The impact of total cost of ownership on MaaS system appeal using an agent-based approach

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Abstract. Despite the interest in the MaaS system is growing fast within the scientific community, it remains uncertain if MaaS could be a potential tool able to reduce car ownership. This study aims to capture the impact of the total cost of ownership (TCO) on MaaS demand by endogenizing the MaaS choice and the TCO within the users' travel choice in an agent-based model. We simulate different TCO price range starting from a benchmark cost in the literature and embed a specific type of MaaS plan which gives unlimited access to the services. Results show a significant growth of MaaS demand when TCO rises, in particular MaaS members are car users who shift their mode choice to public transport by travelling within more trips but in a shorter time slot. In contrast, MaaS users employ public transport for short trips while they still employ cars reducing their travel time but employing the same number of trips when TCO decreases. Results suggest that MaaS might become a more sustainable service by developing specific subsidies to discourage car ownership and by increasing mobility accessibility.

Keywords: MaaS membership, Agent-based model, Car ownership.

1 Introduction and State of Art

The mobility as a service (MaaS) concept keeps gaining the scientific community's attention since 2014 when it was first introduced by Heikkila and Hietanen [1], [2].
MaaS is mainly described in the literature as subscription-based system in which customers purchase several customized mobility plans through a digital platform [3]. This new mobility concept aims to satisfy customers' mobility needs by offering a package of specific mobility services at a fixed cost [4], [5]. For this reason, MaaS is intended to capture a broad range of demands including multiple user profiles with various mobility requirements, which underlines how discovering population mobility tastes, needs, constraints and competitive alternatives they have as options is essential for successful MaaS implementation. The grand ambition of the MaaS system is to progress towards social and sustainability goals by increasing multimodal choice and reducing car ownership and usage [6].
In this context, MaaS has been individualized as a potentially efficient tool with future environmentally and sustainable outcomes able to reduce car ownership [3], [7]. In the

literature, many studies have undertaken the MaaS topic employing different methods and providing distinct results. Due to the lack of data, since the MaaS system is not available on the market yet, one of the main approaches to study the attitude of potential users is the stated and revealed preference survey, in which participants are invited to claim their willingness to subscribe to hypothetical customized MaaS scenarios. Findings have shown how public transport users are the main MaaS potential users since they are more apt to subscribe than car users who are reluctant to shift their mobility choice to an aggregated service as MaaS system [3], [8], [9]. Fioreze et al. have further observed that regular car users are likely to underestimate the cost of MaaS, and therefore they are less apt to subscribe than public transport users [10]. However, MaaS seems to be a potential substitute for the second vehicle household whereas car ownership seems to be a barrier to MaaS adoption [11], [12].
Another approach widely used in the literature is by running and collecting data from pilot projects, many of these have taken place to study MaaS market appeal in different contexts by selecting specific participants and MaaS packages [13], [14]. Pilot projects outcomes have underlined that the new service might be a complement rather than a substitution for the private car, while public transport users remain the main potential customers of the MaaS plan [15], [16].Overall, the shift from car ownership to MaaS seems very difficult to achieve; Several studies in the literature have discussed it suggesting how making users more aware of their current travel expenditure might increase the MaaS appeal [17]. Hensher et al. have underlined that notifying a potential saving in terms of traveling costs by subscribing MaaS might increase the new system market share [18]. In conclusion, findings in the literature seem still far from individualizing a general trend for MaaS potential customers; survey approaches mainly rely on participants' answers about hypothetical scenarios implemented following the specific costs and the mobility services available in the running area. Additionally, interviewing people about a future mobility service even providing a specific description of it to them might not guarantee a realistic and reliable data set. Whereas, pilot projects are developed by choosing specific niches of customers and contexts which are not representative of the whole potential MaaS demand. A general model able to capture potential MaaS demand starting from a heterogeneous population with various mobility habits and supplying different mobility services to them including a MaaS system seems to be currently missing in the literature. In this context, this study aims to develop a tool able to capture MaaS potential demand by embedding MaaS choice in the agent's daily mobility options by using an agent-based model. The agent-based modelling approach allows agents to experience the MaaS service in a synthetic reality in terms of the trade-off between the new service subscription fee and time-linked mobility service costs. Furthermore, the total cost of ownership (TCO) of the private car is embedded in the agents' car mode choice to make them conscious of their travel expenditure while the new MaaS subscription option is available. Through the new tool, this study aims to individualize the sensitivity of MaaS demand across TCO price range, starting from a TCO benchmark cost from the literature [19]. Whereas, the supply side is fixed in the model, as much as the simulated MaaS plan business type which allows unlimited usage of services within the packages and it is simulated within a benchmark fixed cost from the literature [20].Finally, the authors analyse the sensitivity of the MaaS demand

across the TCO variety in terms of the modal split, the average of travel time and the number of trips per mobility service within the MaaS package.

2 Methodology

This study employs an agent-based modelling approach, which provides a microscopic representation of individuals' (or agents') daily mobility choices by giving as input the spatial and temporal distribution of the demand [21]. The advantage of employing an agent-based model is the possibility to capture a dynamic demand response towards supply change which affects the agents in terms of activities performed and travel costs. We adopt the agent-based MATSim software which simulates agents' behaviour 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 computed.
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 [21].

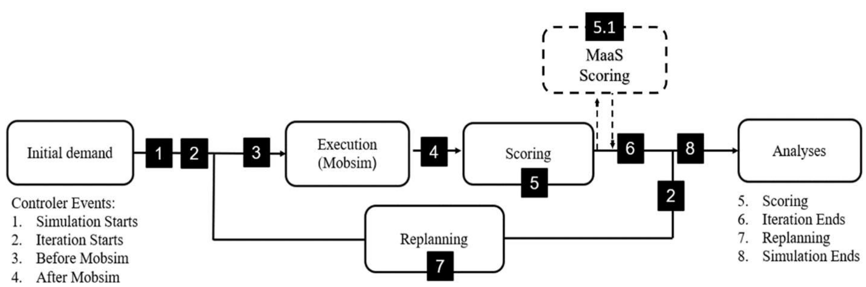

Fig. 1. MATSim conceptual framework.

The conceptual framework loop 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 us the selected modes (3-4 Events)
- The actual performance of the plan is taken to compute the experienced plan and its specific score ,$S_{plan,experienced}$ as it is shown in Eq. 1 (5 Event).
  The user's score 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:

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

where the travel part is calculated as follows:

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

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

Equation 2 represents the daily score of travelling by carsharing [22], 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, 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 just the travel (dis)utilities part of $S_{\;plan,experienced}$ under specific constraints which allows to experience the MaaS subscription (Event 5.1). The assumption that gives MaaS accessibility is that the 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, by selecting the time-linked cost of the mobility services within the MaaS bundle in a scenario where users pay as much as they travel.

$$Score_{plan,MaaS(t)} = \; S_{plan,experienced(t)} + Cost_{included} - Cost_{MaaS,package}$$

$$\text{-TCO}^* \sum_{\text{q=0}}^{\text{q,car}} \text{I}_{\text{q,car}} \tag{4}$$

Moreover, a total cost of ownership euro-per-km (-TCO) is embedded in agents' travel expenditure, independently from the MaaS subscription by counting the number of the trip made by car $(I_{q,car})$.

- Replanning section instead defines how agents can change their travel behaviour to maximize their score by reducing their generalized travel costs. The Event 7 is defined by following predefined strategies which allow re-routing and changing of transport mode, in this way agents have the chance to choose among all the sets of mobility services simulated in the synthetic network (Event 7).
- Finally, the greatest plan score between $S_{plan,MaaS}$ and $S_{plan,experienced}$ is stored in the user's memory.

3 Case Study

This study employs the synthetic population of 25560 agents generated by census data, with heterogenous socio-demographic characteristics and travel patterns in the synthetic network of the city of Berlin [23],[24] . Moreover, the following mobility services are implemented in the supply network: free-floating carsharing, two-way carsharing, public transport, bike, walk and private car. In the carsharing supply, a total number of 62 two-way stations have been simulated, with two available cars per each of them whereas a fleet of 160 cars for free-floating carsharing are simulated and spatially distributed within specific service areas in the city of Berlin.
Furthermore, the carsharing costs are simulated following one of the current company prices in the city of Berlin, while for the public transport we kept the cost simulated and validated in the previous calibrated scenario of Berlin [25], [26] .

The MaaS plan business simulated in the network is instead an unlimited MaaS package in which the potential subscriber has unlimited time access and usage to the services included in the bundle which are the following: free-floating, two-way carsharing services and public transport.
The sensitivity analysis of MaaS demand across TCO variation is calculated starting from a benchmark value of 0.30 €/km following Eisenmann and Kuhnimhof's study [19]. The TCO scenarios are 21 obtained varying the price by 10% from -100% with TCO equals zero to +100% in which TCO has the double cost of the benchmark equal to 0.60 €/km. In all the scenarios the unlimited MaaS bundle price is settled following Caiati et.al study who estimated a positive parameter of monthly price equals 150 € in the Netherlands which has been divided by 20 working days obtaining a 7.50 € as a MaaS daily fee for the current paper [20].
In order to understand the MaaS demand behaviour, the NoMaaS (or Pay-as-you-go) scenario has also been simulated in which users pay for each service as much as they travel by experiencing separable trip-based costs per each mobility service simulated. We start from a set of parameters previously estimated and validated in the literature by following the score specification reported in Equations 1,2,3 and MATSim general framework in Fig 1 without implementing the new Event 5.1 [26]. In the NoMaaS scenario either TCO per car trip or MaaS option are simulated. However, the time-

linked costs of carsharing services and public transport are equal to the TCO scenarios to allow the comparison in terms of travel costs between scenarios.

4 Result

Table 1. MaaS demand variation in terms of number of members and percentage across TCO (€/km) scenarios

TCO range	0	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	**0.30**
Demand	15%	15%	14%	14%	14%	14%	14%	14%	15%	15%	**16%**
Members	3802	3741	3679	3644	3692	3606	3621	3641	3753	3810	**4049**
TCO range	**0.30**	0.33	0.36	0.39	0.42	0.45	0.48	0.51	0.54	0.57	0.60
Demand	**16%**	16%	18%	19%	20%	21%	23%	24%	26%	28%	30%
Members	**4049**	4152	4486	4802	5089	5375	5861	6179	6666	7194	7614

The Table 1 shows the MaaS demand across the TCO price range, the number of MaaS users is around 16 % at the benchmark price of 0.30 €/km and it increases up to 30% as TCO rises 0.60 €/km. Whereas, MaaS demand remains almost constant at around 15% when the TCO decreases from the benchmark until it becomes free of charge. Fig 2 displays the total number of trips per transport mode in each TCO scenario among MaaS members; at the benchmark cost (0.30 €/km) trips made by car represent almost 8% of the total trips, while public transport covers more than 80% of them. The number of trips made by car increases up to 19% of the total number of trips when the TCO is equal to zero, while the number of trips employed by using public transport decreases following an inverse trend from car mode (around 70%).Active modes such as walking and cycling are not employed by Maas members when the TCO is lower than the benchmark cost. In contrast, the total number of trips made by car and public transport remains almost constant in the scenarios in which TCO is higher than the benchmark cost, while the percentage of trips made by active modes slightly increases. The number of trips employs by carsharing instead, remains almost constant among all TCO scenarios. Table 2 shows the average travel time per transport mode of MaaS agents across TCO scenarios; a linear increase of travel time by using public transport is displayed, in which MaaS users travel on average almost 20 minutes longer in the 0.60 €/km scenario than the benchmark one. The travel time employed using public transport does not change consistently when the TCO decreases till being equal to zero, whereas the travel time using car modes decreases almost linearly with the rise of TCO; from more than 30 minutes on average as the TCO is given for free, up to less than 10 minutes as TCO is the double benchmark price (0.60 €/km). Unexpectedly, travel time spent by travelling by free-floating service generally decreases with the rise of TCO, while travel time employed by using active modes increases. In contrast, there is no evident trend of travel time employed using active modes when TCO decreases.

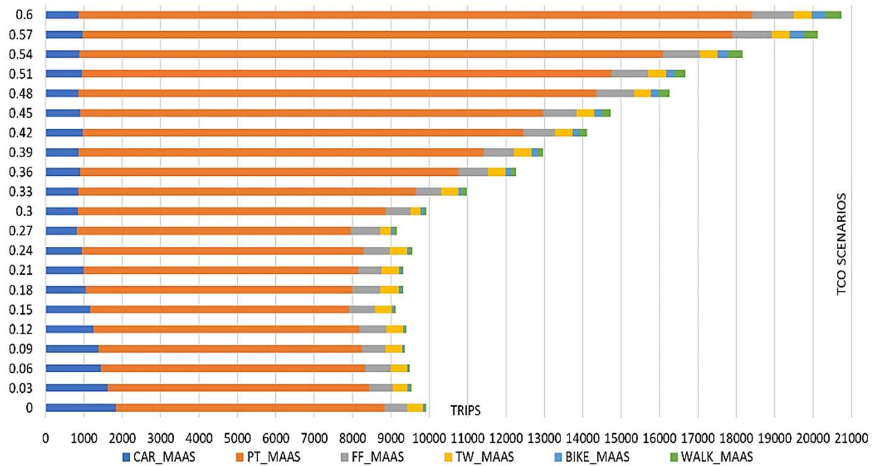

Fig. 2. MaaS members trips distribution across TCO scenarios

Table 2. The average of MaaS agents' travel time (min) per transport mode across TCO (€/km) scenarios

TCO	0	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	**0.30**
PT	89	89	89	95	92	92	93	97	94	87	**93**
TW	44	42	46	46	45	46	43	44	45	36	**35**
FF	31	29	31	32	29	30	26	26	28	27	**29**
CAR	33	29	27	23	22	19	17	16	14	13	**13**
WALK	90	149	106	122	129	125	112	85	105	55	**68**
BIKE	46	39	31	30	36	26	41	20	34	17	**21**
TCO	**0.30**	0.33	0.36	0.39	0.42	0.45	0.48	0.51	0.54	0.57	0.60
PT	**93**	100	106	108	110	110	113	110	111	114	111
TW	**35**	44	44	42	43	42	41	41	40	39	38
FF	**29**	30	28	28	27	25	25	23	22	23	22
CAR	**13**	13	12	13	12	12	11	10	10	10	10
WALK	**68**	85	87	94	95	105	100	105	109	120	121
BIKE	**21**	29	31	30	38	32	39	36	44	41	43

Two-way service instead seems not to have any travel time trend across TCO scenarios. In the same way, the average of the number of trips per transport mode is analysed and as expected for public transport, it rises following the growth of TCO, an inverse trend instead, is shown for car and free-floating modes in which the number of trips decreases as TCO rises.

To further understand the MaaS modal shift demand, we analyse MaaS users' travel behaviour in the NoMaaS scenario. We capture the total number of trips per mode in the NoMaaS scenario among MaaS agents in each TCO scenario, the differential in terms of average of travel time and the number of trips per mode between MaaS members in each TCO scenario and the NoMaaS scenario.

Fig 3 displays the mode choice among MaaS members, in the NoMaaS scenario across TCO scenarios.

Almost 70% of the trips are represented by car mode in every scenario which rises up to 76 % when TCO increases from the benchmark cost of 0.30 euro/km. Whereas public transport is employed as much as bike mode by representing almost 10% of the total trips, in contrast, MaaS users seem to barely use any carsharing service when MaaS and TCO are not simulated.

Table 3 represents instead the differential in terms of travel time between MaaS and NoMaaS scenarios which increases with the TCO price when agents travel by car and the trend follows a linear correlation in which the differential decreases with the decrease of TCO.

A similar inclination is shown for free-floating mode, while public transport mode occurs in the opposite direction in which the differential decreases with the TCO rise.

Equally, the differential of the number of trips per mode shows public transport agents increase their number of trips, while on the other hand car mode is less employed by MaaS agent as TCO increases. Carsharing usage has an opposite trend instead, free-floating service use goes down when TCO rises, while two-way service does not have a defined direction among scenarios.

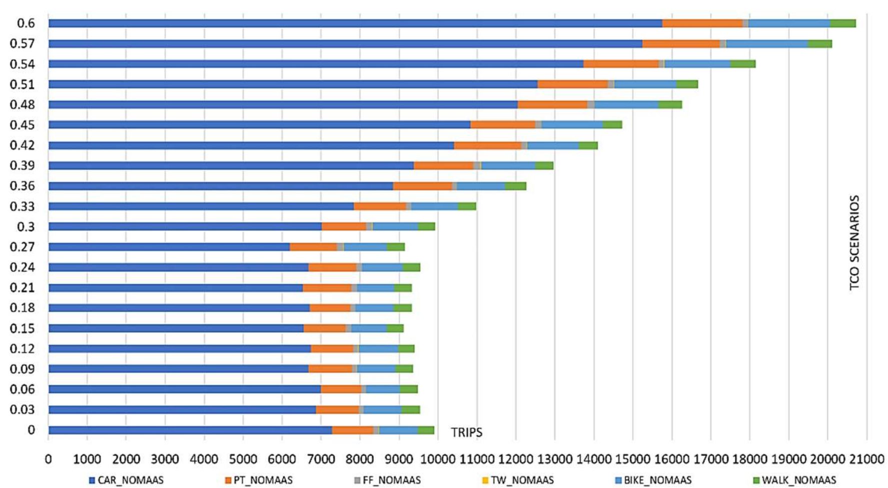

Fig. 3. MaaS members trips distribution across TCO scenarios in NoMaaS scenario.

Table 3. Differential in terms of average of travel time (min) per agent among TCO (€/km) scenarios

TCO	0	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	**0.30**
PT	-10.5	-9.3	-8.8	-12.4	-11.6	-7.6	-6.6	-10.9	-5.4	-11.6	**-3.9**
FF	-5.2	-7.3	-8.8	-8.9	-10.3	-6.3	-14.8	-17.9	-15.2	-16.0	**-19.2**
CAR	-11.3	-13.4	-14.7	-19.1	-18.7	-21.6	-23.2	-25.1	-26.2	-23.9	**-28.8**
TCO	**0.30**	0.33	0.36	0.39	0.42	0.45	0.48	0.01	0.54	0.57	0.60
PT	**-3.9**	-13.9	-16.2	-17.5	-17.6	-13.3	-7.8	-11.6	-6.4	-3.4	-5.5
FF	**-19.2**	-16.7	-14.8	-20.7	-17.6	-22.4	-23.2	-17.0	-19.4	-22.7	-18.2
CAR	**-28.8**	-32.9	-36.4	-36.3	-38.5	-38.3	-40.1	-38.3	-39.0	-40.0	-38.9

5 Discussion and Conclusion

The study analysed the impact of TCO on MaaS demand by employing an agent-based model able to endogenize MaaS system in users' choice set and TCO cost. The MaaS demand grows with the rise of TCO capturing 30% of the whole sample, while the number of agents remains constant at around 15% when the TCO reduces showing how potential customer does not seem to be affected by its reduction.

Findings show two main different MaaS customers' behaviour; the first occurs for high TCO in which Maas members are car users who shift their mode choice to public transport by travelling within more trips but in a shorter time slot. MaaS users drastically reduce car usage both in terms of average of the number of trips and of travel time in order to reduce their TCO daily expenditure. Free-floating instead seems to be unexpectedly employed in the same modality of the car mode; rather than having an increase in terms of travel time and the number of trips as TCO rises. A further result of the TCO growth, MaaS demand seems to reduce the active modes usage in favour of MaaS service, while public transport use follows the opposite direction increasing with the TCO rise. Whereas two-way service does not have a defined direction.

On the other hand, another travel behaviour occurs for a TCO reduction in which MaaS members seem to be car users who shift to public transport and carsharing services without employing any active modes during their daily trips.

MaaS users employ public transport for short trips while they still employ cars reducing their travel time but employing the same number of trips due to the reduced effect of TCO on the agents. In contrast with the other type of MaaS members, as TCO decreases the usage of free-floating increases in terms of both the number of trips and travel time. Two-way usage instead, does not show any difference in terms of usage in each TCO trend probably due to the station-based nature of the service in which the user must drop the car off in the same picking up station. Conversely, free-floating usage appears overturned since its rise might be expected as TCO increases due to its versatile and similarity with private cars [27], [28].

The free-floating usage distribution might be due to a demand-supply unbalance, in fact as TCO rises many users want to book free-floating cars to substitute their cars and as a result, too many booking requests are involved and the system is saturated and not able to satisfy the customers.
On the other hand, as TCO decreases the availability of carsharing fleets is higher than in high TCO scenarios due to the reduced number of bookings in the network.
In this study, we should also not forget that the simulated MaaS bundle provides unlimited time access to the services which might affect their usage among members.
Furthermore, the supply side is a simulation input set up following specific services space distribution and tariffs in the city of Berlin and within these specifics, the result might not be generalized.
In this context, one of the main limitations in this paper is the MaaS unlimited plan simulated that might encourage the overuse of the services within the plan while embedding different MaaS business models might improve the distribution of the supply capacity.
A possible bundle model which provides a time limit access or a discount per each trip made by the transport modes could further help the balance of the supply side.
Moreover, differentiating MaaS bundle might discourage generalized undesirable effects such as the shift from active modes to MaaS subscription.
A possible future study might be focused on simulating different MaaS business models to capture MaaS appeal and identify further characteristics of potential customers. Moreover, by including new mobility services in the MaaS packages it might increase the MaaS appeal in the market. In conclusion, simulating Maas thought an agent-based model using different validated MATSim scenarios ,and comparing them might increase their reliability and reproducibility.

References

1 S. Heikkilä, ‘Mobility as a Service – A Proposal for Action for the Public Administration Case Helsinki’, p. 94.

2 S. Hietanen, ‘Mobility as a service The New Transport Paradigm’, p. 18.

3 M. Kamargianni and M. Matyas, ‘The Mobility-as-a-Service Business Ecosystem’, p. 19, 2016.

4 J. Sochor, H. Arby, I. C. M. Karlsson, and S. Sarasini, ‘A topological approach to Mobility as a Service: A proposed tool for understanding requirements and effects, and for aiding the integration of societal goals’, *Res. Transp. Bus. Manag.*, vol. 27, pp. 3–14, Jun. 2018, doi: 10.1016/j.rtbm.2018.12.003.

5 P. Jittrapirom, V. Caiati, A.-M. Feneri, S. Ebrahimigharehbaghi, M. J. A. González, and J. Narayan, ‘Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges’, *Urban Plan.*, vol. 2, no. 2, p. 13, Jun. 2017, doi: 10.17645/up.v2i2.931.

6 D. J. Reck, D. A. Hensher, and C. Q. Ho, ‘MaaS bundle design’, *Transp. Res. Part Policy Pract.*, vol. 141, pp. 485–501, Nov. 2020, doi: 10.1016/j.tra.2020.09.021.

7 H. Becker, M. Balac, F. Ciari, and K. W. Axhausen, 'Assessing the welfare impacts of Shared Mobility and Mobility as a Service (MaaS)', *Transp. Res. Part Policy Pract.*, vol. 131, pp. 228–243, Jan. 2020, doi: 10.1016/j.tra.2019.09.027.

8 R. Hoerler, A. Stünzi, A. Patt, and A. Del Duce, 'What are the factors and needs promoting mobility-as-a-service? Findings from the Swiss Household Energy Demand Survey (SHEDS)', *Eur. Transp. Res. Rev.*, vol. 12, no. 1, p. 27, Dec. 2020, doi: 10.1186/s12544-020-00412-y.

9 C. Q. Ho, 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', *Transp. Res. Part Policy Pract.*, vol. 117, pp. 302–318, Nov. 2018, doi: 10.1016/j.tra.2018.08.025.

10 T. Fioreze, M. de Gruijter, and K. Geurs, 'On the likelihood of using Mobility-as-a-Service: A case study on innovative mobility services among residents in the Netherlands', *Case Stud. Transp. Policy*, vol. 7, no. 4, pp. 790–801, Dec. 2019, doi: 10.1016/j.cstp.2019.08.002.

11 A. Pickford and E. Chung, 'The shape of MaaS: The potential for MaaS Lite', *IATSS Res.*, vol. 43, no. 4, pp. 219–225, Dec. 2019, doi: 10.1016/j.iatssr.2019.11.006.

12 M. J. Alonso-González, S. Hoogendoorn-Lanser, N. van Oort, O. Cats, and S. Hoogendoorn, 'Drivers and barriers in adopting Mobility as a Service (MaaS) – A latent class cluster analysis of attitudes', *Transp. Res. Part Policy Pract.*, vol. 132, pp. 378–401, Feb. 2020, doi: 10.1016/j.tra.2019.11.022.

13 J. Sochor, I. C. M. Karlsson, and H. Strömberg, 'Trying Out Mobility as a Service: Experiences from a Field Trial and Implications for Understanding Demand', *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2542, no. 1, pp. 57–64, Jan. 2016, doi: 10.3141/2542-07.

14 T. Storme, J. De Vos, L. De Paepe, and F. Witlox, 'Limitations to the car-substitution effect of MaaS. Findings from a Belgian pilot study', *Transp. Res. Part Policy Pract.*, p. S0965856418312564, Sep. 2019, doi: 10.1016/j.tra.2019.09.032.

15 H. Strömberg, 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, pp. 1655–1670, Nov. 2018, doi: 10.1007/s11116-018-9946-8.

16 I. Tsouros, A. Tsirimpa, I. Pagoni, and A. Polydoropoulou, 'MaaS users: Who they are and how much they are willing-to-pay', *Transp. Res. Part Policy Pract.*, vol. 148, pp. 470–480, Jun. 2021, doi: 10.1016/j.tra.2021.04.016.

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

18 D. A. Hensher, C. Q. Ho, and D. J. Reck, 'Mobility as a service and private car use: Evidence from the Sydney MaaS trial', *Transp. Res. Part Policy Pract.*, vol. 145, pp. 17–33, Mar. 2021, doi: 10.1016/j.tra.2020.12.015.

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

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

21 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, 2016, pp. 3–8. doi: 10.5334/baw.1.

22 F. Ciari, B. Bock, and M. Balmer, ‘Modeling Station-Based and Free-Floating Carsharing Demand: Test Case Study for Berlin’, *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2416, no. 1, pp. 37–47, Jan. 2014, doi: 10.3141/2416-05.

23 D. Ziemke and K. Nagel, ‘Development of a fully synthetic and open scenario for agent-based transport simulations – The MATSim Open Berlin Scenario’, p. 11.

24 G. Giorgione, 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, p. 6727, Aug. 2020, doi: 10.3390/su12176727.

25 ‘Stations - Stadtmobil Berlin’. Accessed: Mar. 06, 2020. [Online]. Available: https://berlin.stadtmobil.de/privatkunden/stationen/

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

27 S. Le Vine and J. Polak, ‘The impact of free-floating carsharing on car ownership: Early-stage findings from London’, *Transp. Policy*, vol. 75, pp. 119–127, Mar. 2019, doi: 10.1016/j.tranpol.2017.02.004.

28 C. Cisterna, G. Giorgione, E. Cipriani, and F. Viti, ‘Supply characteristics and membership choice in round-trip and free-floating carsharing systems’, in *2019 6th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*, Cracow, Poland, Jun. 2019, pp. 1–7. doi: 10.1109/MTITS.2019.8883360.