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Analysis of MaaS membership attributes: an agent-based approach

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Abstract

Mobility-as-a-service (MaaS) provides a bundle of mobility services under one plan subscription, allowing its customers to travel on a seamless multimodal system. It is envisioned that MaaS will foster more sustainable mobility, but its expected impact is still unknown, since no MaaS system has been deployed in practice, if not in few pilots. This study aims to identify potential MaaS members attributes applying an agent-based modelling approach including MaaS as alternative for the agents. In particular, we simulate a MaaS system configuration in the city of Berlin, giving accessibility to a basic MaaS plan characterized by a daily subscription fee payment. We evaluate 5 different ranges of MaaS plan price scenarios. For comparison, we simulate a Pay-as-you-go configuration, considering specific trip-based costs per each mobility service and considering the total cost of car ownership in the daily agents' score function. Results generally show a general modal shift from walk, bike and car to MaaS services. Expectedly, the number of MaaS customers decreases as the MaaS price rises. Former public transport and free-floating car-sharing users represent the main potential MaaS customers, as they are the users who employ MaaS services for the longest time during the day. Moreover, car trips have been substituted more than 40% by public transport in MaaS scenarios suggesting that MaaS could have an overall positive impact on the environment.

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1. Introduction

Mobility-as-a-Service (MaaS) is a recent concept in transportation, formally introduced by Heikkilä (2014) and Hietanen (2014), who identified 3 MaaS keywords: bundles, budgets and brokers. The first one indicates the possibility of bundling a range of mobility services under one package, the second aims to capture users' mobility budget and the third is a new actor in the transportation system that plays the role of service aggregator. MaaS has also been described by Kamargianni and Matyas (2016) as a user-centred system that provides different transport modes under one subscription-based single digital platform. After subscribing to a MaaS plan, the members shift the usage costs from trip-based to fixed, having access to a wider portfolio of services to achieve their daily activities. As postulated by Wong et al.(2018), there are 4 main actors involved in a MaaS system: the users, who subscribe for access to the packages, the broker, which is a new figure in charge to gather all the mobility choices under one plan, the mobility suppliers, which provide capacity and services to the MaaS system, and the government, which could grant accessibility and subsidies to companies to encourage MaaS market penetration. MaaS could be interpreted as a supply chain, which regulates the cooperation among stakeholders. Moreover, a MaaS system changes the users' mode choice process by capturing users' heterogeneous travel needs and taking into account individual mobility budget constraints. Indeed, whereas transport users previously used to choose their travel mode according to their travel needs, after the subscription to a MaaS plan, in turn based on habitual travel choices, MaaS users will have a wider choice set of mobility services to fulfil their travel needs.

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Hence, trip-based mode choice models are inadequate to properly capture the behavior of MaaS users and a more sophisticated approach is recommended, which explicitly includes trip chaining behavior. To contribute to fill this research gap, this study simulates a MaaS system in an agent-based modelling framework, by considering the city of Berlin as a test site. The implementation of the case study has been performed by resorting to the open source software MATSim (ETH Zürich et al. (2016)). We extended the travel options within MATSim: MaaS membership has been embedded in the simulation environment, giving agents the option of adopting a basic MaaS solution, under a certain fixed daily subscription cost. In this work we simulate and analyze different scenarios, in turn characterized by different subscription costs, to assess the impact of the MaaS membership fare. Moreover, the MaaS subscribers' behaviour has also been assessed in terms of modal shift (before and after subscription to the MaaS plan) and variation in total travel time. This paper is structured as follows. The next section provides a concise literature review focusing on MaaS behavioral studies and its impact on mode choice; Section 3 presents the methodology used in the case study, followed in Section 4 by the analysis of the main results. Finally Section 5 gives the main conclusions and future research directions.

2. Literature review

Since MaaS services currently have limited market penetration, existing literature has investigated the MaaS potential mainly resorting to stated preference (SP) surveys, where respondents were asked to face hypothetical choice scenarios characterized by choice sets including MaaS services (e.g. through travel modes packages), or through experiences on small pilot studies. Therefore, there is still limited evidence of the actual potential and impact of MaaS systems. Studies have mainly been conducted in Australia (Vij et al. (2018), Ho et al. (2018)), England (Matyas and Kamargianni (2018a)) and the Netherlands (Alonso-González et al. (2020)), with the main objective of inferring which transport modes should be included in a MaaS plan. In the Australian case study, the results showed that public transport users do not perceive MaaS as attractive, and that most of the respondents underestimated their weekly travel expenditures and car ownership marginal costs. Authors have concluded that making users more aware of their total cost of car ownership may increase the MaaS appeal (Vij et al., 2018). In the Netherlands, Alonso-González et al. (2020) showed that the probability to subscribe to the MaaS is greater for users with a low attitude for car driving and a high attitude for public transport usage. Also in England, Matyas and Kamargianni, (2018) showed that the probability to be a MaaS subscriber is higher among habitual public transport users. Caiati et al. (2019) estimated a membership choice model through a portfolio of choices experiment, by asking the survey participants to compose their personal bundle by choosing among 7 different transport modes. Results show that both subscription duration and the inclusion of public transport within the package positively affect the probability of subscribing to MaaS. In general, SP surveys require participants to claim their future intentions on hypothetical scenarios, i.e. scenarios that they have not experienced. This approach may have a strong underlying bias in capturing the actual travel behaviour of users in future real contexts characterized by the presence of a MaaS service, mainly because of incomplete knowledge of MaaS characteristics, as well as the high degree of innovation of the MaaS concept. Moreover, the choice tasks in SP surveys are often built based on participants' revealed travel patterns. Other studies in the literature were based on data collected from pilot projects, as the ones implemented in the Netherlands (Sochor et al., 2016), Belgium (Storme et al., 2019) and Sweden (Strömberg et al., 2018), where participants have been selected within a sub-set of potential beneficiary of the new service. Results of these works were divergent, due to the differences in MaaS bundle configurations and analysed locations. This raises the question about the generality and transferability of the findings from limited pilot studies. Becker et al. (2020) resorted instead to a simulation approach, by implementing a MaaS system within an agent-based model in Switzerland. The study focused on the broker (i.e., the mobility aggregator) perspective, by implementing different supply settings and by varying the values of different parameters in the simulation. However, the impact of subscription fees was not assessed, and the shared modes have been assumed as accessible to all agents indiscriminately, i.e. without any restricted membership (e.g. limited use of certain modes or bundle with a few available travel modes). Our study uses a similar approach and contributes to this research stream by focusing on the MaaS membership costs and their impact on MaaS take up and users' mode choice. Identifying which MaaS package best fits a specific customer's profile represents a key challenge, because it is necessary to figure out how MaaS can meet the current users' mobility needs. Moreover, MaaS membership choice does not depend on one travel need but rather on a combination of achievements and travel patterns, which differs among customers. Therefore, capturing and understanding the impact of these characteristics when bundling several mobility services under a mobility package is one of the main challenges of implementing a MaaS system. In the end, there is still no general MaaS membership choice model that is able to estimate the probability to subscribe to a MaaS plan as a function of different demand characteristics. The long-term goal of this research is to develop such a model. This study is a preliminary step to understand a MaaS membership choice behaviour. We simulate a hypothetical configuration through the aid of the open-source agent-based software MATSim, where we introduced a single MaaS plan that is accessible to all participants, at the cost of a fixed daily subscription price. By contrasting this configuration with a previous one, in turn characterized by a conventional Pay-as-you-go service, we captured the characteristics of potential MaaS users. Moreover, starting from a subscription price value inferred from the literature review, we performed several simulation scenarios, varying the Maas subscription price in each one of them. This allowed us to assess the sensitivity of MaaS demand to the cost of the subscription and to compute its market share elasticity.

3. Methodology

This work resorts to an agent-based modelling framework, which allows to consider the spatial and temporal distribution of transport users within the considered test site, enabling the problem to be simulated at a microscopic (i.e. single individual) level. The simulations have been performed with the open source software MATSim. Such an approach may be useful for the simulation of MaaS services, since the latter can be implemented for different and interrelated purposes and activities ETH Zürich et al. (2016). Moreover, agent-based modelling makes it possible to consider a dynamic response of the demand as the level of service characteristics of the transport supply vary. In the simulation environment, each agent is generated with his/her own daily plan, comprehensive of all destinations to be reached to perform daily duties. Each agent has a *score* S_{plan} associated with his/her plan, which is a daily utility function, in turn given by the sum of all activity utilities $S_{act,q}$ and all travel (dis)utilities $S_{trav,(mode)q}$, where q indicates both the generic daily activity and the corresponding trip, while N is the total number of daily activities:

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

where:

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

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

Equation (2) represents the daily score (disutility) of travelling by car sharing services, where α_{cs} is the mode-specific constant, $\beta_{c,cs} * (c_t * t_r + c_d * d)$ is the part of the score (disutility) for reservation and travelled distance, $\beta_{t,walk} * (t_a + t_e)$ is the part of the score (disutility) for access and egress time, by assuming that access/exits are made by walk, and $\beta_{t,cs} * t$ is the part of the score (disutility) for travel time by car sharing Ziemke et al. (2019). Equation (3) is the generic score specification for all other available modes, namely bike, walk, public transport and car, where α_{mode} is the mode-specific constant and $\beta_{t,mode} * t$ is the part of the score (disutility) for the time spent travelling by that specific mode. Moreover, the agent-based model searches for the configuration that maximizes the users' *score*, by explicitly accounting their daily activities, assuming that a user switches to some mobility alternative from a previously experienced choice if his/her score increases.

In this study, we simulate 2 configurations:

1. Pay-as-you-go (NoMaaS) configuration, where users pay for each service, hence experiencing trip-based costs. In this configuration, we start from a set of parameters previously estimated for the city of Berlin by Giorgione et al. (2019) who assumed the score specification reported in Eq. (1)-(3) to simulate users' mode choice in MATSim.
2. MaaS configuration, where agents have indiscriminate access to a basic MaaS package, which includes free floating and two way carsharing services and public transport. In order to embed the MaaS package as a possible

daily option within the users' memory plans, i.e. the set of feasible user's plans to simulate, we implemented a new controller event in MATSim.

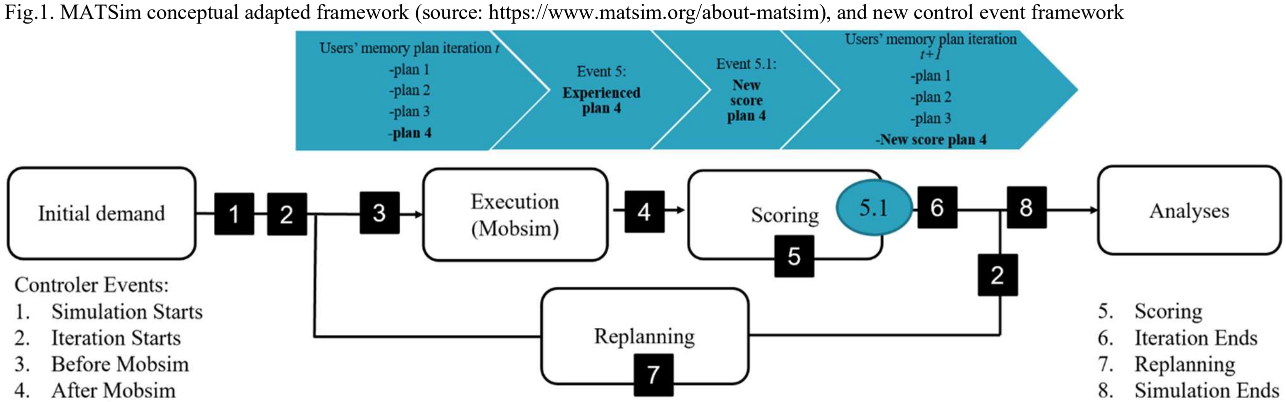
Fig. 1 shows the conceptual framework of a generic MATSim simulation, where a loop process is implemented with several controller events, which in turn control the whole process within specific constraints. In particular, an additional controller event 5.1 has been inserted between the controller events 5 and 6 of the original MATSim iteration loop. After simulating the experienced plan at each generic iteration *t*, a further new event has been executed. At the generic iteration *t*, in the order:

- a plan (indicated in bold) is selected from the set of user's memory plans;
- Mobsim executes the selected plan trying to maximize the user's score (experienced score/plan);
- the new controller event 5.1 computes the new score plan of the experienced plan under specific constraints;
- The new score plan is stored in the user's memory plan at the next iteration *t*+1 and compared with the other stored plans, dependently on the score (see Fig 2).

The above loop is repeated until reaching the user equilibrium. At the equilibrium, if the value of the MaaS score is the best for a certain user, then the Maas plan will be the best plan to fulfil the daily needs of that user. By applying this new approach, we embed the MaaS package as users' possible daily choice per each iteration, to allow users to experience and compare their mode choices until equilibrium, i.e. when they will no longer change their daily mode choice between two successive iterations. The evaluation of the score of the experienced plan has been implemented by assuming that customers perceive their daily public transit costs as fixed (not trip-based), and considering potential MaaS users' choice to be conditioned by the travel choices previously experienced in the synthetic reality (Mobsim).

Furthermore, we included the total cost of ownership (TCO) in the agents daily travel expenditure. Moreover, this study assumes that the generic user has access to MaaS service in cases where the vector of his/her mode choices in the experienced plan at the 5th event comprises at least 2 of the transport modes of the MaaS plan. The part of the individual score for the Maas service has been included in the second term of Eq. (1), by considering a fixed cost for the MaaS plan and no cost for both booking time and eventual service daily tickets (public transport). Moreover, if the user chooses the car, a TCO is embedded within her/his travel expenditure as an additional cost per km, while the portion of disutility due to the travel time is kept for each travel mode.

Fig.1. MATSim conceptual adapted framework (source: https://www.matsim.org/about-matsim), and new control event framework



The score $S_{plan,MaaS_{(t+1)}}$ corresponding to the step of the new controller function 5.1 at the iteration $t+1$ can be computed as follows:

$$S_{plan,MaaS_{(t+1)}} = S_{plan(t)EX} - a_{pt} * \left(\sum_{q=0}^{q,pt} I_{q,pt} \right) - \left(\beta_{c,cs} * (c_t * t_r, tw + c_d * d) \right) * n_b + Cost_{MaaS,package} + TCO * \sum_{q=0}^{q,car} I_{q,car} \quad (4)$$

where $S_{plan(t)EX}$ is the experienced score at the generic iteration *t* downstream the event 5, $Cost_{MaaS,package}$ is the MaaS plan price, n_b is the number of bookings made by car sharing users, while $I_{q,pt}, I_{q,cs}$ are indicator variables that take into account whether the leg mode is public transport or car sharing, as shown in the Eq. (5)-(6):

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

$$I_{q,car} = \begin{cases} 1, & if\ q = q_{,car} \\ 0, & otherwise\ q \neq q_{,car} \end{cases} \quad (6)$$

Finally, the score value for the plan at the iteration *t* +1 is updated in the case $S_{plan,MaaS_{(t+1)}}$ exceeds its value at the previous iteration *t*, i.e.:

If $S_{plan,MaaS_{(t+1)}} > S_{plan,(t)}$ $\quad S_{plan,(t+1)} = S_{plan,MaaS_{(t+1)}}$ (7)

Else $S_{plan,(t+1)} < S_{plan,(t)}$ $\quad S_{plan,(t+1)} = S_{plan,(t)}$ (8)

Eq. (7) holds at equilibrium when a generic user no longer changes her/his mode choice between two consecutive iterations, then MaaS becomes the best plan to adopt to maximize the score for the daily activities of the same user.

3.1 Case study

The city of Berlin represents the test site for the current study. We considered 25,560 agents within the city, each one with his/her own demand characteristics (trip chain, trip purpose, socio-demographic and level-of-service attributes). A total number of 700 iterations has been performed to reach the users' equilibrium, in turn obtained using a co-evolutionary algorithm. We consider the value of the monthly price of MaaS package obtained by Caiati et al. (2019), in which specific price plan weights were estimated, obtaining a daily price by simply dividing the monthly price by 20 working days. Starting from this value of price as reference (7.50€), we simulate the presence of the MaaS plan by considering different values from -20% to +20% of the reference price (henceforth simply referred to as *price scenarios*), whereas for the Pay-as-you- go configuration we considered the current car sharing prices in the city of Berlin[1]. Free floating and two-way car sharing services and public transport represent the services within the MaaS plan. We provided access to a MaaS plan characterized by an unlimited travel time for each service. A total number of 62 two-way stations have been simulated, with 2 available cars per each of them. Moreover, we simulated the presence of 160 cars for free floating car sharing, spatially distributed within specific service areas. According to Eisenmann and Kuhnimhof (2018), we assumed a monthly TCO equal to 310 euros, which corresponds to a value of 0.30 euro per km. It is worth remarking that this cost includes fuel, insurance, depreciation, taxes, repair and maintenance.

4. Results

In this study we focus mainly on the modal split of users between MaaS and NoMaaS (Pay-as-you-go) configurations and the final composition of MaaS users across different price scenarios of the MaaS plan. Table 1 shows the market shares of MaaS users per MaaS price scenario. Overall, there is a clear reticence in the adoption of MaaS, as witnessed by the small values of MaaS market shares. Consistent with expectations, the number of MaaS users decreases as the subscription price increases, with no notable variation between the two scenarios characterized by a subscription price equal to 6.75 and 7.50 euros. Moreover, Table 2 reports the market share elasticities to

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[1] "Stations - Stadtmobil Berlin" , "Your Future Car Rental | SHARE NOW International" .

subscription price. As can be seen, the simulation returns greater sensitivity to price increases than to price decreases. This asymmetry suggests that the score may be specified by embedding a more than linear transformation of the price (e.g., exponential, power). However, in absolute terms, the variation does not appear significant enough to draw general conclusions on users' response. Table 3 shows the modal splits between MaaS and NoMaaS setups per each price scenario, showing that there is a global shift from active modes (bike, walk) and car to MaaS services. This suggests that users perceive the car as main competitor to MaaS services. Moreover, the total number of trips made by car and public transport decreases as the MaaS price increases. Concerning car sharing services, the total number of trips made is greater for free-floating than for two-way and both decrease as the MaaS price increases.

Table 1. MaaS market shares per scenario

6	6.75	7.5	8.25	9
1.29%	1.23%	1.24%	1.12%	1.08%

Table 2.MaaS market share arc elasticity to subscription price

$\Delta Cost_{MaaS,package}/Cost_{MaaS,package}$	- 20%	-10%	+10%	+20%
$E_{MaaS,costMaaS,package}$	+0.2	-0.13	-1.01	-0.66

Table 3. Comparison among MaaS subscribers trip choices among MaaS and NoMaaS configurations

Scenario	Price plan	Tw	Ff	Pt	Car	Bike	Walk
Nomaas	6	26	88	222	1024	160	150
MaaS		170	633	**649**	**103**	26	28
Nomaas	6.75	21	93	157	1040	173	141
MaaS		182	638	**600**	**92**	19	46
Nomaas	7.5	6	112	210	921	154	176
Maas		152	655	**587**	**83**	19	38
NoMaaS	8.25	21	107	164	950	163	125
MaaS		154	645	**585**	**76**	14	45
NoMaaS	9	22	110	168	843	122	123
MaaS		170	555	**554**	**72**	20	26

Acronyms: Tw = two way car sharing, Ff = free floating car sharing, Pt = public transport.

In order to further analyze the modal shift between NoMaaS and MaaS configuration, we cluster MaaS users by their main travel mode chosen in the NoMaaS configuration. The majority of MaaS users (more than 54%) employed the car as main mode in the NoMaaS configuration, followed by public transport (more than 14%) and bike (more than 11%), whereas walk and free floating modes are employed less then 10%, whilst the two-way car sharing users change is not significant (less than 1%). Concerning the segments of users discussed above, we also assessed their modal shift in the MaaS scenarios. Fig 2 shows the percentage of trips substituted by public in MaaS scenarios within MaaS users. It results that more than 40% of car trips and more than 45% of free floating trips are made with different travel modes in the MaaS scenarios, while public transport trips are around 45% in both setups. Moreover, bike and walk modes have been substituted by public transport in less than 40% of trips in the MaaS scenarios. However, there is no evident variation with price changes. Analogously, Fig 3 shows the percentage of trips substituted by free floating car sharing in MaaS scenarios within MaaS users. In particular, around 40% of car trips and more than 40% of public transport and bike trips switch to the free floating service, whereas free floating users retain their travel mode choice in more than 45% of their trips. In parallel with the analysis of the general modal shifts, it is interesting to assess the differential in the total number of free floating and public transport users across configurations and scenarios. Fig 4 shows that both differentials decrease as the MaaS price rises. Moreover, we analysed the users who made the same mode choice in the two setups. Fig 5 shows that both public transport and free-floating users in the NoMaaS configurations keep choosing their mode, although the former increases their average travel time as the MaaS price rises, while the latter increases in number as the MaaS price rises.

5. Conclusion and outlook

This study assessed the willingness to subscribe to MaaS services, by performing a series of agent-based simulations on the City of Berlin. Overall, there is a general shift from car mode to MaaS, which suggests that increasing the awareness of users about actual car expenditure could increase the MaaS appeal, confirming the findings by Vij et al. (2018).

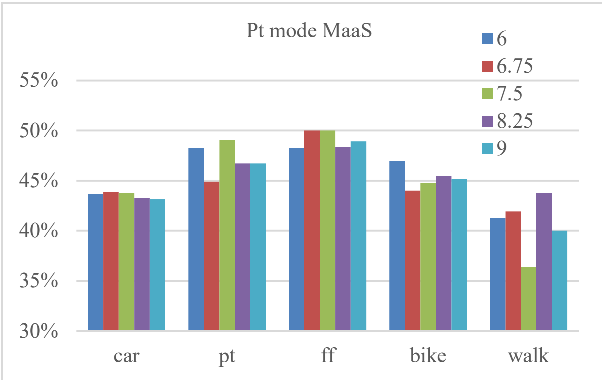

Fig 2. Percentage of trips substituted by public transport in MaaS scenarios.

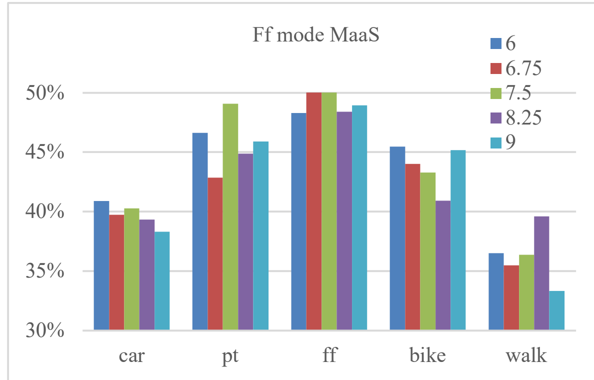

Fig 3. Percentage of trips substituted by free floating car sharing in MaaS scenarios

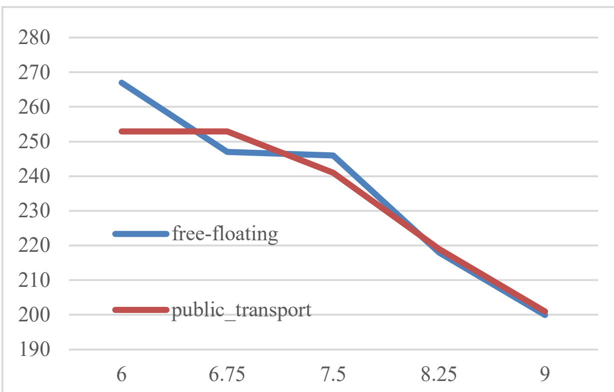

Fig 4 . Differentials in the total number of users across MaaS scenarios.

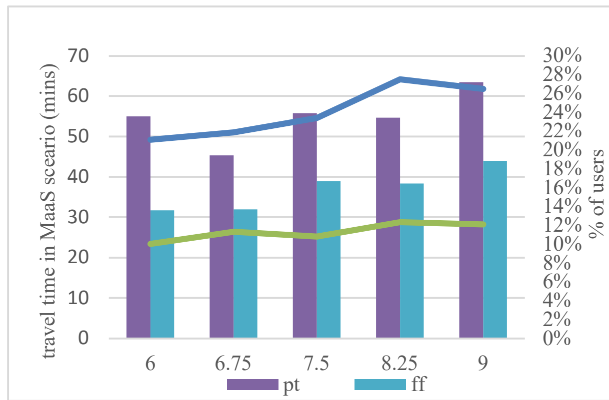

Fig 5. Market shares of users who keep choosing their mode between configurations and total travel time among scenarios

In practice, this increased appeal can be obtained by advertising the actual TCO to transport system users, thus increasing also the environmental impact of MaaS, as it takes market share away from the car. Public transport and free floating users seem to be the main potential MaaS subscribers, as they tend to use both services longer after subscribing to a MaaS plan. In other words, they subscribe to the MaaS service in order to have a cheaper price and a wider availability of those same travel modes they already used before subscribe to MaaS. Public transport and free floating seem to be also the backbone of a hypothetical general MaaS plan, as they are the main candidates to replace the other modes in the considered MaaS scenarios. Furthermore, users do not perceive differences in terms of usage between free floating and public transport within a MaaS plan. Once users purchase the MaaS package, agents have a wider set of travel mode choices, which represents one of the main MaaS goals (Sochor et al. (2018), Beutel et al. (2014)). As expected, the MaaS demand decreases as the MaaS price rises. However, the computation of the elasticities of MaaS demand to price shows that there is an asymmetry, in terms of users' reaction, between the cases of increasing and decreasing price. This suggests that MaaS price has a non-linear effect on daily score that is worth considering in future research steps. The Maas service attracts also new two way car sharing users, who actually represent a negligible share in the NoMaaS setup. In addition, the two way car sharing is not a substitute for any other travel mode, probably due to its fixed-station system, which in turn does not allow the same flexibility to travel with one's own car. On the contrary, this flexibility can be obtained with free floating car sharing services. Indeed, active modes (walk and bike) have also been substituted by MaaS plan, which can be interpreted as an opportunistic users' choice where they take a possible benefit of MaaS in any travel circumstance.

The main limitation of this study lies in one of the underlying assumptions of the methodology, namely that, in order to make the MaaS available as an alternative mode, two MaaS services must be in the vector of the agent's travel choices. This assumption represents a strong constraint, because agents who choose only one of the MaaS services in their daily mode choices might also subscribe to MaaS. Moreover, in this study MaaS is characterized by an unlimited usage of the modes included in the MaaS bundle. In future works we will relax this limitation by considering time or access limits to the services within the MaaS subscription. Future work will take into account time-limit access to MaaS services within different packages, to better assess the willingness to pay for specific services of a bundle or specific additional level of service characteristics (e.g. extra hours budget per single service).

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