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Using revealed preference data to design MaaS plans

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How much of which mode? Using revealed preference data to design MaaS plans

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ABSTRACT

Mobility as a Service (MaaS) seeks to integrate emerging shared mobility modes with existing public transportation (PT). Decisive to its uptake will be attractive subscription plans that cater for heterogeneous mobility needs. Research on willingness to pay for such plans has commenced, yet remains divided on a central question: how much to include of which mode, and how? Complementing previous research building on stated preference data, we use revealed preference data to analyze the viability of different subscription plan components. We find that PT season tickets are viable for 83% of all respondents. In contrast to many current MaaS pilots, car-, bike-sharing and taxi use remains too infrequent to include as recurring credit in MaaS plans. Rather, pay-as-you-go is the economically more sensible option for consumers. This research therefore challenges the idea of all-inclusive mobility flat rates and suggests a more modular design.

Keywords: Mobility as a Service (MaaS), Service Bundling, Multimodal Transportation Plans

INTRODUCTION

Shared and electricity-powered transportation modes (e.g., (e-)scooters, (e-)bikes, ride-hailing) have started to appear in many cities worldwide. Their integration with existing public transportation (PT), often referred to as Mobility as a Service (MaaS), could facilitate their joint use and thereby present a new alternative to the private car. A corresponding shift to shared modes could help reduce congestion and GHG emissions at times when urgently needed (Kamargianni *et al.,* 2016; Jittrapirom *et al.,* 2017; Mulley, 2017).

At its core, MaaS consists of a platform integrating payment and routing across multiple transport providers, allowing customers to plan and pay for intermodal trips through a single app ('one-stop shop') and subscribe to recurring, multimodal transportation plans. Current MaaS pilots (e.g., UbiGo, WHIM, zengo) exhibit a wide variety of plans, typically including a sole 'pay-as-you-go' option, an 'all-inclusive' mobility flat rate and a package in-between consisting of budgets or discounts for specific modes (e.g., car-sharing, bike-sharing, taxi). While it is too early to assess the success of the different pilots, it is clear that plans need to cater for the heterogeneous mobility needs of potential customers.

Research on MaaS plans is still in its infancy (Matyas and Kamargianni, 2018a; Esztergár-Kiss and Kerényi, forthcoming). It has begun with stated preference experiments on willingness to pay (WTP) and adoption rates of different components (Ho *et al.,* 2018; Matyas and Kamargianni, 2018a; Guidon *et al.,* forthcoming), however remains divided on a central question: how much to include of which mode, and how? While Matyas and Kamargianni (2018b) find that respondents in London generally do not prefer shared modes (car-sharing, bike-sharing, taxi) in their plans, Guidon *et al.* (forthcoming) find a higher WTP for PT and car-sharing and a lower WTP for (e-)bike-sharing and taxi in a bundle when compared to stand-alone WTP in Zürich. This suggests that customers prefer *certain* shared modes (car-sharing) in their plans. Ho *et al.* (2018) also find a general preference for car-sharing in bundles, however, note that preferences for shared modes vary significantly across the respondents with discounts for taxi and ride-hailing only appealing to regular taxi/Uber users.

Despite evidence that travel behavior is influenced by habit (e.g., Gärling and Axhausen, 2003) and that MaaS customers may consequently seek to purchase plans that best cater for their current mobility need (Ho *et al.,* 2018; Matyas and Kamargianni, 2018b), revealed preference data has to date not been used for research on the design of MaaS plans. Yet, it offers insight into the amount and variability of transport demand on the individual level and its substitutability with shared modes over time.

In this paper, we use the mobility traces of 555 students over one semester (14 weeks) in Copenhagen, Denmark, to construct a MaaS scenario where private car trips are substituted by shared modes based on generalized costs. We analyze the viability of different subscription plan components (PT, car-sharing, bike-sharing, taxi) and their mode of inclusion (weekly budgets in minutes and season tickets) for each student. Our results offer evidence that a PT season ticket represents a viable core of MaaS plans for the majority. In contrast to current MaaS pilots, car-, bike-sharing and taxi use remains too infrequent in our sample to include as recurring credit. Rather, pay-as-you-go is the economically more sensible option for consumers.

This paper is structured as follows. We first review the literature on MaaS plans. We then introduce our data and methods before reporting on the results. We conclude with a summary and a discussion of the implications for transport research, business and policy.

LITERATURE REVIEW

Matyas and Kamargianni (2018a, 2018b) were among the first to highlight and analyze the research gap on multimodal transportation plans. They conducted a stated choice survey in Greater London, England, asking respondents to choose from different MaaS plans. They estimate mixed multinomial logit (MMNL) models on plan choices and find that coefficients for shared modes besides PT (car-sharing, bike-sharing, taxi) are negative, implying that respondents do not prefer any of these shared modes in their MaaS plans. Interestingly, ~38% of all respondents would still consider buying a MaaS plan, however, the authors note that this could be due to the hypothetical nature of the experiment. In their successive work, Matyas and Kamargianni (2019) find a strong correlation between currently used modes and stated preferences and hypothesize the reason to be habit persistence.

Guidon *et al.* (forthcoming) conducted a stated choice survey in Zurich, Switzerland, to analyze the valuation of components in MaaS bundles vs stand-alone. They find a higher WTP for PT and car-sharing and a lower WTP for (e-)bike-sharing and taxi in a bundle when compared to stand-alone, suggesting that customers prefer *certain* shared modes (car-sharing) in their plans. This contrast to Matyas and Kamargianni (2018b, 2019) may be due to regional or methodological differences in eliciting and analyzing customer preferences in a hypothetical experiment.

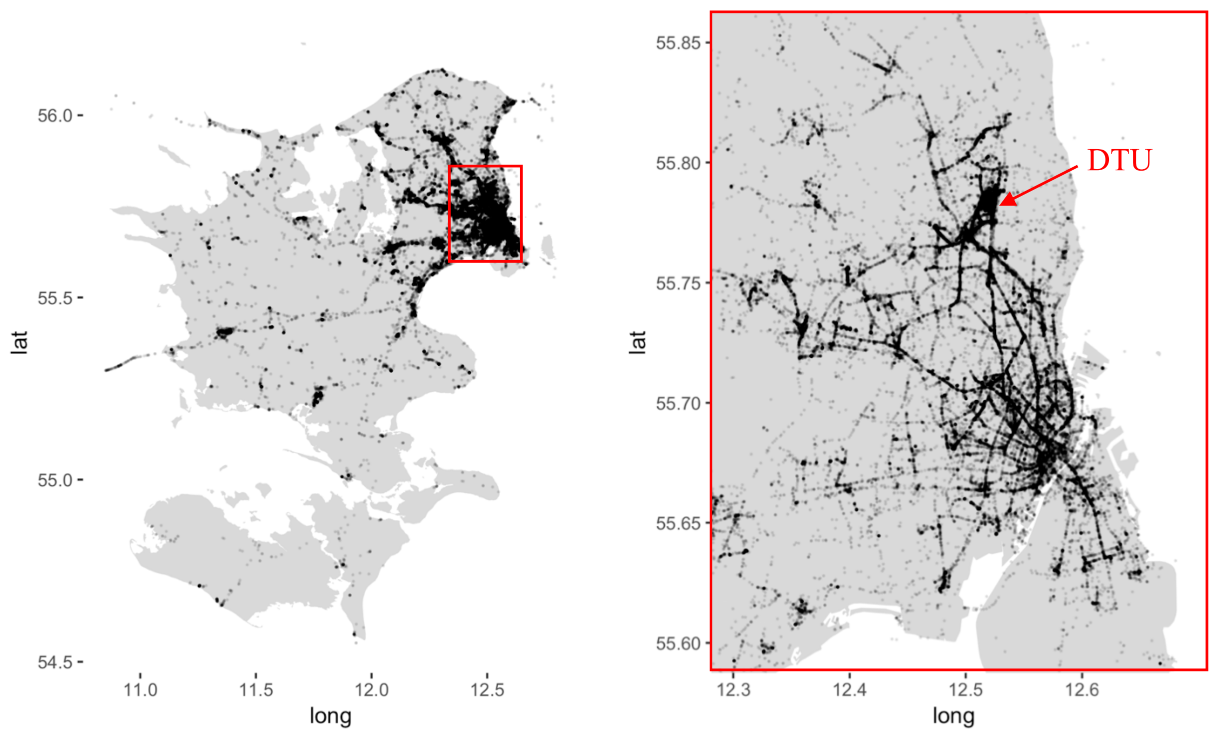
Ho *et al.* (2018) conducted a stated choice survey in Sydney, Australia, to analyze the potential uptake of MaaS plans and the WTP for its components. While also finding a general preference for car-sharing in bundles, they note that preferences for shared modes vary significantly across respondents. This could explain the differences between Guidon *et al.* (forthcoming) and Matyas and Kamargianni (2018b) on car-sharing preferences. Ho *et al.* (2019) also find that uptake levels correlate with current mobility tool usage (e.g., discounts for taxi and ride-hailing only appealed to regular taxi/Uber users). This corresponds with Matyas and Kamargianni's (2019) finding of a strong correlation between currently used modes and stated preferences and is rational to expect given the impact of habit on travel choices (e.g., Gärling and Axhausen, 2003).

Despite the shared finding that MaaS customers may seek to purchase plans that best cater for their current mobility need, which corresponds with earlier evidence on habitual travel behavior, revealed preference data has to date not been used for research on the design of MaaS plans. Yet, it offers insight into the amount and variability of transport demand on the individual level and its substitutability with shared modes over time.

DATA

We use the mobility trajectories of participants in a 24 months longitudinal experiment, the Copenhagen Networks Study (CNS) (for an overview and general study description, see Stopczynski *et al.*, 2014). The CNS was conducted between September 2013 and September 2015 and involved more than 800 students from the Technical University of Denmark. Positions were tracked using their smartphones' GPS and WiFi signals. Locations were identified with an estimation error below 50 meters in 95% of all cases (Alessandretti *et al.*, 2018) and separated into stop-locations (dwell time above 5 minutes) and travel stages within the Danish regions Hovedstaden and Sjælland. For each stage, the mode of travel was inferred with an overall accuracy of 90% (Bjerre-Nielsen *et al.*, forthcoming).

Figure 1: Sample stop-locations in Hovedstaden / Sjælland (left) and Copenhagen (right).



The total number of 634’269 identified stages for 814 students was filtered to contain only semester times (4x13-week periods), as we assume student’s mobility routines to be more stable during these periods, thus more suitable for subscription-based mobility plans. Widely available semester PT cards support this choice.

From the remaining dataset with 365’911 stages for 801 students, we excluded 29 students with a time span of less than 4 weeks between the first observation and the last to ensure sufficiently long mobility trajectories. The remaining 772 students participated with varying reliability in the experiment. While the number of smartphones with GPS and WiFi traces varies over time with its peak in semester two, some traces show gaps of several days or weeks. In order to ensure a sufficiently dense and large dataset, we thus focus our analyses on semester two (of four) and further exclude students with less than one observed stage averaged over all days. The final dataset includes 131’338 stages for 555 students.

METHODOLOGY

Complementing our dataset with observed stages and modes, we construct a MaaS scenario by substituting car stages with the best alternative shared mode (PT, car-sharing, bike-sharing, taxi) in terms of generalized travel costs. This allows a subsequent analysis of the viability of different MaaS plan components.

Consistent values of travel time and cost components for all alternative modes and stages are obtained by mapping our data to the 2015 Danish National Transport Model (DNTM) zones (Rich and Hansen, 2016). We calculate travel time and costs for a given stage *s* according to the following formulas, that have recently been applied by Rich and Vandet (2019) on similar data:

$$time_{PT}(s) = ivt(s) + \gamma_1 * noc(s) + \gamma_2 * wwt(s) \quad (1)$$
$$exp_{PT}(s) = fare(s) \quad (2)$$

Travel time for PT is composed of in-vehicle time *ivt(s)*, the number of changes *noc(s)* multiplied by a transfer penalty γ_1 of 6 minutes, and additional waiting and walking times *wwt(s)* multiplied by a penalty factor γ_2 of 1.5 (see Rich, 2017, for detailed documentation of the DNTM and associated γ-factors). Travel costs are based on 2015 single ticket fares (discounts for season tickets are applied later).

While travel time for car-sharing and taxi stages are assumed to be similar to car stages, travel costs are based on 2015 prices of car-sharing provider DriveNow and taxi company Taxa DK. For bike-sharing, travel times are included in the DTNM, and travel costs are based on the 2015 prices of bike-sharing provider Bycyklen. We assume that car-sharing and bike-sharing are only available in the center of Copenhagen and use an approximation of the current DriveNow zones.

Consistent with the Danish National Transport Model and previous Danish VTTS studies (Rich and Hansen, 2016; Rich and Vandet, 2019), generalized travel costs for each alternative mode *m* and stage *s* are then computed using an income-specific VTTS:

$$gencost_m(s) = time_m(s) + \frac{exp_m(s)}{VTTS} \quad (3)$$

As the income of our student population can be assumed to be fairly homogeneous, we use a VTTS value of 59 DKK/h (~9 USD/h) that was computed for a sample consisting mainly of DTU students (Papu Carrone *et al.*, 2019). Variations across trip purposes and modes was found to be small in previous Danish VTTS studies (Fosgerau *et al.*, 2007) and thus not further considered.

Finally, we add weather data for each trip and constrain the availability of the bike-sharing alternative to trips with a travel time of less than 30 min and times when local precipitation was 0.

RESULTS

Alternative shared modes

Table 2 shows the observed modal split and the modal split in the MaaS scenario, where all stages previously conducted with a car have been substituted with the best alternative available in terms of generalized costs. Overall, PT sees by far the greatest overall gain (+16.41 pp.), while car-sharing (+3.29 pp.) and bike-sharing (+2.64 pp.) account for the remaining stages. Within the car-/bike-sharing zones, which cover a large part of the inner city of Copenhagen, car-sharing sees the greatest gain (+6.95 pp.), followed closely by bike-sharing (+5.57 pp.). These results are plausible as car-/bike-sharing presents a viable alternative to PT on shorter inner-city distances with a median of 3.3 km (~2 mi). Interestingly, taxi trips, although included in existing MaaS packages, are always among the least preferable alternatives in terms of generalized costs (due to high fares), thus 0 car stages are substituted with the taxi.

Table 1: Alternative modes substituting car stages in MaaS scenario.

	All Zones		**Car-/Bike-sharing zones** (~Copenhagen City)	
Mode	**Observed**	**MaaS scenario**	**Observed**	**MaaS scenario**
PT	34.94 %	+ 16.41 pp	34.04 %	+ 0.94 pp
Car	22.34 %		13.46 %	
Car-sharing	NA	+ 3.29 pp	NA	+ 6.95 pp
Taxi	NA		NA	
Bike-sharing	NA	+ 2.64 pp	NA	+ 5.57 pp
Walk / Bike	42.72 %		52.50 %	

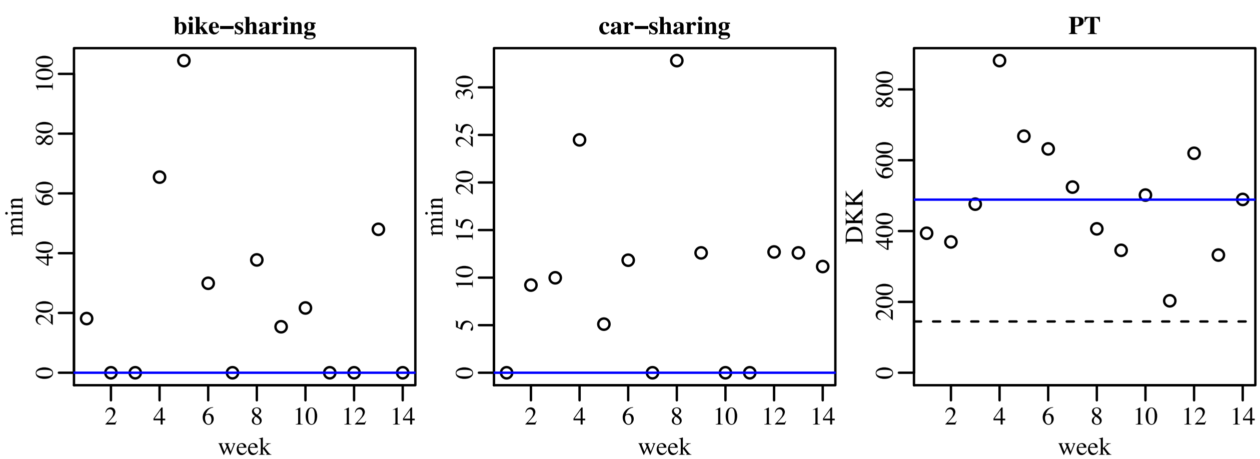
Viability of MaaS plan components

In the following, we test the viability of different MaaS plan components (PT season tickets, weekly budgets for car-/bike-sharing in minutes) for each student.

We assume that a PT season ticket is financially sensible to purchase if a student spends more than its weekly costs on PT during the entire timespan (14 weeks) *on average*. We further assume that a budget of X minutes for car-/bike-sharing is financially sensible to purchase if a student uses *at least* X minutes of the respective mode *every week*. This follows the rationale that car-/bike-sharing are usually paid by the minute, thus a student would be better off not to purchase a certain budget if it were underused.

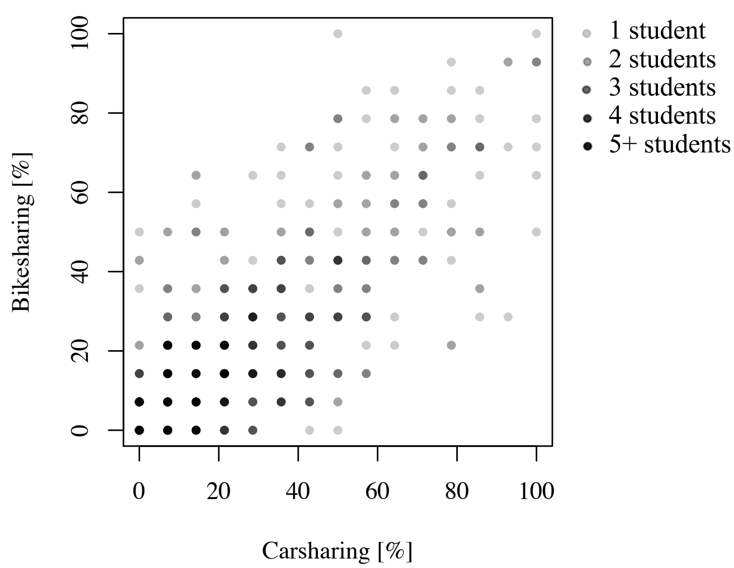
Figure 2 illustrates our approach. We show the weekly demand for bike-sharing, car-sharing and PT for an exemplary student. Bike-sharing is used irregularly with a weekly demand varying between 0 and ~100 min. Car-sharing is also used irregularly (between 0 and ~30 min), however a more stable usage is visible with an average ~13 min per week. PT is used for most trips with an average weekly spent of ~500 DKK (~75 USD). Following our assumptions above, weekly budgets for car-/bike-sharing would not seem sensible to purchase for this student as the minimum weekly demand is 0 (solid blue line). A PT season ticket, however, would seem sensible to purchase, as the average weekly spent on PT (~500 DKK / solid blue line) surpasses its costs per week at the discounted student rate (~145 DKK / dashed black line) for region Hovedstaden, which includes both DTU and Copenhagen municipality.

Figure 2: Weekly demand for an exemplary student.



We conduct this analysis for all 555 students, finding that for 459 students (82.7%) a PT season ticket (region Hovedstaden) would seem sensible to purchase in a MaaS scenario. Only 8 students (1.4%) show a weekly car-sharing demand greater than 0 suggesting the viability of a weekly recurring car-sharing budget. For bike-sharing, the average weekly demand is even lower with just 2 students (0.4%) showing a weekly demand greater than 0. This is due to the high variability of weekly demand for both modes: on average, students show demand for car-/bike-sharing only in 28% / 25% of all weeks, respectively. Figure 3 shows the average share of weeks with car-/bike-sharing demand > 0 per student (each represented with a single grey dot).

Figure 3: Share of weeks with car-/bike-sharing demand > 0 per student.



DISCUSSION

In the outset of this paper we stated that the uptake of MaaS will depend on how well multimodal plans cater for the heterogeneous mobility needs of potential customers. Research on MaaS plans has begun with stated preference experiments, however remains divided on a central question: how much to include of which mode, and how? While the partially contradictory findings of the three main contributions so far (Ho *et al.,* 2018; Matyas and Kamargianni, 2018a; Guidon *et al.,* forthcoming) may stem from regional and methodological differences, all authors agree that there is a strong correlation between current travel patterns and preferences for MaaS plans, suggesting that potential customers will seek to reproduce their current mobility tool usage in a future MaaS plan. Despite this agreement, revealed preference data has to date not been used for research into the design of MaaS plans. Yet, it offers insight into the amount and variability of transport demand on the individual level and its substitutability with shared modes over time.

In this paper, we used the mobility traces of 555 students over one semester (14 weeks) to construct a MaaS scenario where shared modes replaced car trips based on generalized costs. We analyzed the viability of different MaaS plan components (PT, car-sharing, bike-sharing, taxi) and different modes of inclusion (weekly budgets in minutes and season tickets). We found that a PT season ticket forms a viable core of MaaS plans for the majority of our sample (83%). In contrast to many current MaaS pilots, car-, bike-sharing and taxi use remains too infrequent to include as recurring credit for most students. Rather, pay-as-you-go appears to be the economically more sensible option for many.

We acknowledge that demand is not always motivated economically. There is evidence of the 'flat-rate bias' (Train *et al.*, 1991; Lambrecht and Skiera, 2006) in PT season ticket purchasing decisions (Axhausen *et al.,* 1998; Wirtz *et al.,* 2015) and first indications show similar patterns for all-inclusive mobility flat rates (e.g., SBB Green Class, WHIM Unlimited), too (Martin *et al.,* 2019). Yet, all-inclusive mobility flat rates seem to appeal only to a very specific socio-economic group (Martin *et al.,* 2019). Our results suggest a more modular design to appeal to larger parts of the society.

Our findings are consistent with Matyas and Kamargianni (2018b) in that for the majority of our sample, recurring credit for car-/bike-sharing and taxi would not be economically sensible to purchase as part of a MaaS plan. They are also consistent with Ho *et al.* (2018) in that preferences for MaaS plans are likely to vary substantially across potential customers as their individual mobility needs diverge.

While presenting a new approach to designing MaaS plans, this study has two limitations that call for future work. First and foremost, as our sample is composed of students, our results are not necessarily generalizable to other parts of the population. We thus suggest conducting similar analyses with other longitudinal datasets, ideally with revealed preference data from actual MaaS trials to circumvent hypothetical scenarios. Second, we calculate generalized costs with a single VTTS for all students. Estimating individualized VTTS would clearly be preferable, however was not possible due to data limitations in this case. Future studies should consider this as a methodological suggestion.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: D. J. Reck and K. W. Axhausen; data collection: D. J. Reck; analysis and interpretation of results: D. J. Reck; draft manuscript preparation: D. J. Reck; manuscript review and editing: K. W. Axhausen. All authors reviewed the results and approved the final version of the manuscript.

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