

ASSESSING PRICES, DISCOUNTS AND MOBILITY BUDGET SCHEMES IN MOBILITY-AS-A-SERVICE BUNDLES

Carolina Cisterna

Department of Engineering

University of Luxembourg, Esch-sur-Alzette, Luxembourg, L-4367

Email: carolina.cisterna@uni.lu

Federico Bigi

Department of Engineering

University of Luxembourg, Esch-sur-Alzette, Luxembourg, L-4367

Email: federico.bigi@uni.lu

Francesco Viti

Department of Engineering

University of Luxembourg, Esch-sur-Alzette, Luxembourg, L-4367

Email: francesco.viti@uni.lu

Word Count: 7121 words + 1 table (250 words per table) = 7371 words

Submitted on 31/7/2023

ABSTRACT

Mobility-as-a-service (MaaS) has gained worldwide attention in the last decade as a user-centric subscription-based tool capable of offering mobility services in an integrated way, and in turn promote the adoption of shared and sustainable mobility options. In order to provide added value to its potential customers, MaaS should be able to capture the heterogeneity in the demand and the individuals' travel preferences. To accomplish this, a model capable of capturing individual travel needs as well as of considering both time and spatial availability of all services is required. By adopting an agent-based modeling approach, this study aims to incorporate and simulate MaaS bundles into users' daily mode choices. First, we analyze and compare two different MaaS bundle schemes, one offering discounted services, and the other offering free services but with limited use. Second, we apply an efficient experimental design to define and run a limited number of scenarios and investigate the potential effects of different MaaS bundle scheme features on MaaS demand, subscriber daily satisfaction, service revenue, and potential reduction in private car usage. The study findings suggest that public transport remains a foundational service within any MaaS bundle, especially when provided at a heavily discounted rate. Carsharing services, on the other hand, have the potential to substantially impact MaaS revenue if sufficient time allocation under convenient subscription fees are provided. Finally, potential subscribers are more interested in the bundle's mobility options as a replacement for their personal vehicle rather than in a price increase over what they already own.

Keywords: MaaS bundle schemes, Agent-based model, MaaS demand

INTRODUCTION

Mobility-as-a-Service (MaaS) has gained significant attention as an innovative solution to address future mobility challenges (1, 2). MaaS represents a user-centric concept that is expected to revolutionize the delivery and consumption of mobility services by bringing together various mobility services under a single subscription-based platform (3). One of the objectives of MaaS is to repackage and present these services in a manner that is expected to alter individual preferences, and hopefully to promote the adoption of shared and sustainable mobility options (4–8). In order to achieve this goal, MaaS bundle schemes must be carefully designed to include not only various mobility services but also offer attractive characteristics, such as promotions, discounts or (limited) free rides for public transit or sharing services. These bundle characteristics are expected to elicit a different response in terms of subscriber profiles, in particular car owners that are deeply ingrained in their personal vehicle habits (9, 10). To pursue these goals, MaaS bundle schemes and their characteristics must be designed to alter these habits and increase the attractiveness for the services offered by offering a more diverse range of mobility options to private cars, and in turn that can help to reduce traffic congestion, minimize carbon emissions, and improve the overall quality of life in urban areas. In this light, it is critical to study and assess different bundle schemes in order to understand the MaaS system appeal and in turn guarantee its successful deployment.

Recent years have witnessed a surge in academic studies and commercial trials aimed at testing and evaluating different MaaS plans and customers' preferences (for instance, 12–18). However, a comprehensive model able to analyse and evaluate the variety of individual-level travel requirements, mode choices, and mobility costs, considering the diversity of users' mobility needs is required. Such model should also enable the design and comparison of different MaaS bundle schemes, in order to determine their potential demand share (10). Furthermore, the mobility services included in the bundle, such as carsharing, taxis, or on-demand modes, must be represented in the model in a manner that reflects their dynamic availability and accessibility, which are dependent on both geographic location and temporal factors (11). On the other hand, it is also crucial that such model can generate macro-level key performance indicators (KPIs) in order to support and understand policies and behavioral trends. There is still a significant gap in our understanding which varieties of MaaS bundle schemes to offer and what is their impact on the the customers' mobility characteristics.

In this view, the use of agent-based modeling (ABM) has become increasingly popular in studies related to MaaS (11, 19–21). Hence, an agent-based model is used in this study to simulate people's daily travel requirements and activity schedules. This paper extends the methodology described in (21) by embedding MaaS bundle schemes in the users' daily mode choice set, allowing users to compare the costs of bundles and standalone services. Additionally, the study incorporates the Total Cost of Ownership (TCO) to accurately reflect the cost of vehicle ownership, considering its sensitivity to MaaS subscriptions (9).

This research is divided into two parts: Firstly, this study considers two distinct characteristics of MaaS bundle schemes from the literature, one offering discounted costs per trip mode (22) and the other that considers a free but limited use for the modes included in the bundle (23). We explore the impact of these two different mobility characteristics on users' travel behavior. After identifying MaaS schemes with similar potential demand, the customers' travel characteristics and mobility choices are assessed to comprehend their market penetration. In the second part of this study, we further differ the subscription fee and simulate car policies within the MaaS bundle schemes, through an efficient experimental design. Additionally, the impact of MaaS scheme features on KPIs such as MaaS revenue and reduction of car usage (sustainability goal) are analysed, giving insight into potential policies and recommendations to develop a MaaS system to achieve specific goals.

The remainder of this paper is organized as follows: we first describe the extended method in which the MaaS bundle schemes are embedded in the next section. The result section highlights insights into the features of MaaS bundle schemes that have an impact on MaaS demand, MaaS Revenue, and reduction of car usage. The last two sections provide a discussion and practical implication of the findings in terms of policy recommendations as well as it highlights the limitations of the current work and future outlook.

METHODOLOGY

This study employs the widely adopted ABM simulator, MATSim, which is an open-source, large-scale, multi-agent transport simulation software (24). MATSim is designed to model and simulate the daily activities and movements of a group of users, taking into account the interplay between individuals, transportation systems, and the physical environment. By iteratively adapting and refining the behavior of agents, MATSim can produce detailed and realistic models of transport systems, offering valuable insights for urban planning and transport policy analysis.

MATSim models individuals as synthetic agents, which are assigned with an initial plan that defines their activity chains typically generated based on empirical data (e.g., national travel surveys) through sampling techniques (synthetic population generation processes) or discrete choice models. MATSim attempts to replicate the accomplishment of given activities as best as possible through an iterative process, which computes the utility accumulated by reaching and performing the said activities and their relevant characteristics (e.g., schedule, arrival time, and departure time), and by performing trips made with one or more modes of transport on a network-defined synthetic infrastructure.

In the next subsection, the MATSim process is explained, followed by an explanation of how the process has been extended to include MaaS bundle schemes and TCO costs. The final subsection presents the case study setup.

MATSim iteration Framework

Figure 1 shows the iteration framework which consists of multiple controller events (blue squares in **Figure 1**). At the beginning of the simulation loop, an initial demand represented by a number of generated agents is created, and to each agent is assigned a memory containing several daily plans (24), which consist of a chain of activities and an overall score (computed via an economic/satisfaction function) (25). During each iteration, the agents select a plan from their memory and execute it on a synthetic network to complete their daily tasks (Event 3-4). In the next event, (Scoring event 5), the costs of the executed plan are calculated and then interpreted into the experienced score ($S_{experienced}$) through the use of the Charypar-Nagel Utility Function.

This score consists of the sum of a score to perform the activity $S_{act,q}$ and travel (dis)utility $S_{trav,(mode)q}$ (25). The activity score $S_{act,q}$ is obtained from the performance of daily activities. These activities contributes in the scoring in different way: for instance, successful completion of activities contributes positively to the agent's score, whereas deviations from the scheduled arrival and departure times result in a negative impact on the agent's score (25). On the other hand, the travel (dis)utility $S_{trav,(mode)q}$ represents the disutility obtained to reach the activities q by travelling between them using a specific mode of transport.

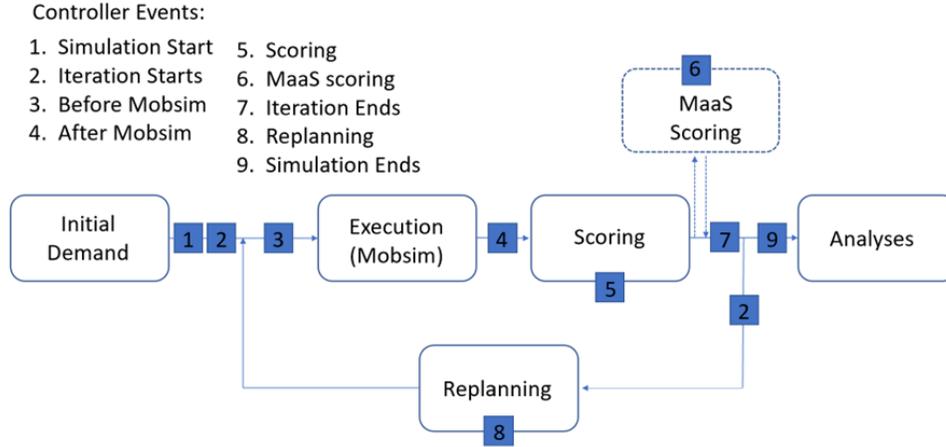


Figure 1 MATSim simulation process incorporating the new MaaS Scoring event (21).

Cisterna et al. (21) introduced a new MaaS scoring event allowing users to select MaaS services as possible transport mode(s). The MaaS system is embedded into the simulation environment through a new scoring event, namely *MaaS Scoring*, which is implemented after Scoring event 5 as for Figure 1. In this event module, the travel (dis)utility score $S_{trav,(mode)_q}$ of each agent is updated once an agent satisfies the eligibility conditions to access to the MaaS bundle. This eligibility that allows agents to access to MaaS bundle assumes that users satisfies specific condition in its last experienced score, such as taking a combination of mode of transports in the same trip. Such a condition relies on previous studies in which users' probability to subscribe to MaaS was found higher among people who have already experienced modes included in the bundle (10, 14). The agents' experienced mobility is represented by the experienced plan executed in the synthetic network; for this reason, a screening process of each agent's mode choice through their experienced plan is performed within the MaaS Scoring event.

At generic iteration t , if an agent used in a trip at least *one* of the services included in the MaaS bundle in their experienced plan, the MaaS score ($S_{MaaS(t)}$), is calculated based on experienced score ($S_{experienced(t)}$) calculated in the Scoring Event 5 as shown in **Equation 1**:

$$S_{MaaS(t)} = S_{experienced(t)} + Cost_{included,bundle} - Cost_{MaaS,bundle} \quad (1)$$

where $Cost_{MaaS,bundle}$ represents the subscription fee, and it is added as an additional cost while $Cost_{included,bundle}$ represents the individual costs of services included in the bundle.

After the MaaS score for the plan at the generic iteration t is calculated the differential between the experienced score ($S_{experienced(t)}$) and MaaS score ($S_{MaaS(t)}$) is compared. If the MaaS score is greater than the experienced score, then the experienced score is added to the agents' memory at the end of the generic iteration t . Conversely, if an agent is not eligible to use MaaS bundle or their $S_{experienced(t)} \geq S_{MaaS(t)}$, the MaaS Scoring is discarded and $S_{experienced(t)}$ is directly stored in the agents' memory.

This study extends the method proposed by Cisterna et al. (21) by embedding two distinct MaaS bundle schemes in the MaaS Scoring event: discounted and time-limited options, which are described later in this section.

At the end of each iteration, a new iteration begins with the Replanning (event 8 in **Figure 1**) (26). This allows the agents to discard the worst scored plan and generate a new plan, according to some predefined strategies. These strategies includes, but are not limited to: changing mode of transport for a specific segment, time shifting for a specific activity, rerouting etc... Given this, agents have the opportunity to modify their mobility behavior by changing transportation modes, re-routing trips, or adjusting departure times and evaluating their existing travel plans from their memory, based on the scoring stored for each plan.

After a number of pre-determined iterations, the co-evolutionary algorithm ensures that the system reaches equilibrium. The co-evolutionary algorithm computes a stochastic user equilibrium by optimizing distinct scoring functions within the context of an agent's set of plans and breaking down a complex problem into smaller subcomponents and solves each one separately to reach a system equilibrium (27).

MaaS bundle schemes implementation

In this study, we simulate two types of bundle schemes:

- 1) Time-limited bundle, and
- 2) Discounted bundle.

The two types of bundle schemes are given as input in the MaaS scoring event. The bundle scheme characteristics are kept consistent during the simulation along with the cost of ownership (TCO) per car user, till equilibrium is reached. In this way, it is possible to compare the impact of different bundle schemes on MaaS demand.

Discounted bundle

The discounted bundle model is developed considering the scheme used in the MaaS trial developed by (22), who included a discounted cost per trip per mode within the MaaS bundle. In this scheme there are two types of services included in MaaS bundle, one using a trip-based pricing system and the other using a time-based pricing system. Under the trip-based pricing systems, the user is charged for each trip taken, irrespective of the experienced travel time. On the other hand, the time-based pricing system charges (c_T) the user based on the travel time (T) service usage commonly used in car-sharing services. In this bundle, the ticket price for the trip-based pricing system is discounted as well as the unit cost of using the time-based pricing system.

The $Cost_{included,bundle(t)}$ at iteration t is calculated following **Equation 2**:

$$\begin{aligned}
 & Cost_{included,bundle(t)} \\
 &= \delta_{trip_based} * C_{tickets} * \left(\sum_{q=0}^Q I_{q,trip_based} \right) + (\beta * (c_T * T)) * \delta_{time_based} \quad (2)
 \end{aligned}$$

where δ_{trip_based} represents the discounts on the ticket cost $C_{tickets}$ per trip I , done by using a trip-based pricing systems included in the MaaS bundle and δ_{time_based} represents the discounted price for the time-based pricing systems and β is a coefficient previous estimated by (28).

Time-limited bundle

The time-limited MaaS bundle scheme has been generated based on a survey study performed by (23), which suggests a travel time limit for the usage of modes included in the bundle. As a result, users can travel for a pre-defined amount of time (a time budget) for free within the bundle. Once they exceed the time budget, users will be charged as if they were no-MaaS subscribers.

In the case of time-based pricing systems, the screening process counts the user's total travel time for a specific mode included in the bundle and subtracts it from the time budget covered by the MaaS scheme. On the other hand, for trip-based pricing systems, a further step is needed since their cost is based on the number of trips instead of the travel time. In this case, an additional function that makes a variable that returns the number of tickets covered $n_{ticktes}$ by the time budget ψ_{trip_based} , is implemented.

$$n_{ticktes, \psi_{trip_based}} = \sum_{q=0}^{q^*} I_{q, trip_based}$$

$$s. t. \sum_{q=0}^{q^*} I_{q, trip_based} * TT_q \leq \psi_{trip_based} \quad (3)$$

Equation 3 is provided to illustrate how this variable is calculated based on the number of trips I induced by the user's activities q (from 0 to q^*) within their time budget. The purpose of this function is to ensure that the total travel time of those trips $\sum_{q=0}^{q^*} I_{q, trip_based} * TT_q$ does not exceed the user's time budget ψ_{trip_based} . In this way, a parameter counting the number of the tickets paid and included in the bundle is calculated $n_{ticktes, \psi_{trip_based}}$. Such parameter is inserted in the $Cost_{included, bundle(t)}$ calculation for discounted bundle scheme at generic iteration t as shown in **Equation 4** :

$$Cost_{included, bundle(t)} = \left(n_{ticktes, \psi_{trip_based}} \right) * C_{ticket} + \left(\beta * (c_T * \omega_{time_based}) \right) \quad (4)$$

where ω_{time_based} represents the time budget for time-based pricing systems included in the MaaS bundle.

Total Cost of Ownership

The MaaS Scoring system incorporates also a component representing the total cost of car ownership (TCO) into the agent's travel cost, as an additional expense per kilometer and independent from MaaS subscription eligibility. This integration of TCO into the scoring system aligns with previous research by (9, 11) aiming to increase drivers' awareness of their car-related expenses. The decision of including the TCO is motivated by the fact that MaaS adoption and willingness to subscribe is a relatively mid-term decision (e.g., a month).

The TCO encapsules both the initial and ongoing expenditures of owning and maintaining a private vehicle. This includes both regular expenditures (e.g. daily fuel prices), as well as one-time expenses (e.g. car depreciation, repair...). By considering the daily depreciation cost in this

comprehensive definition of TCO, the MaaS Scoring system may precisely include long-term automotive purchasing decisions into the day-to-day decisions made by MaaS customers.

In summary, the MaaS Scoring event provides 3 different scores:

1) in case an agent does not employ a private car but is eligible to subscribe to the MaaS bundle, **Equation 1** will be applied;

2) if the agent employs a private car and is eligible to subscribe to MaaS, the MaaS score will be calculated as shown in **Equation 5** below:

$$Score_{TCO(t)} = S_{experienced(t)} + Cost_{included,package} - Cost_{MaaS,bundle} - TCO * \sum_{q=0}^{q,car} I_{q,car} * d \quad (5)$$

where I_q is a Boolean variable to indicate whether or not the trip induced by activity q is made by car or not, along with the distance travelled d .

For both options 1 and 2 a comparison between experienced costs and MaaS scores is performed. Conversely,

3) if the agent is not eligible to subscribe to MaaS but employs a private car, **Equation 6** only provides the additional cost of owning a car to the experienced score at generical iteration t :

$$Score_{TCO(t)} = S_{experienced(t)} - TCO * \sum_{q=0}^{q,car} I_{q,car} * d \quad (6)$$

CASE STUDY

The new MaaS scoring module presented in the previous section allows to model any range of subscription fees, discounts and mobility budget schemes, enabling one to simulate different scenarios and generate various KPIs.

In this paper we test this new scoring method and assess different bundle schemes for the city of Berlin. The aim is to understand the impact of MaaS bundle characteristics on individuals' willingness to subscribe and mode choice and in turn on KPIs related to users' satisfaction, business profitability, and sustainability.

A synthetic population of 25560 agents with heterogeneous demand characteristics has been used from a previously developed study (29). The private transport modes simulated in the network are private cars, walking, and cycling, which are considered available to all agents, while a trip-based pricing systems (public transit) following the real fare scheme is simulated. Free-floating¹ and two-way² carsharing services are simulated as time-based pricing systems following real-life prices and services in the city. For the carsharing supply, a total number of 62 two-way stations have been simulated, with two available cars per station, whereas a fleet of 160 cars for the free-floating services are simulated and spatially distributed within specific service areas.

Regarding the subscription fee, we consider as a benchmark cost the value of the monthly price of the MaaS bundle following the study of Caiati et al. (18) in which specific price plan weights were

¹ <https://www.share-now.com/de/en/berlin/>

² <https://www.stadtmobil.de/>

estimated, and a daily price of 7.50 € was estimated by simply dividing the estimated monthly price (150€) by 20 working days.

For the assessed scenarios, the TCO was also included for the car mode by considering a value of 0.30€/km following Eisenmann's study (30).

As for the replanning strategies (event 8 in **Figure 1**), in this study we opted for a mix of strategies that allows the agents to use a switch from one to another mode of transport on a single trip (including carsharing services), as well as trip chains generation strategies that promotes them to explore multimodal strategies. To enable the population to reach equilibrium, as well as guaranteeing them to explore different solution in an unbiased way, 700 iterations per simulation have been performed.

In the first part of the study different discount and time limit ranges have been simulated (**Table 1**). From all scenarios, two revealing a comparable number of MaaS members were used to analyse the estimated travel choices when different bundle schemes are offered. In the second part, through adopting an efficient experimental design (31), 140 simulations have been performed by varying MaaS fees, TCO values, public transport discounts and carsharing time limits on a feasible range of possible values to understand the impact of these four types of variables on MaaS adoption, potential revenue, and reduction of car usage that the MaaS system may induce.

Comparison of MaaS bundle schemes

Table 1 shows the variants of the mobility characteristics for the two MaaS bundle schemes simulated and compared in terms of attracted MaaS members.

TABLE 1 MaaS scheme mobility characteristics and number of MaaS members

DISCOUNTED SCHEME (%)				
Mobility characteristics			Scenario Name	MaaS members
Public transit	Free-floating	Two-way		
50	50	50	Discount 1	1302
30	50	50	Discount 2	341
90	30	30	Discount 3	3197
MOBILITY BUDGET SCHEME (minutes)				
Mobility characteristics			Scenario Name	MaaS members
102	32	42	Time Limit (ave)	2530
30	30	30	Time Limit 1	1553
120	32	42	Time Limit 2	2605
150	32	42	Time Limit 3	2660
150	40	42	Time Limit 4	2900
150	32	50	Time Limit 5	2670
150	60	42	Time Limit 6	3052

A NoMaaS scenario was simulated and used as baseline scenario, where the implementation of MaaS as a possible mobility option is not implemented. Therefore, this NoMaaS scenario represents the mobility choices for each agent before the MaaS system is embedded in the simulation and it is therefore used as benchmark to assess the change in travel behaviour after MaaS is deployed.

To test the MaaS scoring function with both time-limited and discounted options, we first simulated three scenarios involving different discounts to both public transit and car sharing services.

Scenario *Discount 1* gives the same discount per trip to each transport mode included in the MaaS bundle (50%). In the *Discount 2* scenario we simulate 50% of carsharing booking discount and 30% of public transit discount per trip. Instead, in scenario *Discount 3* we simulate a 90% discount per each public transit trip and we offer a discount of 30% per each carsharing booking time.

We then simulated different Time limit schemes. The scenario *Time Limit (ave)* uses the average travel time of each mode in the service that was observed in the NoMaaS scenario. *Time Limit 1* considers a flat bundle scheme that gives the a relatively small time budget to all services (30 minutes). The other Time Limit scenarios are simulated by increasing the time budget of both carsharing and public transit service in an incremental way to reach approximately the same demand attracted by *Discount 3*. A further increase of discount leads essentially to unlimited usage of the public transit, therefore a different type of bundle scheme would be analysed (unlimited).

The trends observed in **Table 1** suggest that higher discounts and more time budget offered for public transit contributes the most to the MaaS adoption. In fact, when the discount cost increases from 50% to 90% in the discount scheme the MaaS subscribers double, while when a reduction of the discount is simulated, the demand drastically decreases to only 341 subscribers. Similar trend is found for the Time scheme in which an increase of the time budget for public transit from 100 to 150 minutes increases the demand by 20% (500 new customers). Conversely, carsharing services seem not to have such an impact on MaaS demand, suggesting how they may be seen as additional services within the bundle rather than the main services.

Travel habits of MaaS bundle schemes subscribers

Since the scenarios *Discount 3* and *Time limit 6* appear to have a similar number of potential MaaS members, they have been selected as the two bundle schemes to be analysed and compared. Focusing on these two schemes, we separate the agents population by those members who subscribed to only one type of scheme and not for the other, and those members (MaaS captive or indifferent) who subscribe to both schemes. The latter group represents only 2% of the population, while the 12.5% chose only the Discount scheme and almost 12% subscribed only to the Time limited scheme, suggesting that offering the two variants may result in more effectively capturing the mobility needs of the agents.

We first analysed the travel behaviour of the MaaS members before MaaS was implemented to try and identify differences in mobility habits and travel choices. The top chart in **Figure 2** presents the modal split for each type of bundle scheme in the NoMaaS scenario for the three groups of MaaS members. The second chart depicts the average travel time by mode, while the last chart displays the average number of trips taken by each user type across transport modes. In these charts the analysis of walking and cycling modes, as well as two-way car sharing were omitted since they did not result in any significant insight.

Analysing the charts, the *indifferent* members are characterized by a slightly lower number of private car trips (around 45%) and a slightly higher number of public transit trips (19%) than the other two groups. The most significant difference is in the number and duration of trips for all three analysed modes: indifferent users spend over 2.5 hours traveling by public transit and almost 1 hour using a private car during their day. Furthermore, they tend to employ free-floating services for more than 1 hour on average throughout their daily journeys (see **Figure 2**, second chart). It is therefore suggested that the users who adopt MaaS independently on the specific scheme are among the most frequent travellers in the system (which however we again stress that they are only 2% of all the agents).

Time limited bundle adopters are characterized by substantially lower travel times for public transit and car-sharing, indicating that are those agents who manage to use the services without exceeding the mobility budget. Customers of the Discount bundle, on the other hand, have a higher share of car trips (58% of their trips) and perform longer travel times compared to Time Limit users for the two integrated MaaS services. Having mobility needs that exceed the Time Limit bundle, this group of users find more convenient to benefit of a discount for all their trips.

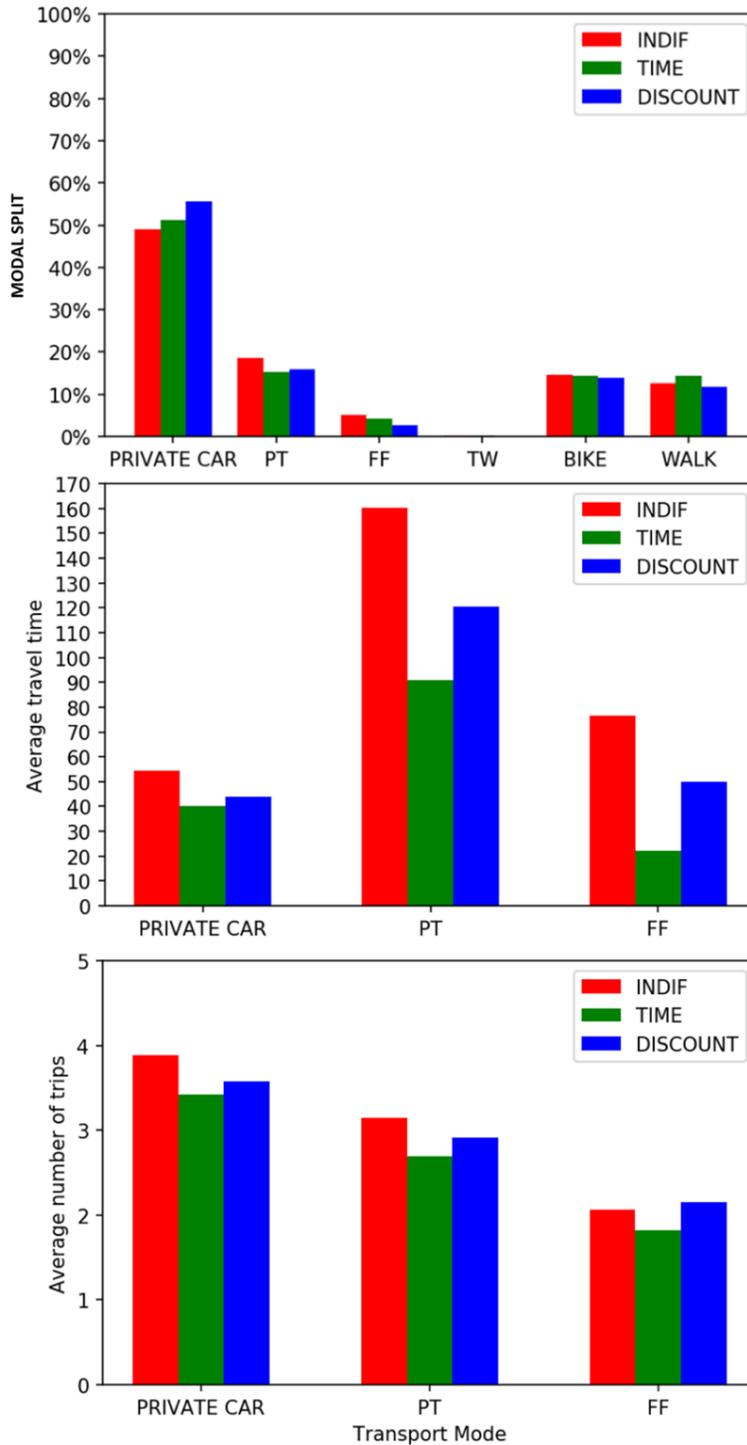


Figure 2 Travel characteristics of MaaS schemes subscribers

After analyzing the customer profiles by looking at their mobility patterns in the No MaaS scenario, we investigate the modal split of MaaS users after the implementation of the MaaS bundle schemes. **Figure 3** illustrates the modal split of users after subscribing to both the *Discount 3* (shown in blue) and *Time Limit 6* (shown in green) schemes. In this part of the analysis we do not separate the users opting for either scheme anymore.

A significant shift from private cars to public transit for both schemes is observed when comparing to the top chart of **Figure 2** with **Figure 3**. The share of car trips drops from around 50-55% of all trips to 5-10%, indicating that MaaS adopters are those agents that find a clear saving in the MaaS services. One should recall that these members represent around 12% of the generated population.

Moreover, looking at **Figure 3**, a significant difference in the modal split between the two bundle schemes is observed when comparing the modes car, public transit and especially free-floating car-sharing. Approximately 20% of Time Limit scheme subscribers utilize free-floating services, whereas only 5% of them employ private cars. Interestingly, the opposite trend is observed for the Discounted scheme, with over 10% of customers still using their private cars after subscribing, while only 5% utilize free-floating services. The majority of discount scheme customers (80%) rely on public transit. These results may suggest that the discount scheme could strongly encourage the use of public transit, whereas the Time Limit scheme seems to encourage the use of free-floating services as direct alternative to private cars.

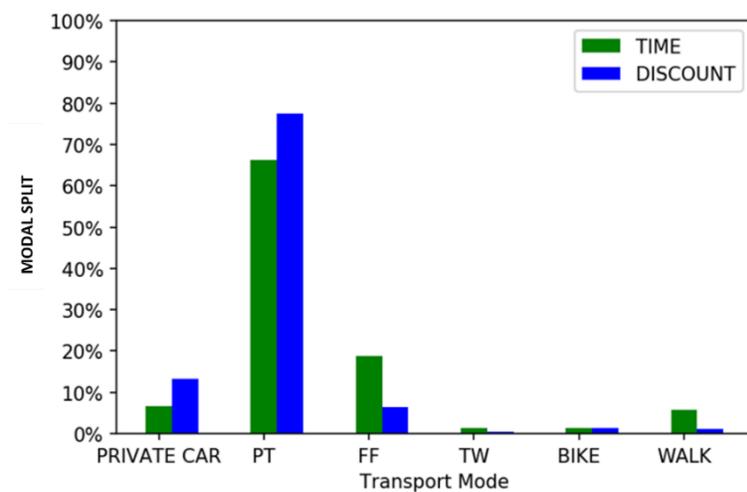


Figure 3 Modal split of MaaS bundle schemes after subscription

It should also be pointed out that active modes such as walking and cycling are significantly impacted by the introduction of MaaS services in both bundle schemes scenarios, which may be seen as a negative effect of MaaS, since it tends to incentivize the maximal use of the integrated services, also at the expense of the active modes.

Impact of bundle prices, TCO and bundle schemes

In the previous section we presented the travel characteristics of users in the MaaS bundle schemes, while keeping the total cost of ownership (TCO) and subscription fee parameters constant. In this section, we want to vary all parameter schemes namely the subscription fee, TCO, and bundle schemes. The aim of this part of the study is to explore how specific key performance indicators (KPIs)

are affected by these parameter types, and to identify specific bundles that can be more effective in pursuing different goals. The KPIs considered are potential business profitability (MaaS revenue), the potential MaaS attractiveness in the market (MaaS Users satisfaction), and the possible reduction of private car usage for MaaS subscribers (Car Reduction).

Figure 3 showed that the Discount scheme provided the strongest shift towards public transit, whereas the Time Limit scheme generated more free-floating car-sharing trips. It is important to note that the public transit discount is, in the analyzed scenario, at a value of 90%, meaning users only pay 10% of the actual ticket cost. On the other hand, in the chosen Time Limit scheme users may perceive all services included in the bundle as free as long as they stay within the time budget. These findings may imply that a hybrid bundle scheme that combines subsidized public transit costs with a time-based budget for carsharing services would encourage customers to use both forms of transportation while maximizing the benefits provided by the MaaS system. This motivated us to further look for an efficient combination of discounted public transit and time limited car-sharing service to exploit the characteristics of both services.

Due to the large number of potential parameter combinations and the time required for performing MATSim simulations, it was not realistic to perform a full scan of all possible combinations, which would have resulted in a few thousand simulations. Instead, we have chosen to use the efficient experimental design proposed by Rose and Bliemer (31). This approach allows to explore the effects of different parameter values effectively while using a limited number of combinations.

To apply the efficient design method, we established a value range for each parameter. We varied the TCO by increments of 0.05 €/km from 0.00 €/km to 0.60 €/km, and the subscription fee ranges from 0 to 15 € per day (increasing by 1 € increments). Building on the findings from the previous section, we decided to focus on bundles where carsharing services are offered using a time limited budget ranging from 30 minutes to 90 minutes, with 15-minute increments, while public transit is offered with discounted costs ranging from 0% to 100%, increasing by 10% increments. Using the efficient design method, we obtained 140 scenarios from a total of 14,440 combinations of all MaaS scheme parameters, representing only 1% of the entire solution space.

Analysis of selected Key Performance Indicators

Figure 4 shows the correlation between Demand (number of MaaS users) and (average) daily satisfaction (in terms of change in score) after subscribing using the 140 scenarios. The trend shows an increasing relationship between the number of MaaS members and the increase in MaaS score if compared to the NoMaaS scenario. Hence, in this context, score gain can be regarded as an indicator of increased MaaS appeal. The range between 3000 and 3500 demand values represents the group of users that adopt MaaS regardless of the bundle scheme, but linearly increasing with lowering the subscription price. Then, a quadratic trend is observed, suggesting that the combination of lowering prices and offering specific bundles has a positive impact on MaaS adoption.

To show more clearly these relationships we analyse the scenarios in detail. First we performed a correlation analysis of all features extracted from the 140 scenarios, in particular focusing on the correlation between the design parameters subscription fees, TCO values, discount percentage and time limit for car sharing with the KPIs potential score gain, share of private car trips and MaaS revenues. We focus only on the most relevant results in this paper. In particular, we found that private car use reduction and potential gain are much less sensitive to the design parameters than revenues, with a slightly positive correlation with public transit discounts. Therefore, giving a bundle scheme with a highly discounted cost per public transit would facilitate the shift from car to MaaS services and make users more satisfied with their travel choice while increasing the MaaS appeal.

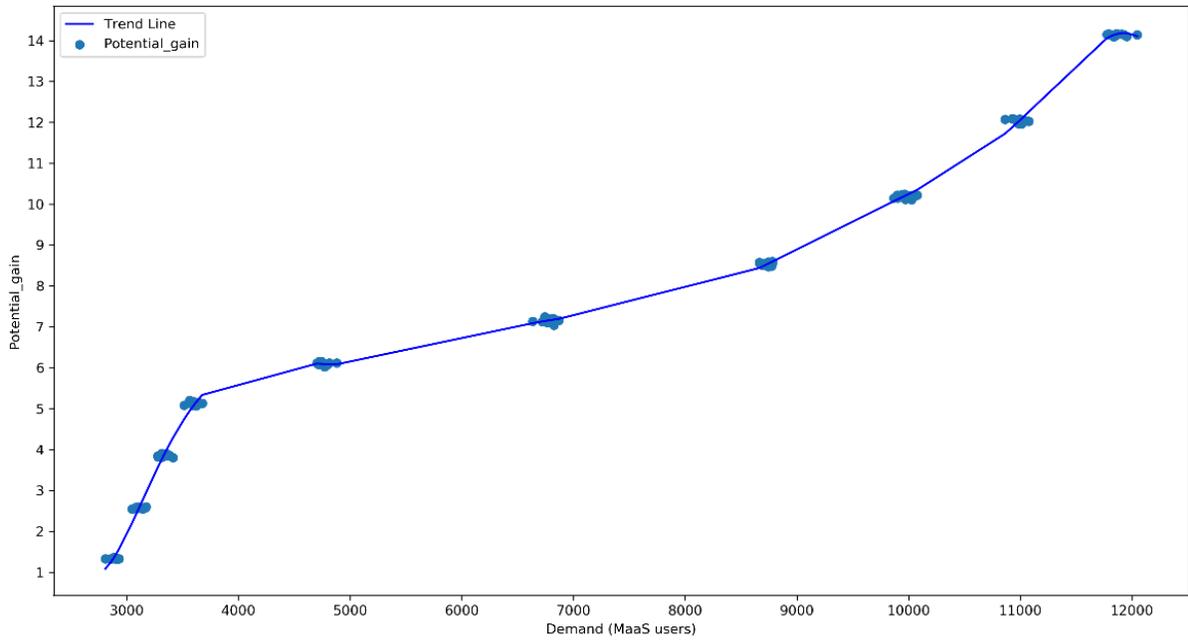
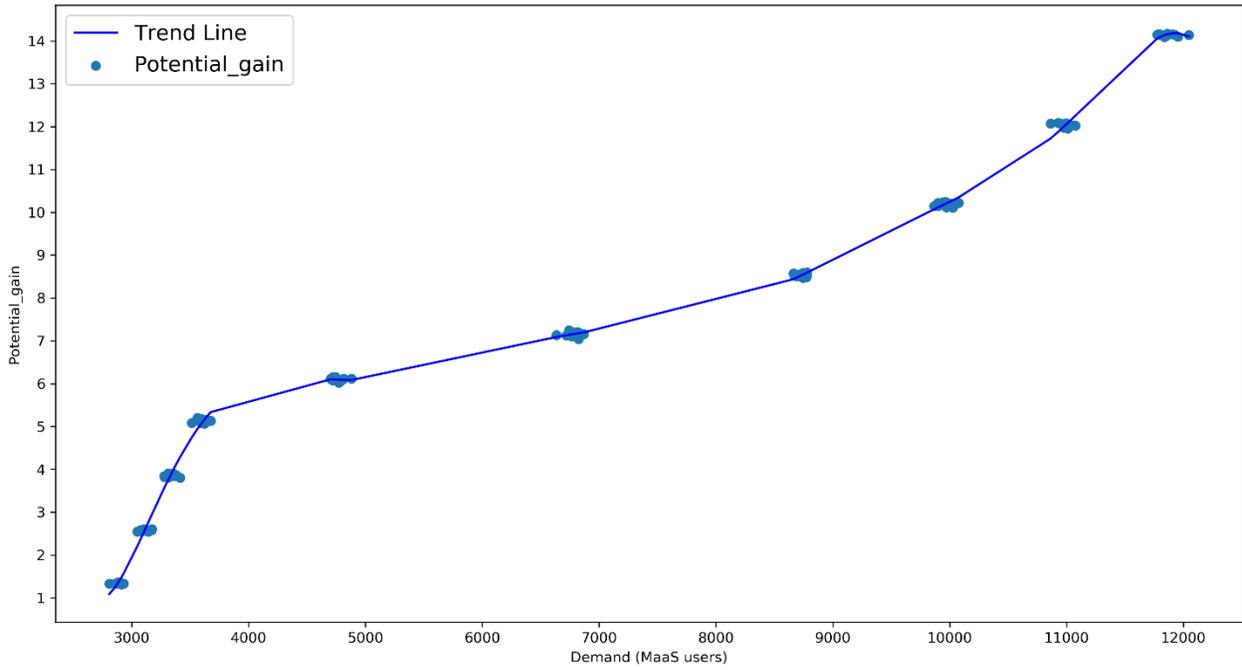


Figure 4 The correlation between Demand (MaaS users) and its increment of satisfaction (Potential gain)

Figure 5 shows how the revenue varies within the parameters discounted cost of public transit (y-axis) and carsharing time budget (x-axis) through a heatmap visualisation. The figure suggests that offering extended time availability for carsharing services, combined with unlimited public transit costs, could increase MaaS adoption.

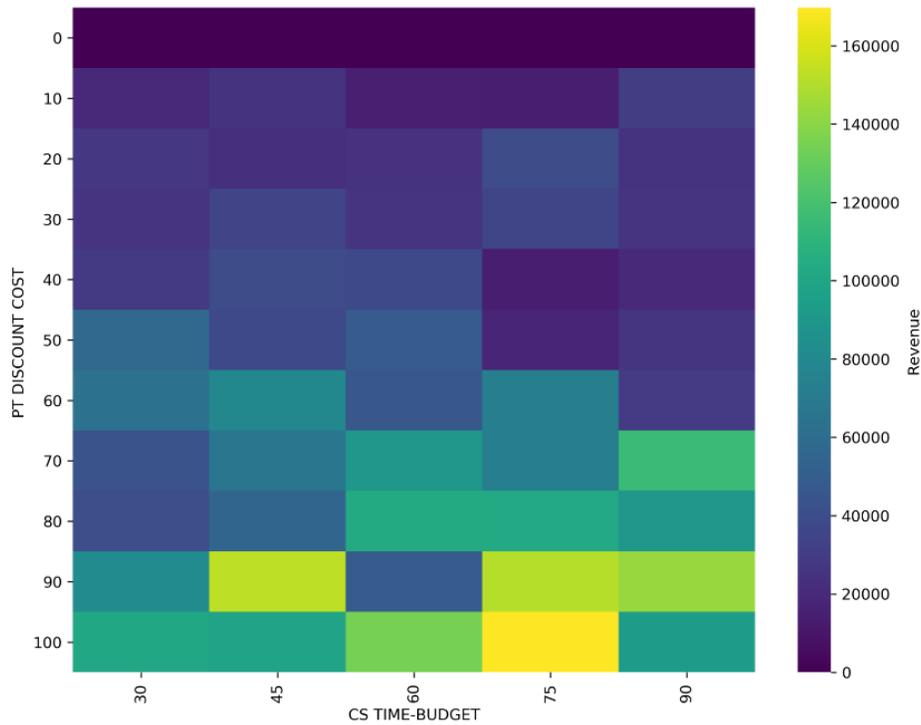


Figure 5 Heatmap chart of Revenues vs. PT and carsharing variations

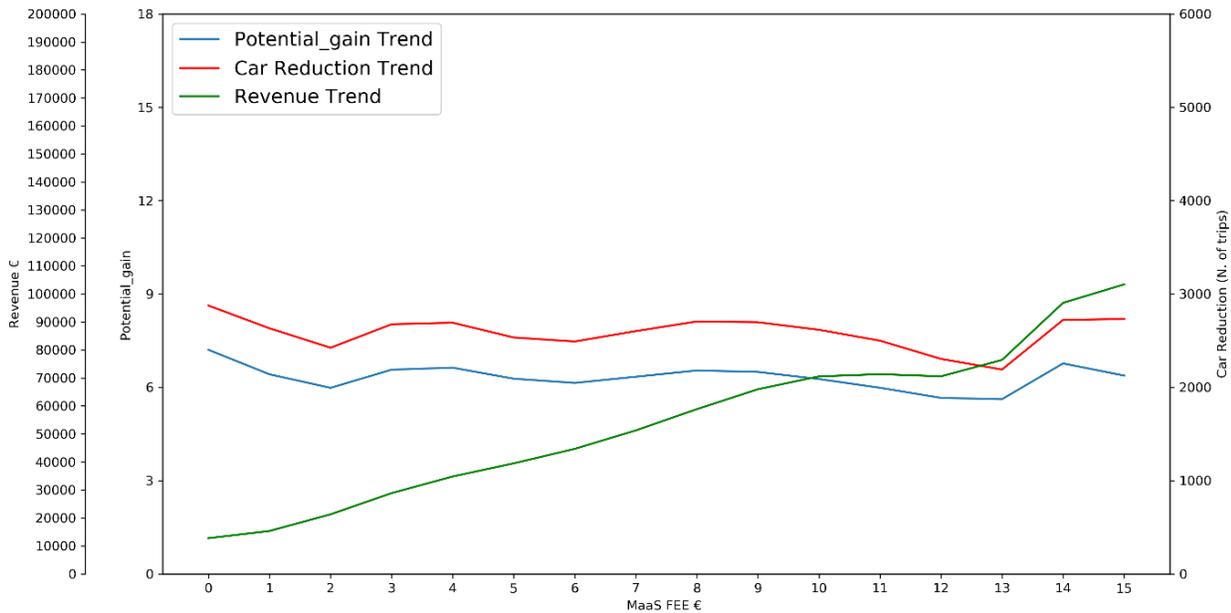


Figure 6 KPIs trend for MaaS subscription fee variation

Figure 6 illustrates the trend of each KPI with respect to the variation in MaaS subscription fees. The graph shows that Car Reduction (in red) and the satisfaction of users (Potential gain, in blue) are not influenced by the subscription fee, and potential MaaS subscribers may decide to subscribe based on the services offered rather than the cost to acquire them. On the other hand, the Revenue for the MaaS system monotonically increases with an increase in the subscription fee.

This result, combined with the earlier findings displayed in **Figure 5**, suggests that offering a MaaS bundle scheme with a higher subscription fee, which includes heavily discounted public transit costs and a high time budget for carsharing, may increase MaaS demand and revenue while at the same time resulting in a decrease in private car trips in the network. Regarding the TCO analysis, which might be related to a prospective car policy involved in the MaaS development (e.g., increased taxations), it appears that no KPIs are significantly impacted by a change in TCO values, except the design variable subscription fee. Hence, straightforwardly a simultaneous increase of MaaS fees and TCO values results in higher revenues, MaaS demand and reduction of private car trips. In fact, the scenario(s) that provide the highest KPIs are those with (nearly) free public transit use (at least 90% discount), at least 60 minutes car-sharing free use, with subscription fees of 9€/day or more and a TCO of 0.5€/km or more.

CONCLUSIONS

This study simulated two types of MaaS bundle schemes, drawing inspiration from existing trialed solutions (22, 23). During our analysis, we focused on comparing MaaS bundle schemes that had a similar number of subscribers. Three different types of members have been identified and analysed: users characterized by long trip chains within a long daily travel time are likely to adopt MaaS independently on the types of bundles, whereas the members that subscribe for having a specific time limit within the bundle substitute the car travels by MaaS services to exhaustively use the time-budget included in their membership. Such subscribers also book free-floating carsharing services to fulfill their daily activities.

Instead, the members of the MaaS discounted schemes primarily substitute all the modes by public transit after subscribing. On the other hand, both MaaS schemes become competitive alternatives to active modes, which may be viewed as a drawback of MaaS adoption. In addition, , in a context in which both bundles are offered, 20% of the whole population would adopt MaaS, suggesting how differing mobility characteristics of services within the MaaS bundle may help to increase the overall MaaS subscription appeal.

The second part of this study utilized an efficient experimental design to widely examine how design features of MaaS bundle schemes can impact MaaS demand, subscribers' satisfaction, MaaS revenue, and potential decrease in private car usage. The analysis of the results indicates that users who are willing to subscribe are more influenced by the services offered within the bundle and the way they are offered, rather than the price of accessing them. Additionally, to increase MaaS demand and subsequently enhance satisfaction, public transit should be offered with a significant discount. A similar trend is observed for reducing the number of car trips in the network, which can be a desirable goal for sustainability targets (8, 32).

From the perspective of the MaaS business profitability, an optimal scheme to increase revenue would involve selling a bundle with free public transit and a generous allocation of free booking time for carsharing, while maintaining a higher subscription fee.

This study only simulated three types of services while MaaS can potentially encompass a wider range of services such as bike sharing, one-way carsharing, carpooling, ride-hailing and taxis. Adding more services in the bundle is expected to increase MaaS appeal. Additionally, we did not conduct a thorough cost-benefit analysis of suppliers involved in the MaaS system, since our calculations focused solely on the revenue from the perspective of the whole MaaS system, without considering the costs incurred by the individual suppliers. Furthermore, the second generation of the MaaS system, known as Mobility-as-a-feature (MaaS), will not only encompass mobility services but also a diverse range of features that cater to household needs rather than individual user preferences (22). Therefore, future studies should incorporate not only diverse product offerings but also consider membership options for groups of users such as family members or employees (21, 33).

ACKNOWLEDGMENTS

This research is part of the project MaaS4All funded by Fonds National de la Recherche Luxembourg (Grant Number 13769009).

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: CC, FV; CC, FB; analysis and interpretation of results: CC, FV; draft manuscript preparation: CC, FV. All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Matyas, M., and M. Kamargianni. The Potential of Mobility as a Service Bundles as a Mobility Management Tool. *Transportation*, Vol. 46, No. 5, 2019, pp. 1951–1968. <https://doi.org/10.1007/s11116-018-9913-4>.
2. Schikofsky, J., T. Dannewald, and M. Kowald. Exploring Motivational Mechanisms behind the Intention to Adopt Mobility as a Service (MaaS): Insights from Germany. *Transportation Research Part A: Policy and Practice*, Vol. 131, 2020, pp. 296–312. <https://doi.org/10.1016/j.tra.2019.09.022>.
3. Wong, Y., D. Hensher, and C. Mulley. Stated Preference Design for Mobility as a Service (MaaS) Broker/Aggregator Contracts. 2018.

4. Mulley, C., C. Ho, C. Balbontin, D. Hensher, L. Stevens, J. D. Nelson, and S. Wright. Mobility as a Service in Community Transport in Australia: Can It Provide a Sustainable Future? *Transportation Research Part A: Policy and Practice*, Vol. 131, 2020, pp. 107–122. <https://doi.org/10.1016/j.tra.2019.04.001>.
5. Jittrapirom, P., V. Marchau, R. van der Heijden, and H. Meurs. Future Implementation of Mobility as a Service (MaaS): Results of an International Delphi Study. *Travel Behaviour and Society*, 2018, p. S2214367X18300966. <https://doi.org/10.1016/j.tbs.2018.12.004>.
6. Karlsson, I. C. M., J. Sochor, and H. Strömberg. Developing the ‘Service’ in Mobility as a Service: Experiences from a Field Trial of an Innovative Travel Brokerage. *Transportation Research Procedia*, Vol. 14, 2016, pp. 3265–3273. <https://doi.org/10.1016/j.trpro.2016.05.273>.
7. Mulley, C. Mobility as a Services (MaaS) – Does It Have Critical Mass? *Transport Reviews*, Vol. 37, No. 3, 2017, pp. 247–251. <https://doi.org/10.1080/01441647.2017.1280932>.
8. Wong, Y. Z., D. A. Hensher, and C. Mulley. Stated Preference Design for Mobility as a Service (MaaS) Broker/Aggregator Contracts. 2018, p. 18.
9. Vij, A., S. Ryan, S. Sampson, and S. Harris. Consumer Preferences for Mobility-as-a-Service (MaaS) in Australia. *Transportation Research Part C: Emerging Technologies*, Vol. 117, 2020, p. 102699. <https://doi.org/10.1016/j.trc.2020.102699>.
10. Liljamo, T., H. Liimatainen, M. Pöllänen, and R. Utriainen. People’s Current Mobility Costs and Willingness to Pay for Mobility as a Service Offerings. *Transportation Research Part A: Policy and Practice*, Vol. 136, 2020, pp. 99–119. <https://doi.org/10.1016/j.tra.2020.03.034>.
11. Becker, H., M. Balac, F. Ciari, and K. W. Axhausen. Assessing the Welfare Impacts of Shared Mobility and Mobility as a Service (MaaS). *Transportation Research Part A: Policy and Practice*, Vol. 131, 2020, pp. 228–243. <https://doi.org/10.1016/j.tra.2019.09.027>.
12. Hensher, D., C. Ho, C. Mulley, J. Nelson, G. Smith, and Y. Wong. MaaS Trials—What Have We Learnt?, pp. 59–75.
13. Ho, C. Q., D. A. Hensher, C. Mulley, and Y. Z. Wong. Potential Uptake and Willingness-to-Pay for Mobility as a Service (MaaS): A Stated Choice Study. *Transportation Research Part A: Policy and Practice*, Vol. 117, 2018, pp. 302–318. <https://doi.org/10.1016/j.tra.2018.08.025>.
14. Matyas, M., and M. Kamargianni. Survey Design for Exploring Demand for Mobility as a Service Plans. *Transportation*, 2018. <https://doi.org/10.1007/s11116-018-9938-8>.
15. Sochor, J., I. C. M. Karlsson, and H. Strömberg. Trying Out Mobility as a Service: Experiences from a Field Trial and Implications for Understanding Demand. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2542, No. 1, 2016, pp. 57–64. <https://doi.org/10.3141/2542-07>.
16. Storme, T., J. De Vos, L. De Paepe, and F. Witlox. Limitations to the Car-Substitution Effect of MaaS. Findings from a Belgian Pilot Study. *Transportation Research Part A: Policy and Practice*, 2019, p. S0965856418312564. <https://doi.org/10.1016/j.tra.2019.09.032>.
17. Strömberg, H., I. C. M. Karlsson, and J. Sochor. Inviting Travelers to the Smorgasbord of Sustainable Urban Transport: Evidence from a MaaS Field Trial. *Transportation*, Vol. 45, No. 6, 2018, pp. 1655–1670. <https://doi.org/10.1007/s11116-018-9946-8>.
18. Caiati, V., S. Rasouli, and H. Timmermans. Bundling, Pricing Schemes and Extra Features Preferences for Mobility as a Service: Sequential Portfolio Choice Experiment. *Transportation Research Part A: Policy and Practice*, Vol. 131, 2020, pp. 123–148. <https://doi.org/10.1016/j.tra.2019.09.029>.
19. Nishida, R., R. Kanamori, and I. Noda. *Modeling of a Mode Choice Behavior toward Agent-Based Mobility as a Service Simulation*. 2021.
20. Kucharski, R., and O. Cats. Simulating Two-Sided Mobility Platforms with MaaSsim. *PLOS ONE*, Vol. 17, No. 6, 2022, p. e0269682. <https://doi.org/10.1371/journal.pone.0269682>.
21. Cisterna, C., F. Bigi, and F. Viti. The Impact of Total Cost of Ownership on MaaS System Appeal Using an Agent-Based Approach. *CSUM 2022: Advances in Mobility-as-a-Service Systems*, 2022, p. 12.

22. Hensher, D. A., C. Q. Ho, and D. J. Reck. Mobility as a Service and Private Car Use: Evidence from the Sydney MaaS Trial. *Transportation Research Part A: Policy and Practice*, Vol. 145, 2021, pp. 17–33. <https://doi.org/10.1016/j.tra.2020.12.015>.
23. Tsouros, I., A. Tsirimpa, I. Pagoni, and A. Polydoropoulou. MaaS Users: Who They Are and How Much They Are Willing-to-Pay. *Transportation Research Part A: Policy and Practice*, Vol. 148, 2021, pp. 470–480. <https://doi.org/10.1016/j.tra.2021.04.016>.
24. ETH Zürich, A. Horni, K. Nagel, TU Berlin, K. W. Axhausen, and ETH Zürich. Introducing MATSim. In *The Multi-Agent Transport Simulation MATSim* (ETH Zürich, A. Horni, K. Nagel, and TU Berlin, eds.), Ubiquity Press, pp. 3–8.
25. TU Berlin, K. Nagel, B. Kickhöfer, A. Horni, ETH Zurich, D. Charypar, and ETH Zurich. A Closer Look at Scoring. In *The Multi-Agent Transport Simulation MATSim* (ETH Zürich, A. Horni, K. Nagel, and TU Berlin, eds.), Ubiquity Press, pp. 23–34.
26. ETH Zürich, A. Horni, K. Nagel, TU Berlin, K. W. Axhausen, and ETH Zürich. Destination Innovation. In *The Multi-Agent Transport Simulation MATSim* (ETH Zürich, A. Horni, K. Nagel, and TU Berlin, eds.), Ubiquity Press, pp. 165–174.
27. Senozon AG, M. Rieser, A. Horni, ETH Zürich, K. Nagel, and ETH Zürich. Let’s Get Started. In *The Multi-Agent Transport Simulation MATSim* (ETH Zürich, A. Horni, K. Nagel, and TU Berlin, eds.), Ubiquity Press, pp. 9–22.
28. Giorgione, G., F. Ciari, and F. Viti. Dynamic Pricing on Round-Trip Carsharing Services: Travel Behavior and Equity Impact Analysis through an Agent-Based Simulation. *Sustainability*, Vol. 12, No. 17, 2020, p. 6727. <https://doi.org/10.3390/su12176727>.
29. Ziemke, D., I. Kaddoura, and K. Nagel. The MATSim Open Berlin Scenario: A Multimodal Agent-Based Transport Simulation Scenario Based on Synthetic Demand Modeling and Open Data. *Procedia Computer Science*, Vol. 151, 2019, pp. 870–877. <https://doi.org/10.1016/j.procs.2019.04.120>.
30. Eisenmann, C., and T. Kuhnimhof. Some Pay Much but Many Don’t: Vehicle TCO Imputation in Travel Surveys. *Transportation Research Procedia*, Vol. 32, 2018, pp. 421–435. <https://doi.org/10.1016/j.trpro.2018.10.056>.
31. Rose, J. M., and M. C. J. Bliemer. Constructing Efficient Stated Choice Experimental Designs. *Transport Reviews*, Vol. 29, No. 5, 2009, pp. 587–617. <https://doi.org/10.1080/01441640902827623>.
32. Kamargianni, M., and M. Matyas. The Mobility-as-a-Service Business Ecosystem. 2016, p. 19.
33. Parida, S. Exploring Preferences in the Netherlands for MaaS Mobility Packages, as a Transportation Alternative for Short-Distance Trips: A Stated Preference Experiment: Mobility as a Service. 2020.