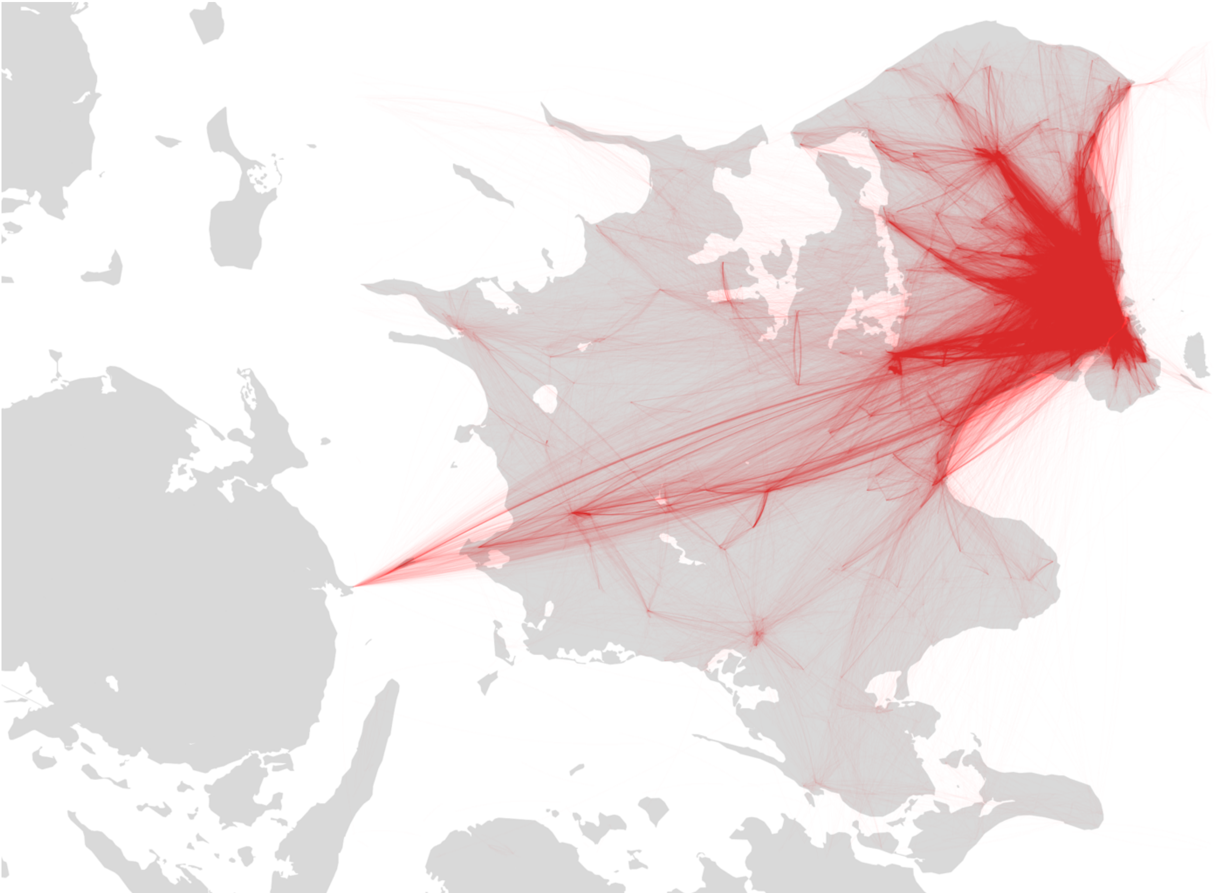

Understanding long-term multimodal mobility demand to inform MaaS service bundling

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Abstract

The integration of novel, shared mobility services within existing public transport (Mobility as a Service, MaaS) could offer an alternative to private car ownership and thereby improve travel sustainability. Research on willingness to pay and potential uptake of recurring MaaS packages has commenced with *stated-preference* experiments yet it remains unclear on a central question: how much to include of which mode? Using longitudinal multimodal *revealed-preference* data, we construct a MaaS scenario where car stages are substituted with shared modes based on generalized costs. We find that PT season ticket viability for students increases substantially (+13pp.) with PT substituting most previous car stages (~76%). In contrast, car- and bikesharing use, despite their potential to substitute the remaining car stages, remains too infrequent to include as a recurring credit in MaaS packages. This research therefore challenges the idea of all-inclusive mobility flatrates for car-/bikesharing, showing that in this case pay-as-you-go is economically more sensible for consumers.

Keywords

Mobility as a Service, Service Bundling, Longitudinal Data

1. Introduction

In many countries and cities, daily travel distance per capita has increased continuously over the past decade and personal motorized travel remains the preferred mode. This leads to a number of challenges experienced by many on a daily basis: congestion, pollution and traffic accidents. Climate change is a more long-term, yet no less threating consequence of current, fossil-fuel-powered individualized travel patterns.

Novel, often electricity-powered and shared transport modes (e.g., eScooters, eBikes, ride-hailing) have started to appear in major cities worldwide. Their integration with existing public transport (PT), often referred to as Mobility as a Service (MaaS), could offer an alternative to the private car, thus contributing to solving the challenges outlined above (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 transport trips through a single app ("one-stop shop") and subscribe to recurring, multimodal transport packages (MaaS packages). Research in willingness to pay and potential uptake of MaaS packages has commenced with *stated-preference* experiments (Ho *et al.,* 2018; Guidon *et al.,* forthcoming) as real-life pilots are yet too limited in size and number.

We argue that longitudinal multimodal *revealed-preference* data could further enrich our understanding of viable MaaS packages as it offers insight into the amount and variability of intrapersonal transport demand and its substitutability with shared modes over time. This perspective is useful to study even where no MaaS packages are available yet, as customers may change their travel patters eventually as a *result* of MaaS package (mobility tool) ownership (Beige and Axhausen, 2012), however, simultaneously may only decide to purchase a MaaS package *in the first place* if it covers their current mobility demand.

This paper thus reports on our analysis of the multimodal mobility traces of 108 students over two years in Denmark. Specifically, we address the following research questions:

1) Without access to a private car, which modes would have been chosen and how would travel expenses have changed in terms of times and costs?

2) Which MaaS packages retrospectively cover mobility demand and how viable are recurring packages considering variability transport demand over time?

Our results are of relevance to academia, as they can inform the MaaS package design of future stated-preference experiments and simulations. They also offer practical advice to policy-makers and mobility providers in terms of components, volume and viability of potential MaaS packages.

The remainder of this paper is structured as follows. Chapter 2 provides an overview of related work, focusing on the existing stated-preference experiments and longitudinal transport studies. Chapter 3 introduces our data and methods. Chapter 4 presents our results with regard to each research question. We conclude with a discussion and directions for future research.

2. Related work

Research into multimodal mobility packages have methodologically focused on stated-preference experiments.

Ho *et al.* (2018) conducted a stated-choice experiment in Sydney, Australia, asking participants to choose between their current travel record and individualized MaaS packages including different volumes of PT, carsharing, taxi and Uber. They find approx. half of the experiment's participants would buy MaaS packages. Uptake levels correlated with current mobility tool usage: infrequent car users were the most likely buyers, and car non-users the least.

These differences in valuation of transport services in bundles vs stand-alone have been further analyzed by Guidon *et al.* (forthcoming). They conducted a stated-choice experiment in Zurich, Switzerland, asking participants to choose between MaaS bundles and stand-alone services, separately. Customer valuation for PT, carsharing and park and ride services was found to be higher in bundles, while customer valuation for (e-)bike and taxi services was lower compared to stand-alone services.

Stated-preference experiments are well-established for exploring choice such as described above in hypothetical markets. They are, however, of limited use for exploring design aspects such as components and volume of MaaS packages as they are subject to cognitive biases (e.g., recency effect, neglect of probability). We argue that analyses of longitudinal multimodal *revealed-preference* data, to our knowledge yet untapped for research into MaaS packages, could fill this gap. As the results of Ho *et al.* (2018) suggest, customers may seek to cover their *current* mobility demand with a MaaS package before *adapting* their travel behavior due to the specific mix included. Thus, in order to design viable MaaS packages, we need to understand actual long-term multimodal mobility demand.

Longitudinal multimodal revealed-preference data is notoriously difficult and expensive to collect with traditional elicitation tools such as mobility surveys. Schönfelder and Axhausen (2016) provide an overview of the rare examples including the 35-day Uppsala Household Travel Survey (Sweden, 1971), 42-day Mobidrive (Germany, 1999) and the 42-day Thurgau diary (Switzerland, 2003). These long-term studies, despite improvements, remain susceptible to known inaccuracies (missing trips, low spatio-temporal precision) and are yet too short for viability analyses of retrospectively fitted, recurring MaaS packages.

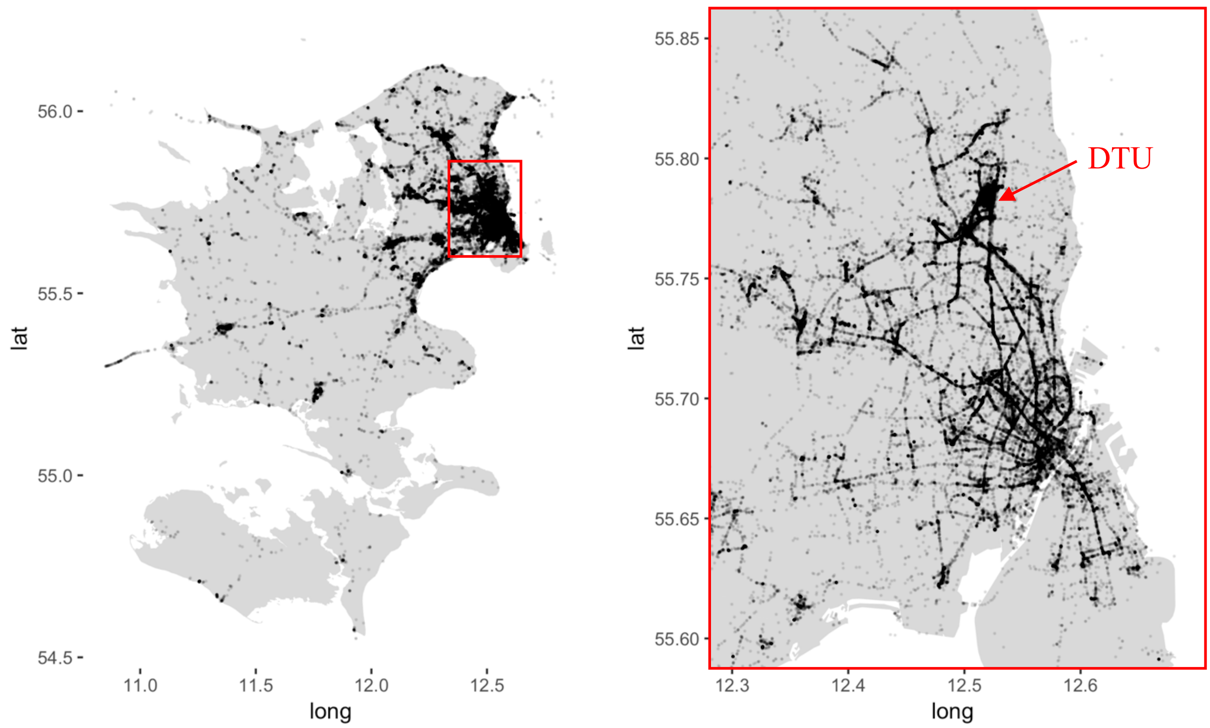
The proliferation of smartphones with GPS/WiFi has enabled mobility tracking with high spatio-temporal accuracy for long timeframes. In their study, Eagle and Pentland (2006) tracked 100 mobile phones over the course of 9 months. Recent advances in mode inference (e.g., Zheng *et al.*, 2008; Montini *et al.*, 2014; Bjerre-Nielsen *et al.*, forthcoming) solve the final missing link to longitudinal mobility diaries with durations of one year and more, such as the Copenhagen Networks Study (Stopczynski *et al.,* 2014).

3. Data and methods

3.1 Data

This study is based on 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 ~1000 students from the Technical University of Denmark. Positions were tracked using their smartphones' WiFi and GPS 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 669 702 identified stages for 814 students (averaging 1.90 stages per participant per observed day) was pre-filtered to contain only semester times (4*13-week periods), as we assume student's mobility routines to be more stable during these periods, thus more suitable for mobility packages. Widely available semester mobility cards support this choice. From the remaining 365 911 stages we excluded

- students with a time span of less than 4 weeks between the first observation and the last, leaving 365 202 stages / 772 students, and
- students with less than an average of 2 stages per day between the first observation and the last, thereby ensuring dense mobility trajectories without long gaps in observation for further analysis.

The remaining data includes 61 688 stages of 108 students (averaging 3.61 stages per participant per observed day). Weekly average trips (24.8) and standard deviations (11.7) are similar to reported values of earlier multimodal longitudinal studies (Table 1) assuming 1.3 stages per PT trip (Seaborn *et al.*, 2009).

Table 1: Trips per week

Study	Year	Mean	Std.
Uppsala	1971	24.2	11.3
Mobidrive	1999	24.4	8.8
Thurgau	2003	28.2	9.2
CNS sample	*2013-2015*	*24.8*	*11.7*

Table adapted from Schönfelder and Axhausen, 2010 (p. 142).

3.2 Approach

We construct a MaaS scenario by substituting car stages with the best alternative shared mode (PT, carsharing, bikesharing, taxi) in terms of generalized travel costs. Consistent values of travel time and cost components for each mode and stage are obtained by mapping our data to the 2015 Danish National Transport Model (DNTM) zones (Rich and Hansen, 2016). As part of our future work, we plan to implement a Monte-Carlo-Simulation for mode choice based on probabilities as a function of generalized costs.

We calculate travel time and costs for a given stage *s* according to the following formulas, that have recently also been applied by Rich and Vandet (2019) on the similar data

$$time_{car}(s) = ft(s) + \gamma_1 * ct(s) + \gamma_2 * fst(s) + \gamma_3 * fwt(s) + feat(s) \quad (1)$$

$$exp_{car}(s) = \gamma_4 * dist(s) + ame\ (s) \quad (2)$$

where travel time for cars is composed of free-flow time *ft(s)*, additional congestion time *ct(s)*, ferry sailing time *fst(s)*, ferry waiting time *fwt(s)* and required early arrival time *feat(s)*. Travel costs for cars is composed of a flat fee per distance (covering fuel, oil and tires including taxes) and additional monetary expenses (e.g., ferry cost, road pricing, bridges). 2015 γ-factors can be found in the DNTM documentation (Rich, 2017).

Generalized travel costs are then computed by using an income-specific VTTS (Rich and Vandet, 2019), which is standard practice in the DNTM. Variations across trip purposes and modes was found to be small in previous Danish VTTS studies (Fosgerau *et al.,* 2007).

$$gencost_{car}(d) = time_{car}(s) + \frac{exp_{car}(s)}{VTTS} \quad (3)$$

Similarly, travel time for PT is composed of in-vehicle time *ivt(s)*, the numbers of change *noc(s)* multiplied by a transfer penalty, and penalized additional waiting and walking times *wwt(s).* Travel costs are based on 2015 single ticket fares (discounts for season tickets are applied later).

While travel time for carsharing and taxi stages are assumed to be similar to car stages (it is assumed that access time (carsharing), initial waiting time (taxi) and parking time (car) roughly cancel out), travel costs are based on the 2015 prices of DriveNow and Taxa DK. For bikesharing, travel times are included in the DTNM, and travel costs are based on the 2015 prices of Bycyklen. We assume that carsharing and bikesharing are only available in the center of Copenhagen and use an approximation of the current DriveNow zones.

4. Results

4.1 Investigating alternative modes

Our first research question concerns the alternatives to the private car: Which modes would have been chosen and how would travel expenses have changed in terms of times and costs?

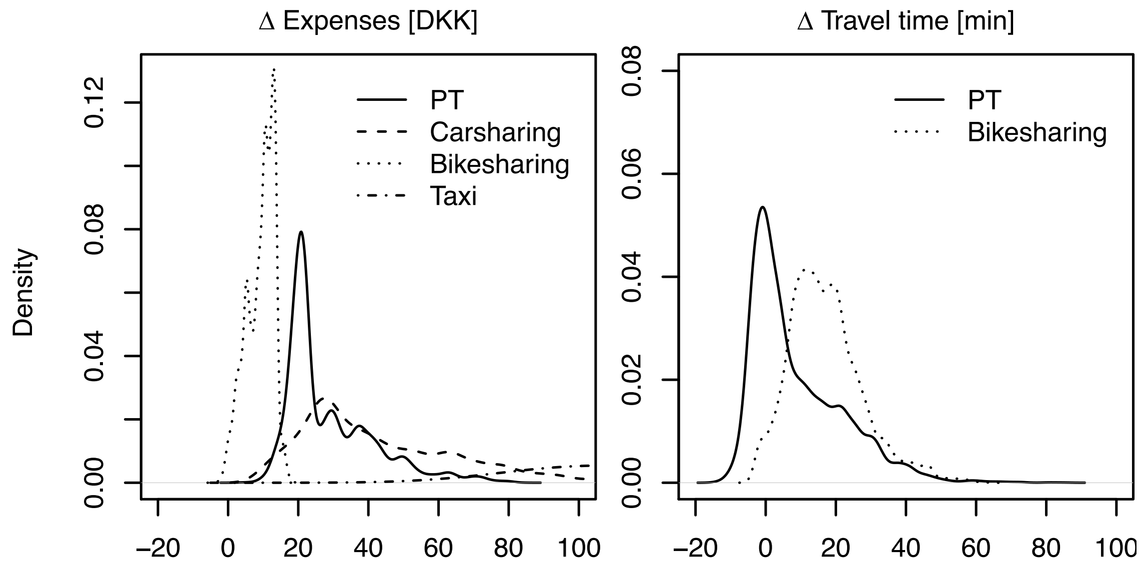
Table 2 shows the observed modal split and the modal split in the MaaS scenario, where all stages previously conducted with a car have been substituted with the best available alternative in terms of generalized costs. PT sees by far the greatest gain (+19.32 pp.), while bikesharing (+4.56 pp.) and carsharing (+1.66 pp.) account for the remaining stages. Interestingly, taxi trips, although included in existing MaaS packages, are always among the least preferable in terms of generalized costs (due to high fares), thus no car stages are substituted with the taxi here.

Table 2: Mode choice comparison

Mode	Observed	MaaS scenario	
PT	34.61 %	53.93 %	(+ 19.32 pp)
Car	25.54 %	0 %	(– 25.54 pp)
Carsharing	NA	1.66 %	(+ 1.66 pp)
Taxi	NA	0 %	(+ 0 pp)
Bikesharing	NA	4.56 %	(+ 4.56 pp)
Bike/Walk	39.85 %	39.85 %	

Figure 3 shows differences in terms of monetary expenses and travel time for all alternative modes. While alternative modes are more expensive than the private car for most stages, PT and bikesharing are sometimes quicker. Here, trade-offs between the main components of generalized costs become particularly evident. PT, *on average*, is only slightly more expensive and slower than the private car (+29 DKK, +9 min), which makes it a "popular" alternative (+19.32 pp.). Bikesharing is the least expensive alternative (+9 DKK), however considerably slower than the private car and PT (+17 min) and only available in downtown Copenhagen, thus making it second most "popular" (+ 4.56 pp.). Carsharing is more expensive than the former alternatives (+44 DKK) and taxi most (+217 DKK), while similar travel times to the private car are assumed in both cases.

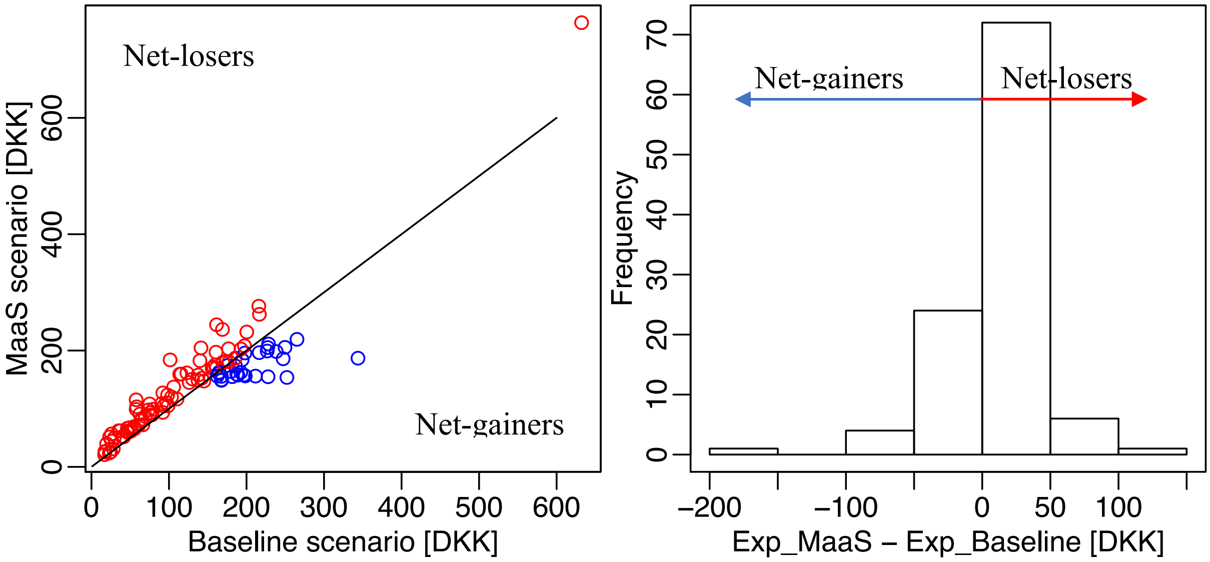
Figure 3: Stage-based comparison of alternative modes



While the *stage-based* comparison suggests that students' travel expenses and travel times would increase in a MaaS scenario, we are interested in exploiting our longitudinal data to explore how travel expenses and travel times would have changed for *individuals*.

Here, PT season tickets, available to students at a discounted rate of ~145 DKK per week for Hovedstaden region (corresponding to MOVIA zones 1-99), are applied. While PT trips might be more expensive in a stage-based comparison, they could add up to a sufficient (previously not reached) amount to save extra expenses by buying a season ticket. This, indeed, appears to be true. Figure 4 shows the weekly average spent per student in the baseline scenario compared to the MaaS scenario. While, on average, students would spend 6% more on mobility in the MaaS scenario, for some it is even cheaper ("net-gainers"), as season ticket viability increases. In the baseline scenario, a PT season ticket is economically sensible to purchase for 39 students, while this number increases to 53 students in the MaaS scenario.

Figure 4: Comparison of average weekly spent

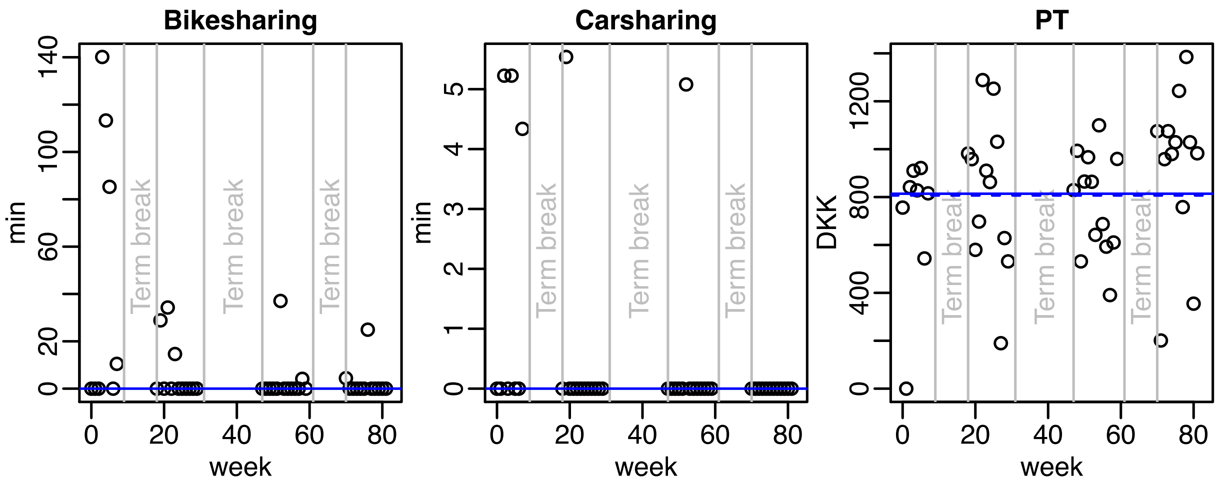


4.2 Viability of MaaS packages

Our second research question concerns MaaS packages: Which MaaS packages retrospectively cover mobility demand and how viable are recurring packages considering variability transport demand over time?

Figure 5 illustrates our approach: for each student, we aggregate weekly demand by mode in the MaaS scenario. For each mode, we then calculate the minimal and average weekly demand (solid horizontal blue lines). The minimal weekly demand is useful when considering the amount of car-/bikesharing minutes in a MaaS package, while the viability of a PT season ticket as part of a MaaS package depends on the average weekly amount spent.

Figure 5: Average weekly demand for an exemplary student

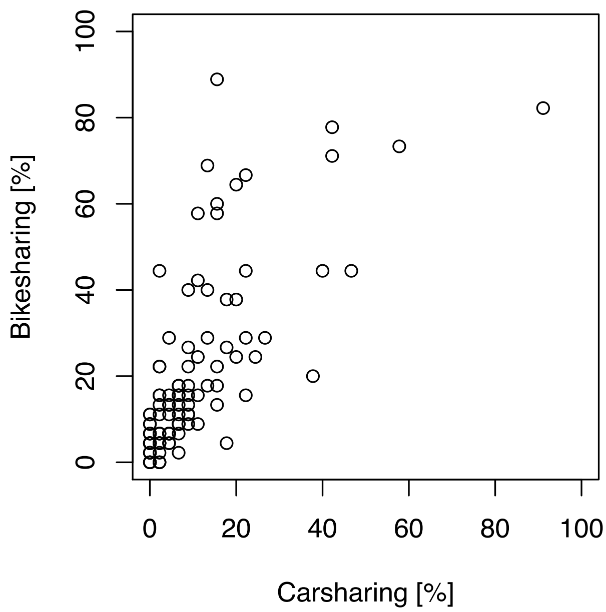


For the exemplary student, the minimum weekly demand of car-/bikesharing is 0/0 min, respectively. Thus, due to very occasional use, any recurring weekly number of minutes would not seem sensible to purchase. For PT, the average weekly consumption is 814 DKK. As PT season tickets are sold by regions, we also calculate the share within MOVIA zones 1-99 (region Hovedstaden), which includes both DTU and the Copenhagen municipality area. Average weekly PT consumption here is 806 DKK, which is substantially higher than the reduced student season ticket (~145 DKK per week). Thus, a weekly package containing a PT season ticket for region Hovedstaden would seem sensible to purchase.

We conduct similar analyses for all 108 students, finding that for 53 students a PT season ticket (region Hovedstaden) would seem sensible to purchase, while no student has a minimal weekly demand for car-/bikesharing above 0. This is due to great variability of interweekly demand for both modes: on average, students show demand for car-/bikesharing only in 10%/20% of all weeks, respectively. Figure 6 shows the average share of weeks with car-/bikesharing demand > 0 per student.

These results suggest that, in contrast to a PT season ticket, recurring weekly credit both for car- and bikesharing would not seem economically viable for students in our sample to purchase. Rather, a pay-as-you-option seems sensible to include in MaaS packages.

Figure 6: Share of weeks with car-/bikesharing demand > 0 per student



5. Discussion and conclusion

In the outset of this paper, we suggest that longitudinal multimodal *revealed-preference* data could further enrich our understanding of viable MaaS packages – currently only investigated with *stated-preference* data - as it offers insight into the unbiased amount and variability of intrapersonal transport demand and its substitutability with shared modes over time.

We use the mobility traces of 108 Danish students over two years to construct a MaaS scenario, where car stages are substituted by shared modes (PT, carsharing, bikesharing, taxi). We then compare the MaaS scenario to the originally observed mobility behavior both on a stage-, and on an aggregated level (weekly).

Our stage-based comparison shows significantly higher travel expenses in the MaaS scenario both in terms of travel time and costs. PT appears to be the most attractive alternative, substituting ~76% of all previously private car-based stages. Bikesharing is second most attractive (~18%) and carsharing is least attractive (~6%). Interestingly, albeit included in many real-life MaaS packages, the taxi does not substitute any car-based stages in our sample. While, on average, students would spend 6% more on mobility in the MaaS scenario, for some it would be even cheaper, as season ticket viability increases with more PT trips.

PT season ticket viability increases by 12 pp. from 37% to 49% of all students in the MaaS scenario. In contrast, recurring weekly credit both for car- and bikesharing would not seem sensible to purchase due to infrequent use. Rather, a pay-as-you-option seems more sensible to include in a MaaS package.

We aim to improve this work in several ways as part of future work. First, a Monte-Carlo-Simulation based on probabilities as a function of generalized costs should replace our current procedure to select an alternative mode. Second, weather information should be integrated as it is an important criterium for mode choice. Third, we plan to explain the viability of different MaaS packages with relevant socio-demographic data.

We further suggest conducting similar analyses with other longitudinal datasets. This paper presents first results, but conclusions to the wider population are limited due to the specificity of the sample.

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