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Effective determination of MaaS trip modes in activity-based demand modelling

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Abstract

The rising Mobility as a Service (MaaS) concept integrates many new transport options for the travelling public, such as the use of public bikes and car-sharing services. As such, it offers more mobility combinations within a single journey than ever. To effectively handle the choice for such a mobility combination inside an activity-based travel demand model, we propose a travel mode structure which integrates all these new travel modes next to the conventional ones. This mode structure explicitly models the access and egress modes for each trip, since the impact of the access and egress modes can be significant. We also propose a procedure that efficiently generates all possible combinations of modes for the trips within a tour, while ignoring all infeasible ones. In doing so, we present the tools for the effective determination of MaaS trip modes in the choice component of an activity-based travel demand model.

Keywords: Mobility as a Service; Activity based travel demand modelling; Multimodal modes

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1. Introduction

In recent years, the rising number of innovative mobility services (e.g. Uber and Mobike), the introduction of autonomous vehicles and the growing opportunities offered by smartphone technology has led to an increasing interest in the Mobility as a Service (MaaS) concept. While this mobility concept has been defined in multiple ways in the literature (cf. [1, 2]), MaaS can be thought of as a novel service that allows users to get from their origin to their destination by combining several available mobility options (such as public transport, shared bike, etc.) and presents those in a single online interface, while the user is not required to e.g. own a car or bike her/himself.

Due to the popularity of MaaS and its enormous impact that it is expected to have on the daily travel patterns of travellers in the future, it is crucial to gain an in-depth understanding of this impact through traffic modelling. For instance, the influence of MaaS on the travel behaviour of individuals and/or complete households needs to be assessed. To do so, one requires a travel demand model that can capture all travelling activities of each individual traveller and handle the sheer number of combinations of travel modes that MaaS will offer. Due to their high level of detail, Activity-Based travel demand Models (ABMs) are most suitable for this purpose.

Only few studies have been aimed at using ABMs for the assessment of the MaaS concept. For example, [3] reports ongoing process on an ABM-framework that studies the effect of MaaS on the individual car ownership of travellers. Likewise, the studies of [4, 5] investigate the impact of MaaS on the transport system by focusing on a single choice module within an ABM. Nevertheless, several hurdles still need to be

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overcome to apply ABMs effectively (cf. [2, 6]). For example, the many available travel modes brought by MaaS lead to a much higher uncertainty in the travellers' decision making compared to traditional traffic models. Next to this, while travel demand models often assume the traffic behaviour of different households to be completely independent, this would not be the case anymore with the introduction of MaaS because of its facilitation of e.g. ride-sharing between households [7]. In fact, to the best of the authors' knowledge, no study in the literature has concentrated on the question how to include all novel travel modes in a flexible mode structure that MaaS facilitates, such as ride-sharing and bike-sharing, in an ABM.

In this paper, we specifically address this question. More particularly, we propose a travel mode structure that allows for the effective implementation of MaaS modes in an ABM. Unique for this structure is that it not only includes unimodal modes such as 'car' and 'public transport'. It also includes multimodal modes, which, apart from the main mode, also contain information on the access and egress mode used to undertake a trip. In many studies so far, the travel modes for access and egress are assumed fixed (e.g. travellers always walk to/from their own car or the bus station) [8, 9], so that a unimodal mode suffices. However, MaaS facilitates the combination of many possible new travel modes within a single trip, so that this assumption is not valid anymore [9] and multi-modal modes are required. For example, as alluded to in [10], travellers may now opt to use a point-to-point service such as Uber (access mode) to reach the bus station, while a shared bike takes the traveller to the final destination (egress mode). Another advantage of this structure is that it is flexible: additional unimodal or multimodal modes can be added without any additional effort. Therefore, the structure can keep up with the increasing number of mode alternatives MaaS will offer.

Other than the travel mode structure, we also introduce a procedure that explores all the chain mode sets (sets containing the modes of all trips making up a tour), and discards all infeasible ones. More particularly, inspired by [11], we propose the use of four different consistency checks between the modes within a chain mode set to filter out the infeasible chain mode sets. These checks reduce the number of alternatives in the choice set with several hundreds or even millions depending on the number of trips in a tour and the number of modes considered. Because of this reduction, the introduction of new travel modes will not lead to an explosive increase of choices. Yet, if the introduction of new modes still implies a significant computational burden in the future, GPU parallelisation [12] can be used to tackle this problem.

The remainder of this paper is organised as follows. Section 2 explains our travel mode structure and the above-mentioned procedure in detail, after which Section 3 provides numerical illustrations. Finally, Section 4 concludes the paper and describes future work.

2. Method

In this section, we explain our travel mode structure and consistency check procedure in detail. In particular, Section 2.1 discusses how the travel mode structure can integrate all the various MaaS modes. Then, Section 2.2 categorises the traveller's trips, after which Section 2.3 explains how our procedure discards infeasible travel mode combinations.

2.1. MaaS modes

In Figure 1, we display an example of a set of conventional travel modes which could be considered for modelling in a non-MaaS setting. There are unimodal modes, such as 'car', which means the traveller uses only the car to get from origin to destination. It also lists multimodal modes that can be encountered in a non-MaaS setting, such as 'Car-PT-Walk'(Park & Ride), which means that the traveller drives as an access mode to the bus stop or train station (PT=public transport). After the bus or train ride, the traveller walks to the destination of the trip. In this figure, all mobility options together lead to 12 mode choices (both unimodal modes and multimodal modes).

MaaS, however, will introduce more travel modes. For example, MaaS creates a platform for car-sharing, i.e. short-term car rental. MaaS will also provide the opportunity to carpool, so that travellers will also have the opportunity to ride-share on a wide scale. We also mention bike-sharing, increasingly popular in cities, where subscribed travellers can make ad-hoc use of public bicycles to go from one bike station to the other.

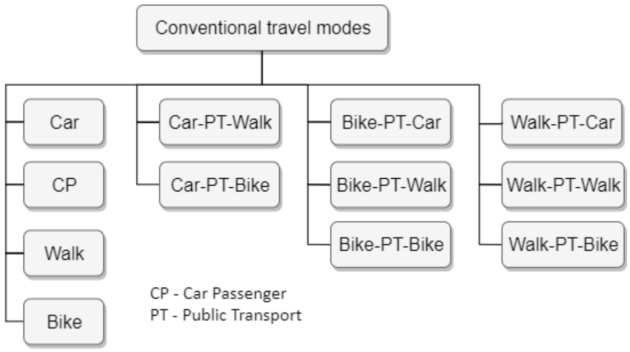


Figure 1: Possible mode choices in a non-MaaS setting (12 choices).

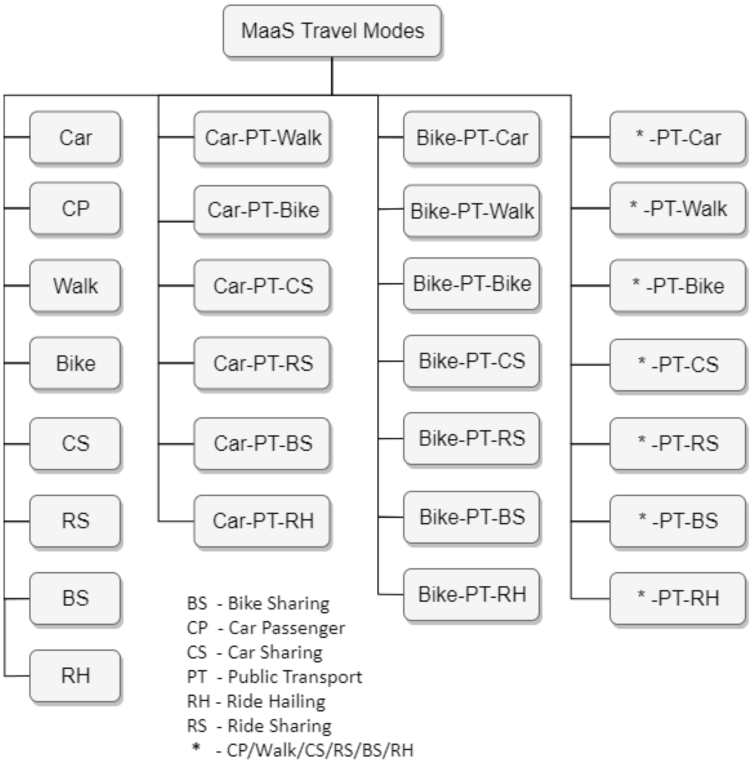


Figure 2: Possible mode choices in a MaaS setting (63 choices).

As Figure 2 shows, adding such mobility options could lead to a total of 63 mode choices, rather than just the 12 of Figure 1. This supports the claim that MaaS integrates many more modes, especially considering the fact that MaaS may lead to more novel mobility options than the ones we mentioned above. Figure 2 also show why this structure is flexible: new unimodal (such as 'e-scooter') or multimodal modes can be easily added. In an ABM, whether or not the traveller uses MaaS could be one of the traveller's long-term decisions. This serves as input for the mode-selection step of an ABM: in case the traveller has a MaaS subscription, Figure 2 lists all the modes, otherwise only the choices in Figure 1 are valid.

2.2. Classification of trips

Now that we have discussed the modes that can be used within a trip, we classify the trips themselves. It is important to note that trips make up a daily tour, as we will explain in more detail in Section 2.3. We distinguish between the following classes of trips.

- A trip is called an *outbound trip* if its origin coincides with a destination of another trip which takes place later in the tour. The origin of an outbound trip is an *anchor point* [11, 13]. A tour always starts with an outbound trip.
- An *inbound trip* is a trip of which the destination is an anchor point. A tour always ends with an inbound trip.
- All trips which are neither outbound or inbound trips are *intermediate trips*. These trips do not originate or end at an anchor point.

This classification allows us to check whether a certain mode can be used for a certain trip within the tour. For example, if the traveller does not take her/his own car for an outbound trip, then it is not possible to use the car for the inbound trip either. Likewise, if a tour for example consists of the outbound trip 'home to work' and the inbound trip 'work to home', the multimodal mode 'walk-PT-car' will be unfeasible for the outbound trip, since the traveller's car will still be at home rather than at the bus/train station. This multimodal mode would however be feasible for the inbound trip if the traveller chose 'car-PT-walk' as the mode for the outbound trip.

2.3. Generation of all feasible chain mode sets

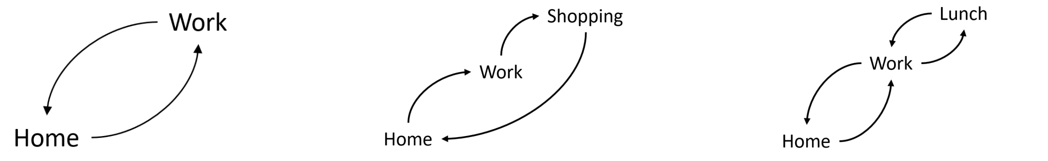
Now that the trips of a tour are categorised, we introduce our procedure that generates all the feasible chain mode sets. Recall that a feasible chain mode set of a tour amounts to a feasible combination of modes chosen for each trip of a tour. This procedure is suitable for different kinds of tours, for example simple tours such as Figure 3a, tours which have multiple destinations in sequence such as Figure 3b or tours which have sub-tours in them such as Figure 3c.

To generate the feasible chain mode sets of a tour, the procedure recursively considers each of its trips, and iteratively checks whether each of the modes shown in Figure 1 or Figure 2 is consistent both with the trip itself and the previous trips. If a candidate mode for some trip does not satisfy the consistency check, chain mode sets containing that candidate mode for that trip will be discarded. In the end, all possible chain mode sets which have not been discarded will form all feasible chain mode sets.

The consistency check contains the following parts.

- *Mode ownership/subscription*: for candidate modes such as 'car', 'bike' and 'bike-PT-walk', the procedure checks whether the traveller owns the required car or bike or has the right subscription to use a shared mode (which is a long-term choice made in an earlier stage of the ABM-model). If this is not the case, the candidate mode is discarded.
- *Mode availability*: the procedure checks whether the required mode is available at the origin of the trip. For example, if the traveller's owned bike is not at the origin of the trip for instance because walking is used in the previous trip, 'bike-PT-walk' must be discarded.
- *Final location*: The procedure checks whether the traveller's own vehicles (car/bike) are back at the anchor point at the end of a (sub)tour.
- *Mode allowance/presence*: check if the mode is allowed at the origin or destination of the trip. For instance, congested zones in cities may not allow cars. Also, some shared services might not be available for certain trips.

Note that for the multimodal modes, these checks mainly concern the access and egress modes. We explain this using the tour of Figure 3b, which consists of three trips: from home to work, from work to the shopping mall, and back home again. According to the trip classification of Section 2.2, the 'shopping mall-home' trip is inbound. When considering the multimodal mode 'bike-PT-walk' as a candidate mode (i.e., the bike forms the access mode, while the egress mode is simply walking), the mode ownership check first verifies whether the agent has a bike. If not, the complete multimodal mode is discarded. Otherwise, the mode availability subsequently checks whether the traveller's bike is available as a result of the mode choice for the trip 'work-shopping mall'. If not, this check fails. If this would not fail, however, the final location check would still fail, as at the end of the tour, the traveller's bike will not have returned home. Since the final location check already disqualifies this particular multimodal mode, the mode allowance check is not performed any more.



(a) A tour with two trips (b) A tour with three trips (c) A tour with a sub-tour(4 trips)

Figure 3: Tours with different trips

By recursive construction of the chain mode sets and repetitively applying these consistency checks, all feasible chain mode sets are generated, while all infeasible ones are discarded. In the choice model for the mode selection part of the ABM, the utility of each chain mode set can be computed by simply summing the utilities of all mode choices for each of the trips within the tour. The strength of the travel mode structure and this checking procedure is that, provided that the mode choices are sufficiently different in nature, no nested choice model will have to be used. More particularly, a simple multinomial logit model now suffices for simulation purposes. Moreover, no utilities will have to be calculated for infeasible chain mode sets, increasing numerical efficiency. Given the still potential large number of feasible chain mode sets, the computation of utilities and the subsequent can be made even more efficient by using parallelisation techniques [12].

3. Numerical illustration based on the Rotterdam-The Hague area

In this section, we provide numerical evidence why discarding infeasible chain mode sets is important. We do this based on a recent study called V-MRDH (Verkeersmodel Metropoolregio Rotterdam Den Haag) [14], that models the traffic network of the Rotterdam-The Hague area in the Netherlands. This study considers the following eight travel modes: 'car', 'car passenger', 'bike', 'walk-PT-walk' (wptw), 'walk-PT-bike' (wptb), 'bike-PT-walk' (bptw), 'bike-PT-bike' (bptb) and 'walk'. We also consider the utility functions as derived in [15], which are based on this traffic network. These functions incorporate a total of 13 attributes including personal and household properties. In this network, we consider a home-work-shop-home tour of a traveller as shown in Figure 3b. The distances of the home-work and shop-home trips are more than 25 kilometres, while the work-shop distance is about 7.5 kilometres, which can be traversed by bike. The traveller we consider owns a bike, but not a car.

Table 1: Mode probabilities of each trip in the home-work-shop-home tour.

Trip	P_{car}	P_{cp}	P_{bike}	P_{wptw}	P_{wptb}	P_{bptw}	P_{bptb}	P_{walk}
home-work	0.00%	14.61%	12.00%	71.95%	0.06%	1.15%	0.24%	0,00%
work-shop	0.00%	4.36%	68.88%	24.35%	0.02%	0.29%	0.05%	2.04%
shop-home	0.00%	17.81%	8.77%	71.49%	0.08%	1.51%	0.34%	0.00%

The mode choice probabilities for these trips corresponding with the utility functions of [15] are shown in Table 1. In a trip-based approach, it is highly likely that 'wptw', 'bike' and 'wptw' would be chosen as modes for each of the respective trips. The probability of having this chain set would be 35.5%. However, this mode combinations is not a valid combination: the traveller cannot use the bike during the second trip since it was not used during the first trip either.

Under our approach, with 51% probability, 'wptw' would be chosen for each trip, which is feasible. Particularly, our procedure only flags 37 chain mode sets out of all 512 possible combinations as feasible and discards the rest. This reduction would be even more pronounced when more mode alternatives would be considered. If one would for example consider all 63 mode choices of Figure 2, only 48825 out of $63^3 = 250047$ chain mode sets would be deemed feasible.

4. Conclusions and future work

In this paper, we proposed a MaaS-oriented travel mode structure for use within a travel mode choice component in an ABM. We made effective use of unimodal modes and multimodal modes so that the trip choice model remains non-nested, as long as mode options differ significantly from one another. When similar modes such as shared bikes and shared e-scooters are regarded, a nested choice model should be considered so that the joint probabilities of similar modes are not overestimated. We also described a consistency check procedure that prevents the evaluation of infeasible mode combinations, improving numerical efficiency.

Several other hurdles still need to be overcome to model MaaS inside an ABM. One of the remaining challenges is to acquire information such as the typical travel time of models, cost, etcetera. Only with this information can utility functions be constructed and reliable utilities be computed. When these hurdles are overcome, however, the presumably significant impact of MaaS on the traffic system and the population of travellers can be assessed.

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