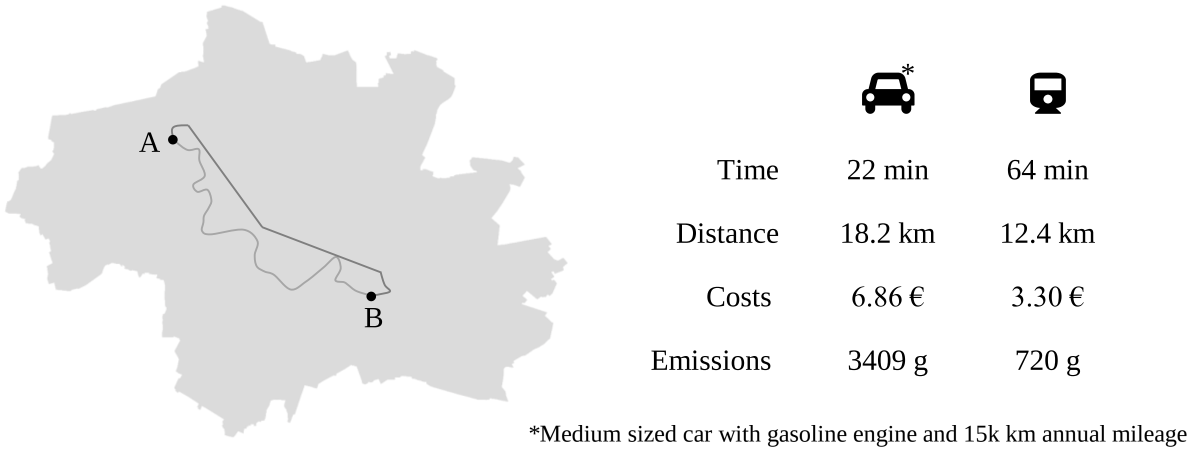

Figure 5 Schematic illustration of the full cost calculator with example cost, time, distance and emission calculations for different transport modes from (*18*)

Level 2 adds transactions and ticketing to the routing and planning mechanisms of Level 1. By integrating these adaptations, it now represents a standard MaaS platform with extended planning functions and full cost calculations. Operational and transactional integration is for all transport modes and services in the region. Service and ticket prices are mainly defined by the operators, and intermodal trips can be planned and paid for in the mobile application. The payment model is ‘pay-as-you-go’ (PAYG).

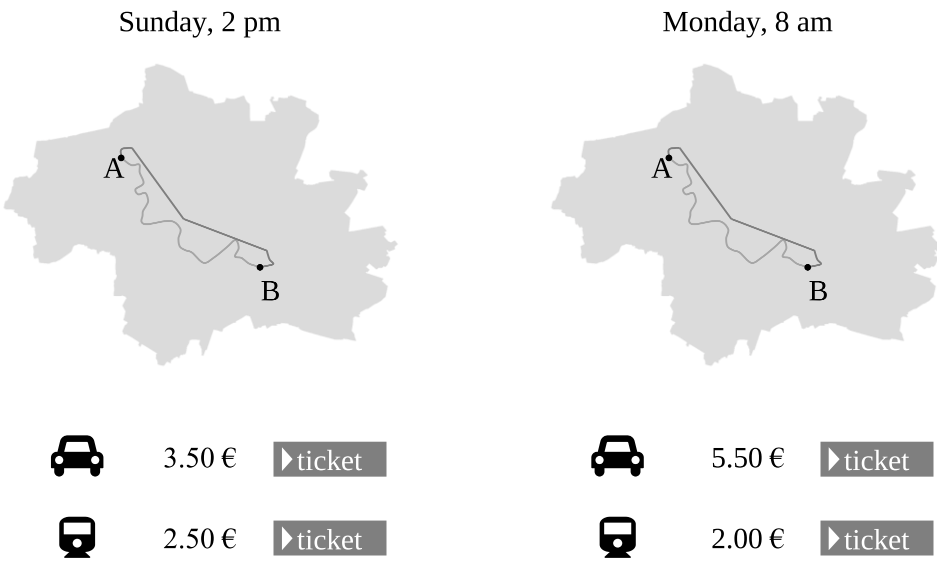

Figure 6 Schematic illustration of example Level 3 MaaS functionalities

In Level 3, the local government directly procures the mobility broker, as described in the introduction, with the government-contracted MaaS model by Wong et al. (*1*). Dynamic pricing mechanisms according to the time of day, geography (location and road type), modal properties (spatial and temporal) and full costs are all integrated. Active and sustainable mobility according to full cost calculations are promoted and incentivized based on the sustainability objectives of the government. The pay model is still PAYG. **Figure 6** shows an example scenario of functionalities in Level 3. The same trip is planned for 2 pm on Sunday and 8 am on Monday. On the Sunday, the prices of trips by car enforced by road tolls, or by public transport, are solely based on the static full costs of each transport mode. On the Monday, the live data of the city traffic shows a high level of activity on streets and public railway transport, which influences the dynamic full costs. Stop-and-go traffic increases the full costs due to higher vehicle consumption and emission rates. The full costs of public railway transport decrease, however, due to higher occupancy rates and, in turn, higher efficiency.

In the system's ultimate form, a new mobility coin currency may be introduced in order to decouple real-world currency from the dynamic prices in the MaaS application (*19*). This includes additional pay and subscription models, mobility packages, and product bundles to increase the system's attractiveness to customers. Bundles and budget plans also offer new control opportunities for the government. One example of a control mechanism is the introduction of a mobility budget for every citizen, which limits access to non-sustainable transport modes but not to sustainable ones. Budget trading is an option for increasing the available budget. **Figure 7** shows an example scenario of the functionalities in Level 4. At this level, the user has a certain weekly or monthly mobility coin budget, which increases or decreases depending on the sustainability, time and location of the selected transport mode. At the end of the time period, budget trading can take place. Any remaining budget can be sold, or, if it is depleted, additional budget purchased.

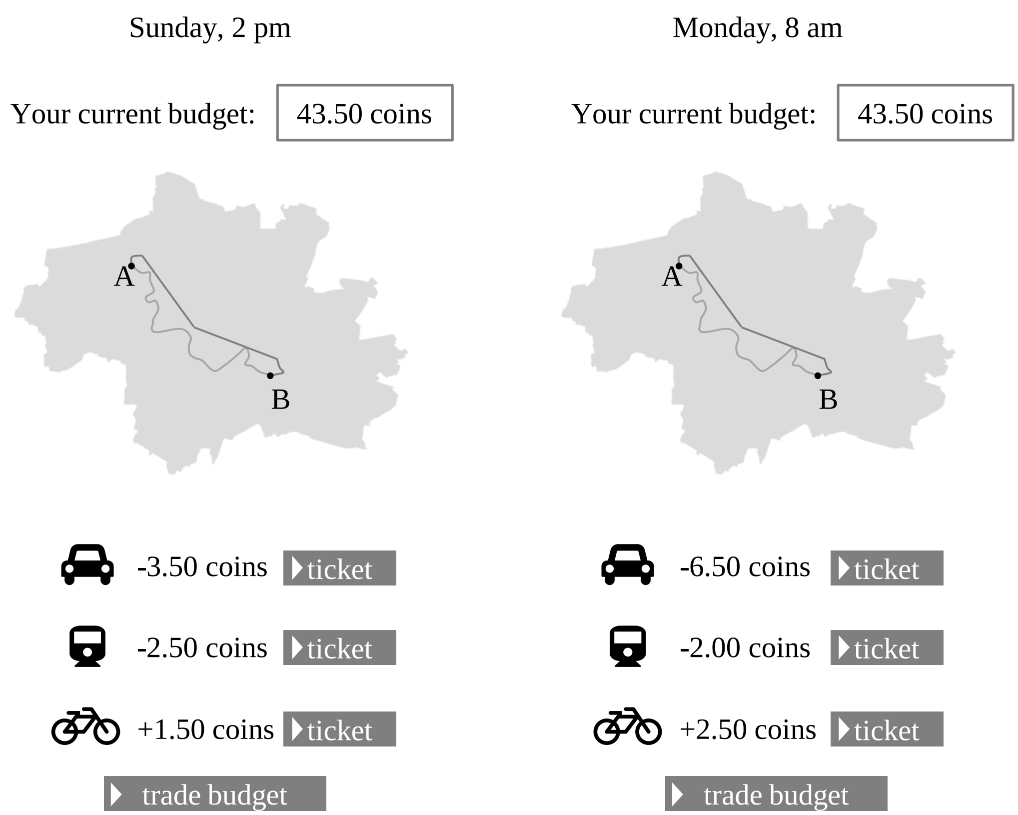

Figure 7 Schematic illustration of example level 4 MaaS functionalities

The different levels of the implementation process utilize different kind of policy instruments. While the first two rely primarily on information-based schemes, Level 3 and 4 use regulatory and economic instruments. Level 3 tries to internalize external costs in the Pigouvian sense, which places several limitation on the transportation systems (*20, 21*). For example, the market is large with many different actors and transaction costs between the polluter and the polluted leading to the problem of who exactly imposes congestion on whom. In other words, based on the Coase theorem, the "polluter pays" principle of Pigou is not applicable to the complexity of a regional transport network. It is for this reason that we propose in Level 4 a cap-and-trade approach, in which mobility budgets in the form of mobility coins can be traded, in a similar way to carbon trading (*21, 22*). In such system, the cap-and-trade approach gives MaaS users their own regulated market platform, where they can generate additional income if they behave sustainable.

RISKS AND BENFITS

As described in the previous sections, the government-contracted MaaS model that integrates a sustainability objective can overcome major difficulties in the implementation of MaaS. Regulatory issues are addressed by the procuring local government. The conflict between profitability and sustainability is solved by incentives and cross-subsidizations by the government in combination with dynamic full cost pricing methods. However, the new MaaS model still faces challenges on operational and individual levels. The following section critically discusses the tool's requirements, risks, benefits and expected impact.

The development of the proposed MaaS model is data-intensive. External cost indicators and system boundaries need to be defined, as the final external cost values of different transport modes are highly dependent on the system boundaries. The process of defining these factors is critical and represents a major challenge in the MaaS concept presented here. In addition to predefined values and factors for external costs, MaaS requires real-time road traffic and public transport occupancy data. Data availability generally depends on the global data provider (Google / Apple) and the local authorities. To be independent of global data handlers, the city needs to focus on its own data collection, using smart city solutions such as live sensors, mobility patterns, and connectivity and communication between infrastructure and cloud services.

Another crucial factor in the successful implementation of this MaaS model is the behavior of citizens and users of the app. There may be multiple reasons for public reluctance to use the tool. In the case of a MaaS with an integrated sustainability objective, full costs as a sustainability measurement would not be acceptable to the public. People might not see sustainability as their objective or at least not in such dimensions. The level of convenience offered by cars might be underestimated, meaning that the majority of people do not wish to change their daily travel habits. Another approach could be to include convenience in the full costs. However, it is very difficult to objectively quantify these factors. The behavioral aspects of MaaS users will be examined by trials and citizen surveys in future MaaS studies.

Private operators or service providers pose an additional risk, since they are part of the free market, and their main interests comprise the generation of revenue and expansion into other regions. Unlike public transport authorities, private companies are not restricted to a specific region. Part of the MaaS model has to be an extensive business plan, which potentially offers private companies an adequate cooperation incentive in the form of expected profits. A smart balance of revenue redistribution and road price will be a key factor of the model. Additionally, the procuring government needs to use its considerable regional influence to provide platforms for communication, exchange, and cooperation between operators. This MaaS concept is based on solid, shared sustainability goals that are acceptable to and understood by all the stakeholders involved.

However, once a critical mass of users has been achieved, the government-contracted MaaS model that integrates a sustainability objective will be able to ease traffic congestion and improve sustainability by reducing car-focused travel while interconnecting the most sustainable transport modes on intermodal trips. It can provide seamless, on-demand travel for citizens and, at the same time, foster sustainable mobility for society.

CONCLUSIONS

This concept paper presented and discussed the key features, implementation steps, and requirements of a government-contracted MaaS model that integrates a sustainability objective. The literature review pointed out the key challenges facing the implementation of MaaS and categorized them as technical, individual, social, economic, operational and regulatory, respectively. Cooperation between private and public mobility service providers and the conflict between profitability and sustainability were identified as the most critical factors. Adequate regulation is required to enable and support these complex forms of cooperation. The MaaS model presented here incorporates the concept of space-time road or transport mode pricing based on full cost calculations. With this pricing method, more sustainable transport modes are incentivized and cross-subsidized by less sustainable travel (such as combustion engine cars during rush hours). A four-level process was proposed for the development and implementation of this MaaS concept. The transactional and operational integration of the tool is gradually increasing, and additional features and pay methods are being applied step by step.

The proposed process will be applied in a research project within the MCube research cluster funded by the BMBF's (Federal Ministry of Education and Research of Germany) clusters4future initiative. Over the next nine years, the implementation and trial of a MaaS model similar to the one presented here is planned for the metropolitan region of Munich. Studies and research into external costs, pricing methods, the impact of this MaaS and the behavior of citizens will follow.

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AUTHOR CONTRIBUTIONS

The authors confirm their contributions to the paper as follows: as the first author: D.S.; study conception and design: D.S., J.K., A.L., R.R.; literature review and literature processing: D.S.; development of new concept: D.S., J.K., A.L., R.R.; concept features and implementation steps: D.S., A.L.; discussion: D.S.; draft manuscript preparation: D.S.; supervision and amendment: J.K., A.L., R.R. All authors reviewed the results and approved the final version of the manuscript.

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