Comparing MaaS Business Plans Using an Agent Based Modelling Approach

Carolina Cisterna*[1], Federico Bigi[2], Francesco Viti[3]

[1] PhD, Faculté des Sciences, de la Technologie et de la Communication, University of Luxembourg, Luxembourg

[2] PhD, University of Luxembourg, Luxembourg

[3] Associate professor, University of Luxembourg, Luxembourg

SHORT SUMMARY

The Mobility-as-a-service is based on customized bundles in which different mobility services are gathered under one subscription-based digital platform. Currently, in the literature MaaS packages have been customized and hypothesized through surveys and pilot projects, underlining the lack of a model able to capture and compare MaaS business plans when different bundles are provided. This study aims to simulate different MaaS plans in the users' mode choice set using an agent-based model and to study the MaaS potential demand heterogeneity.
Results show that MaaS users who experience long daily travel times are indifferent to the type of package provided, while time-limited package members substitute the car by travelling longer distances using public transport and free-floating car-sharing services. In contrast, the trip-discounted bundle members are less willing to substitute the car and they use public transport within a long trip chain, reducing their trip time.

Keywords: Agent-based model, Business models, MaaS membership

1. INTRODUCTION

Mobility-as-a-Service (MaaS) was first introduced by Heikkilä and Hietanen in 2014. Since the beginning this new smart mobility concept has become very popular and is currently at the center of attention within the scientific community (Hietanen, 2014).
MaaS is a user-centred system that provides different transport modes by integrating public and private mobility services under a single subscription-based-digital platform (Kamargianni and Matyas, 2016; Sochor et al., 2015a). MaaS business models may offer services with a limited usage (e.g. only a specific number of free trips by public transport could be included in the package, or a limited number of booking hours of carsharing). Another option could instead be to offer the services with some discount, e.g. PT tickets could be offered at a lower cost than without the subscription. Clearly, each of these plans is expected to induce a different response in terms of mode choices. Limiting the use or providing discounts may in fact help at better distributing the users on the different services, and in turn it may be attractive for different customers.
Currently, in the literature, different MaaS business models have been tested in pilot projects by selecting a niche of participants and limited business model variants, and in surveys by customizing the plans per each interviewee disallowing the comparison of the different models for the same participants target (Matyas and Kamargianni, 2017; Sochor et al., 2015b). A general membership model that aims to capture users' heterogeneous travel needs within MaaS business packages with specific mobility variants and capable to compare those businesses on the market is currently missing.

For this reason, this study aims to endogenize MaaS business models choice within users' choice set, applying a microscopic approach by employing an agent-based model which allows to simulate user's daily travel needs and activities. By employing a tool capable of embedding different MaaS business models with users' choice we are able to estimate the potential demand in terms of number of customers and analyze their mobility habits to understand MaaS subscription appeal. To consider the trade-off of paying a daily or monthly subscription fee and the costs of owned resources such as private car, in this paper we take into account the total cost of ownership (TCO) to reflect the true cost of vehicle ownership and expenditure considering them sensible in MaaS membership choice (Vij et al., 2018).

2. METHODOLOGY

This study employs an agent-based modelling approach, which provides a microscopic representation of individuals' mobility choices resulting in emergent spatial and temporal distribution of the demand (ETH Zürich et al., 2016). We adopted the agent-based MATSim software which simulates agents' behavior by running a configurable number of iterations, schematically represented by the conceptual framework in Figure 1. In our approach, a new event (5.1) is introduced. Each agent has a memory containing fixed numbers of daily plans, where each plan represents a specific activity schedule with an associated score or economic function. The agent-based model allows agents to maximize their score to achieve their plans through the iteration process which is repeated until the agents' average score stabilizes and the system equilibrium is reached (ETH Zürich et al., 2016).

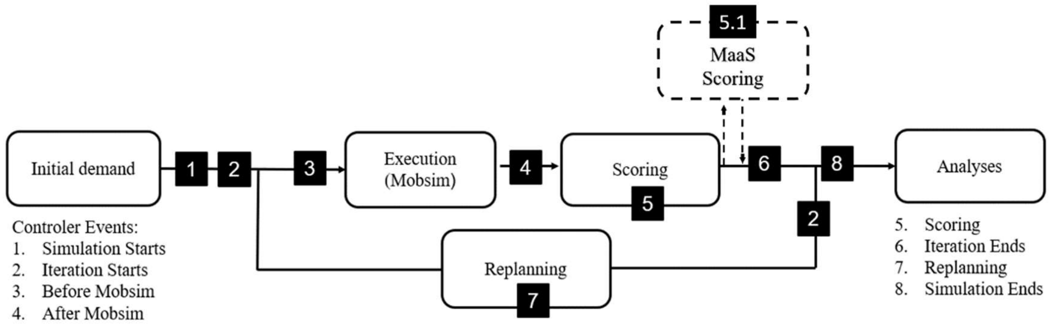

Figure 1 – MATSim conceptual framework

The conceptual framework can be summarized through the following iteration steps:

- A plan is selected from the user's memory plans as initial demand; (1-2 Events)
- Mobsim executes the selected plan in a synthetic reality where agents travel on the network and using the selected modes (3-4 Events)
- The actual performance of the plan is used to compute the experienced plan and its specific score, $S_{plan,experienced}$ following Eq. 1 (5 Event), which is given by the sum of all daily activities performed or utilities $S_{act,q}$ and travel (dis)utilities $S_{trav,(mode)q}$, where q indicates both the generic daily activity and the trips:

$$S_{plan,experienced}(\mathrm{t}) = \sum_{q=0}^{N-1} S_{act,q} + \sum_{q=0}^{N-1} S_{trav,(mode)q} \tag{1}$$

where the travel (dis)utilities are calculated for each mode. In particular, Equation 2 represents the daily score of travelling by carsharing (Ciari et al., 2014):

$$S_{trav,q,cs} = \alpha_{cs} + \beta_{c,cs} * (c_t * t_r + c_d * d) + \beta_{t,walk} * (t_a + t_e) + \beta_{t,cs} * t \tag{2}$$

where:

- α_{cs} is the carsharing-specific constant;
- $\beta_{c,cs} * (c_t * t_r + c_d * d)$ is the portion of the score (disutility) regarding reservation time and travel distance;
- $\beta_{t,walk} * (t_a + t_e)$ is the portion of the score (disutility) regarding access and egress time, by assuming that access/exits are made by walk;
- $\beta_{t,cs} * t$ is the portion of the score (disutility) regarding travel time experienced via carsharing.

Equation 3 is the generic score specification for all other available modes:

$$S_{trav,q,mode} = \alpha_{mode} + \beta_{t,mode} * t \quad (3)$$

where:

- α_{mode} is the mode-specific constant;
- $\beta_{t,mode} * t$ is the part of the score (disutility) for the time spent travelling on that mode;

The $S_{plan,MaaS}$ (Eq. 4) is calculated modifying the travel (dis)utilities part of $S_{plan,experienced}$ by introducing the MaaS subscription (5.1 Events):

$$Score_{plan,MaaS_{(t)}} = S_{plan,experienced\,(t)} + Cost_{included} - Cost_{MaaS,package} - TCO * \sum_{q=0}^{q,car} I_{q,car} \quad (4)$$

where

- $I_{q,car}$ is a Boolean variable indicator which considers if the leg mode is car or not as it is shown in eq (5):

The assumption that gives MaaS accessibility is that potential users subscribe according to their predetermined or experienced travel mode choices specifically if the experienced users' plan includes at least 1 of the services in the MaaS bundle. Once the accessibility to the MaaS system is given, the MaaS package cost ($-Cost_{MaaS,package}$) is added to the score and the cost included in the MaaS membership ($Cost_{included}$) is subtracted.

$$I_{q,car} = \begin{cases} 1, & if\ q = q_{,car} \\ 0, & otherwise \end{cases} \quad (5)$$

Moreover, if the users choose to take the car in their plan, a total cost of ownership (TCO) is embedded in their travel expenditure as an additional cost per km.

- The Replanning module instead, defines how agents changes their behavior following the defined strategies which allow re-routing and change of transport mode giving the chance to choose among all the set of mobility services in the synthetic network (7 Event).
- Finally, the best plan between $S_{plan,MaaS}$ and $S_{plan,experienced}$ is stored in the user's memory.

In this study, we consider two types of business plan variants:

1. Time_limit access: This business model considers adding a time limit access to the mobility services included in the MaaS plan. This subscription type has been chosen from the literature following the packages provided in the stated preference surveys (Matyas and Kamargianni, 2017) following the eq (7):

$$Cost_{included} = +\boldsymbol{\psi_{pt}} * \left(\sum_{q=0}^{q,pt} I_{q,pt}\right) * a_{pt} + \left((\beta_{c,cs} * (c_t * \boldsymbol{\omega_{cs}})\right) * n_b) \quad (7)$$

where $\boldsymbol{\psi_{pt}}$ and $\boldsymbol{\omega_{cs}}$ are the new variables which represent the trips and the travel time of public transport and carsharing services included in the MaaS bundle.

2. Discount: This MaaS business model has been simulated, based on the MaaS trial developed by Hensher et al. who implemented different bundles including specific discounts per trip per mode included in MaaS package (Hensher and Mulley, 2019). The cost function has been computed following the eq (8):

$$Cost_{included} = +\boldsymbol{\delta_{pt}} * \left(\sum_{q=0}^{q,pt} I_{q,pt}\right) * a_{pt} + \left((\beta_{c,cs} * (c_t * t_r + c_d * d)\right) * n_b) * \boldsymbol{\delta_{cs}} (8)$$

where $\boldsymbol{\delta_{pt}}$, $\boldsymbol{\delta_{cs}}$ are the new variables which represent the discounts included in MaaS plan for public transport and carsharing service.

In all the business models $I_{q,pt}$ is an indicator variable which considers if the leg is made using public transport or not, as it is shown in eq (9):

$$I_{q,pt} = \begin{cases} 1, & if\ q = q_{,pt} \\ 0, & otherwise \end{cases} \quad (9)$$

In order to understand the MaaS market appeal, a Pay-as-you-go (PAYG) scenario has been also computed in which users pay for each service as much as they travel, hence experiencing separable trip-based costs. To simulate this model, we start from a set of parameters previously estimated following the score specification reported in Equations 1,2,3 and MATSim general framework in Fig 1 without implementing the new Event 5.1 to simulate agents in the agent-based environment without MaaS system option (Giorgione et al., 2019).

3. CASE STUDY

This paper uses a synthetic population of 25560 agents with heterogeneous characteristics representing the population of Berlin, Germany. In the synthetic network, 62 two-way stations are simulated each offering two cars, while a free-floating area is simulated within a specific usage section with 160 available cars. The fixed price of all the MaaS packages is settled following Caiati's study with a price of 7.5 euro per day (Caiati et al., 2019). The TCO price is set to 0.30 €/km according to Eisenmann and Kuhnimhof (Eisenmann and Kuhnimhof, 2018). We first simulate the TIME_LIMIT_STANDARD scenario embedding the average travel time of both carsharing and public transport service of the PAYG scenario as a benchmark to start the simulation of scenarios. From this benchmark as Table 1 shows, several scenarios are simulated in order to reach an equality in term of potential demand. Additionally, to reach the users' equilibrium a total number of 700 iterations have been performed in all the scenarios, in turn obtained using a co-evolutionary algorithm.

Table 1: MaaS scenarios

SCENARIO NAME	PT	TWO-WAY	FREE-FLOATING
	DISCOUNT (%)		
DISCOUNT_1	50	50	50
DISCOUNT_2	30	50	50
DISCOUNT_3	90	30	30
	TIME (min)		
TIME_LIMIT_STANDARD	100	42	32
TIME_LIMIT_STANDARD_1	30	30	30
TIME_LIMIT_STANDARD_2	120	42	32
TIME_LIMIT_STANDARD_3	150	42	32
TIME_LIMIT_STANDARD_4	150	42	40
TIME_LIMIT_STANDARD_5	150	50	32
TIME_LIMIT_STANDARD_6	150	42	60

4. RESULTS AND DISCUSSION

After simulating different MaaS business scenarios we identify the two different business models resulting in attracting a very similar potential demand as it is shown in Table 2. It should be noted that a large part of the members is represented by different agents in the two scenarios. The number of the users which choose both offers are displayed (Indifferent) is only 2.1%, whereas the exclusive members of DISCOUNT_3 scenario represent the 10.4% of the whole population which decreases up to 9.8% for the TIME_LIMIT_STANDARD_6 . From now on, this paper focuses on the DISCOUNT_3 as discount scenario and TIME_LIMIT_STANDARD_6 as time scenario.

Table 2: comparable scenario

Name	Indifferent	%	Members	%
DISCOUNT_3	548	**2.1%**	2649	**10.4%**
TIME_LIMIT_STANDARD_6	548	**2.1%**	2504	**9.8%**

Table 3 and 4 display the mode choice and the average travel time per modes in the PAYG scenario and for both MaaS scenarios across the exclusive and indifferent members; public transport and car are employed more by indifferent users than the exclusive, while travel time by car is similar between the exclusive users but higher for the indifferent users.
In contrast, a broader difference among users in terms of average travel time by public transport is shown; indifferent users travel almost the double than exclusive members in the time limited package, while exclusive users travel on average 40 minutes less than the indifferent in the PAYG scenario.

Table 3: Mode choice (PAYG)

MODE CHOICE (%)	PT	WALK	BIKE	TW	FF	CAR
INDIFFERENT	**21**	8	17	1	6	**66**
NEW_USER_TIME	15	11	15	1	**4**	**53**
NEW_USER_DISCOUNT	16	8	14	1	**2**	**59**

Table 4: Average travel time (PAYG)

AVERAGE TRAVEL TIME (min)	PT	WALK	BIKE	TW	FF	CAR
INDIFFERENT	**160**	74	107	54	**78**	**54**
NEW_USER_TIME	**91**	83	78	24	**35**	**40**
NEW_USER_DISCOUNT	**120**	91	90	38	**50**	**44**

The mode choice matrices for the exclusive members per each transport mode are examined in the Table 5 and 6. In the time scenario, there is a general shift to public transport which substitutes more than 81% of the car trips, 84% of the bike trips and 68% of the walk trips, while the 88% of the public transport trips are employed by the same service.
The percentage of free-floating trips also increase up to 12 % of the total trips by substituting 10% of the car trips, 21% of the walk trips, while 58% retain the same service.

Table 5: MATRIX MODE CHOICE_TIME

PAYG/TIME	CAR	PT	FF	TW	BIKE	WALK	TOT TRIPS
CAR	**6%**	**81%**	**10%**	1%	1%	1%	**65%**
PT	0%	**88%**	9%	0%	0%	2%	**13%**
FF	0%	30%	**58%**	0%	0%	11%	**1%**
TW	0%	0%	0%	100%	0%	0%	**-**
BIKE	0%	**84%**	12%	1%	0%	3%	14%
WALK	0%	**68%**	21%	0%	0%	11%	7%
TOT TRIPS	**4%**	81%	**12%**	1%	-	2%	

Table 6: MATRIX MODE CHOICE_DISCOUNT

PAYG/DISCOUNT	CAR	PT	FF	TW	BIKE	WALK	TOT TRIPS
CAR	**12%**	**83%**	**4%**	0%	1%	0%	**69%**
PT	0%	**96%**	3%	1%	0%	0%	**13%**
FF	0%	**70%**	30%	0%	0%	0%	1%
TW	0%	0%	0%	0%	0%	0%	-
BIKE	0%	**97%**	3%	0%	0%	0%	12%
WALK	1%	**97%**	1%	0%	0%	1%	4%
TOT TRIPS	**8%**	87%	**4%**	-	-	-	

In contrast with the time limited scenario, 12% of the trips are still employed by car in the discount scenario as displayed in Table 6 while only 4% are substituted by free-floating mode covering 4% of the total trips. Whereas public transport is the main substitute of all the modes in discount scenario covering 87% of the total trips.
Furthermore, the differential in term of average travel time between MaaS and PAYG scenarios across exclusive members have been analyzed, showing that in the time limited scenario members travel longer by public transport and less by car mode than in PAYG scenario instead, travel time using free-floating remains unchanged. In contrast, discount scenario members reduce the average travel time of all the services employed in the MaaS scenario.
Additionally, the modal shift has been analyzed in which 72% of the agents are new public transport users in time scenario followed by 22% of free-floating, whereas the percentage rises up to 81% for public transport and decrease to 7% for free-floating in discount scenario.
Instead, car mode is still employed by 19% of the users in discount scenario, while the percentage decreases up to 8% in time scenario, opposite trend is found for free-floating mode which is 1% in discount and 4% in time scenario.
Globally, in both scenarios the percentage of active modes (walking and cycling) have decreased and are substituted by MaaS services while two-way service is almost not employed by members.

5. CONCLUSIONS

This study analyzed the choice of different MaaS business models in the users' daily mode choice set through an agent-based model to develop a tool able to capture MaaS market penetration.
Three different types of members have been analyzed; users being indifferent, i.e. which are willing to become members indistinctly of the offered MaaS business models, are characterized by long daily travel times and they employ mainly car and public transport, whereas the members of MaaS time scenario substitute the car by traveling longer by employing public transport to exhaustively use the time slot included in their membership booking also free-floating.
Instead, the members of MaaS discount scenario have a different behavior, in which they mainly substitute all the modes by public transport, employing it to achieve more trips but within shorter travel times with respect to the scenario without discounts. In contrast, discount members use the car as main mode, which is not substituted by free-floating service making this mode a no-appealing service in the MaaS discount bundle.

In addition, the total MaaS market appeal is more than 20% of the whole population which suggests how differing the businesses within MaaS bundle might help to increase the MaaS subscription appeal. However, we should not forget that this study considers the TCO to increase the awareness of car users of their expenditure, therefore a scenario with MaaS system without such impact is not analyzed in this study. Moreover, a fixed price of MaaS plan has been selected to analyse how MaaS business models influence the demand, while a further sensitivity analysis on the MaaS membership price between the current business models could lead to different results. For this reason, a possible future outlook is to simulate different ranges of prices per different MaaS scenarios, increasing the supply capacity by including other public services such as bike sharing, one-way carsharing, carpooling, taxi/uber to capture further potential MaaS members.

ACKNOWLEDGMENTS

This work is funded by the Fonds Nationale de Recherche (FNR), Luxembourg, under the grant MaaS4All BRIDGES19/MS/13769009.

REFERENCES

Caiati, V., Rasouli, S., Timmermans, H., 2019. Bundling, pricing schemes and extra features preferences for mobility as a service: Sequential portfolio choice experiment. Transp. Res. Part Policy Pract. S0965856418309534. https://doi.org/10.1016/j.tra.2019.09.029

Ciari, F., Bock, B., Balmer, M., 2014. Modeling Station-Based and Free-Floating Carsharing Demand: Test Case Study for Berlin. Transp. Res. Rec. J. Transp. Res. Board 2416, 37–47. https://doi.org/10.3141/2416-05

Eisenmann, C., Kuhnimhof, T., 2018. Some pay much but many don't: Vehicle TCO imputation in travel surveys. Transp. Res. Procedia 32, 421–435. https://doi.org/10.1016/j.trpro.2018.10.056

ETH Zürich, Horni, A., Nagel, K., TU Berlin, Axhausen, K.W., ETH Zürich, 2016. Introducing MATSim, in: ETH Zürich, Horni, A., Nagel, K., TU Berlin (Eds.), The Multi-Agent Transport Simulation MATSim. Ubiquity Press, pp. 3–8. https://doi.org/10.5334/baw.1

Giorgione, G., Ciari, F., Viti, F., 2019. Availability-based dynamic pricing on a round-trip carsharing service: an explorative analysis using agent-based simulation. Procedia Comput. Sci. 151, 248–255. https://doi.org/10.1016/j.procs.2019.04.036

Hietanen, S., n.d. Mobility as a service The New Transport Paradigm 18.

Kamargianni, M., Matyas, M., 2016. The Mobility-as-a-Service Business Ecosystem 19.

Matyas, M., Kamargianni, M., 2017. A stated preference experiments for mobility-as-a-service plans, in: 2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS). Presented at the 2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), IEEE, Naples, Italy, pp. 738–743. https://doi.org/10.1109/MTITS.2017.8005610

Sochor, J., Strömberg, H., Karlsson, I.C.M., 2015a. Implementing Mobility as a Service: Challenges in Integrating User, Commercial, and Societal Perspectives. Transp. Res. Rec. J. Transp. Res. Board 2536, 1–9. https://doi.org/10.3141/2536-01

Sochor, J., Strömberg, H., Karlsson, I.C.M., 2015b. The Added Value of a New, Innovative Travel Service: Insights from the UbiGo Field Operational Test in Gothenburg, Sweden, in: Giaffreda, R., Cagáňová, D., Li, Y., Riggio, R., Voisard, A. (Eds.), Internet of Things. IoT Infrastructures, Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering. Springer International Publishing, Cham, pp. 169–175. https://doi.org/10.1007/978-3-319-19743-2_26

Vij, A., Ryan, S., Sampson, S., Harris, S., 2018. Consumer preferences for Mobility-as-a-Service (MaaS) in Australia 8.