

Modelling mobility tool ownership using a global indicator for accessibility

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Abstract

Mobility tool ownership, meaning the availability of resources that enable a person to use a particular transport system such as a car or a season ticket for public transport, is one of the most important factors influencing individual travel behavior. It is obvious that transport supply has an impact on this variable. For this reason, it should be determined integrally on a model-driven basis in travel demand models. The paper suggests a global indicator describing accessibility to be applied in this matter. The indicator is calculated based on the results of travel demand modelling, namely a combination of trip generation, trip destination and mode choice. It is implemented in a non-spatial travel demand model at municipal level. An example illustrates the effect and importance of considering mobility tool choice in strategic transport planning.

Keywords

mobility tool ownership, mobility resources ownership, accessibility, travel demand modeling

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1 Introduction

Mobility tool ownership (MTO), meaning the availability of a car, a season ticket for public transport, a registration with a carsharing provider or all other resources that enable a person to use a particular transport system, is one of the most important factors influencing individual travel behavior. In the recent past, two additional reasons have emerged for determining MTO-choice integrally in strategic transport demand models. Firstly, in order to counter climate change, it might be necessary to take measures that considerably change transport behavior. It seems obvious that corresponding measures such as increasing the fuel price to a multiple of its current state or fare-free public transport will also have impact on MTO-choice. Secondly, the market introduction of autonomous vehicles in combination with the offer of new mobility services is expected to bring about a disruption in both travel behavior and MTO [1–3]. Nevertheless, in regional transport demand models it is still common to specify MTO as an exogenous model input variable.

This paper focuses on an approach of modelling MTO choice integrated in a strategic transport demand model on municipal level. The demand model reproduces the decision-making processes of trip generation, trip distribution and mode choice. The MTO choice model uses the output of the transport demand model interpreting it as an indicator of accessibility. The overall model framework, the model input data and calibration process are described in detail by Schmaus [4].

2 Relevant literature

There is a wide range of approaches to model vehicle ownership and vehicle type choice. One group of models can be categorized as “static disaggregate car ownership models” [5]. These models have in common that they reproduce a static state and use the foundation of discrete choice theory [5]. The following will focus on these type of models. Regarding the model theory, reference is made to Ben-Akiva and Lerman [6]. Already in earlier models of this category, accessibility measures were included as explanatory variables in the utility functions [5]. As an example, the Sydney Strategic Transport Model uses the logsums of the results of mode and destination choice for home-work trips [7]. The specification suggests that it was a Hansen-based measure of accessibility A as it is defined as the logsum of the opportunities O_d (e.g. number of jobs, population) at a destination d multiplied by a function of generalized travel costs reaching this destination c_d [8]. The higher the travel cost the less attractive the opportunities, so one option among others to transform the travel costs is using an exponential function with a negative parameter β (equation (1)).

$$A = \log \sum_{d \in D} O_d \cdot \exp(\beta \cdot c_d) \quad (1)$$

In opposite to vehicle ownership modeling, MTO modeling just appeared within the last years in literature, e.g. [9–12]. MTO models have in common, that they usually focus on personal level rather than on household level as car ownership models usually do. Different model specifications are applied. Weis et al. [9] estimated a mixed-logit model including variables such as the age of the current vehicle and the current holdings of season ticket. In order to counter the possibility of owning several mobility tools at the same time, Kieser et al. [10] chose

the approach of modelling the decision between ownership and non-possession for each mobility tool separately (binominal logit models). Car-availability was taken into account as a negative constant in the decision on season ticket ownership. Travel times to the nearest urban center by car and public transport held as variables indicating accessibility. Plevka et al. [11] included bicycle ownership as further option in the decision making process. They applied a nested logit approach and an indicator of accessibility based on the concept of a „Perceived Activity Set“ (PAS) developed by Le Vine et al. [13]. This concept allows taking different types of opportunities into account within a single indicator. The indicator was computed on the results of a mode choice model. Loder and Axhausen [12] used a certain type of multivariate probit model and several indicators describing transport supply and accessibility. The accessibility indicators are based on Hansens definition [8] for car or public transport and the two opportunities employment and population.

3 Modeling approach

3.1 Model framework

The model framework was developed to enable a strategic assessment of measures under changing surrounding conditions with regard to greenhouse gas emissions from transport at the municipal level. It reproduces the everyday travel behavior of the inhabitants of a municipality. The framework involves a population and household model, a vehicle fleet model, a travel demand model, the MTO model and several further submodels for the final calculation of greenhouse gas emissions. For the illustration of the functionality of the MTO model, the following levels of disaggregation are of importance:

- Seven person categories c
- Ten activities, each connected to a certain opportunity (e.g. work and number of jobs) a
- Six combinations of mobility tool ownership t
- Five modes m
- 100 destination zones d

The vehicle fleet model deals with different vehicle types, nevertheless the travel demand model and MOT choice model assumes only average cost values. The travel demand model reproduces the first three steps of the conventional four-step algorithm: Trip generation, trip distribution and mode choice. It is of a non-spatial approach. Destination choice is modelled considering rings of a width of one kilometer around the origin as destination zones. Due to that, modelling the fourth step of the four-step algorithm (traffic assignment) is not possible and travel distances are estimated by using detour factors. The MTO model determines the shares of the six possible combinations of mobility tool ownership, car only ($t = \text{car}$), public transport season ticket only ($t = \text{st}$), both ($t = \text{both}$) or neither ($t = \text{none}$) for driving licence holders as well as public transport season ticket ($t = \text{noDL, st}$) or no public transport season ticket ($t = \text{noDL, n}$) for persons without driving licence for each person category.

3.2 Travel demand model and accessibility computation

The trip generation model provides the number of trips per year for each person-category distinguished by ten activities $D_{c,a}$. The combined distribution and mode choice model is disaggregated in terms of activities and MTO combinations, meaning that for each combination (in total 60 combinations) different sets of model parameters are used. This model approach carries the simplifying assumption that travel behaviour differs due to the available mobility tools, but does not vary between person categories within a MTO combination. The nested logit model determines the probabilities of choosing a destination zone to be reached with one of the transport modes modelled (walk, bicycle, car as driver, car as passenger, public transport) $P_{m,d|t,a}$ according to equation (2) and (3). For simplification, in equation (3) the scaling parameter within the nests is not shown as it is normalized to 1 for the reasons of model estimation [6].

$$P_{m,d|t,a} = P_{m|d,t,a} \cdot P_{d|t,a} \quad (2)$$

$$P_{m,d|t,a} = \frac{\exp(v_{m,d,t,a})}{\sum_{m \in M} \exp(v_{m,d,t,a})} \cdot \frac{\exp\left(\left(v_{d,a} + \ln \sum_{m \in M} \exp(v_{m,d,t,a})\right) \cdot \mu_a^d\right)}{\sum_{d \in D} \exp\left(\left(v_{d,a} + \ln \sum_{m \in M} \exp(v_{m,d,t,a})\right) \cdot \mu_a^d\right)} \quad (3)$$

The probability $P_{m,d|t,a}$ is a combination of the probabilities choosing a certain destination $P_{d|t,a}$ and reaching this destination by using a certain mode $P_{m|d,t,a}$. $v_{m,d,t,a}$ is the systematic component of the utility of a mode, depending also on destination, mobility tool ownership and trip purpose. It is a linear combination of different mode-specific cost terms. $v_{d,a}$ is the systematic component of the utility of a destination depending additionally on the trip purpose. Number of opportunities and the direct distance are the explanatory variables used within this utility term. The reference for detailed information on all model parameters and the calibration process is Schmaus [4].

The approach of the developed accessibility term follows the idea, that this decision process and its input data involves all information describing the perceived accessibility of an individual of each person category. To extract this information, firstly the model is extended in thought by one level (equation (4)).

$$P_{m,d,t|a} = P_{m|d,t,a} \cdot P_{d|t,a} \cdot P_{t|a} \quad (4)$$

The marginal choice probability of choosing a MTO combination t includes the logarithm of the denominator of the lower nests (comparable to the marginal probability of destination choice using the sum from the mode choice probability in equation (3)). Inserting the utility function of $v_{d,a}$, this term describes an accessibility according to the definition of Hansen [8]

(equation (5)). In this equation, $O_{d,a}$ are the opportunities for each activity in each destination zone, $\beta_a^D \cdot D_D$ are the weighted direct distances.

$$A_{t,a} = \ln \sum_{d \in D} O_{d,a} \cdot \exp \left(\beta_a^D \cdot D_d + \left(\ln \sum_{m \in M} \exp(v_{m,d,t,a}) \right) \cdot \mu_a^d \right) \quad (5)$$

As the MTO models disaggregation level are person categories, this accessibility term is weighted by the number of trips per activity computed in the trip generation model (equation 6).

$$A_{t,c} = \frac{\sum_{a \in A} D_{c,a} \cdot A_{t,a}}{\sum_{a \in A} D_{c,a}} \quad (6)$$

The measure $A_{t,c}$ thus describes the accessibility a person perceives under a certain MTO condition taking into account all trips a person requires to make. It is important to point out that this way summing up the accessibilities carries the risk of inconsistency of the model for two reasons. Firstly, it implies the assumption that each trip is of equal importance for the MTO decision. It can be argued that frequent trips on the same origin-destination relation (e.g. work trips) effect MTO choice more. For that reason, Le Vine et al. [13] include an activity-dependent weighting factor in their definition of accessibility. However, estimating a corresponding factor was not possible in this work due to the use of aggregated behavioral data. Secondly, the parameters of the mode and destination choice model were estimated for each $a-t$ -combination separately. Nevertheless, the results of $A_{t,c}$ were reasonable in terms of differences between MTO combination for all person categories in different scenarios tested.

3.3 Mobility tool ownership model

The MTO model is of hierarchical structure (Figure 1). On top level, the share of persons holding a driving licence is determined based on a model-exogenous variable. A binary multinomial logit model computes whether a person without driving licence owns a season ticket or not. Decisions on car and season ticket ownership of persons holding a driving licence are modelled using a nested logit approach. Interestingly the model parameter estimation indicated a structure determining season ticket ownership on the upper level and car ownership within the models nests.

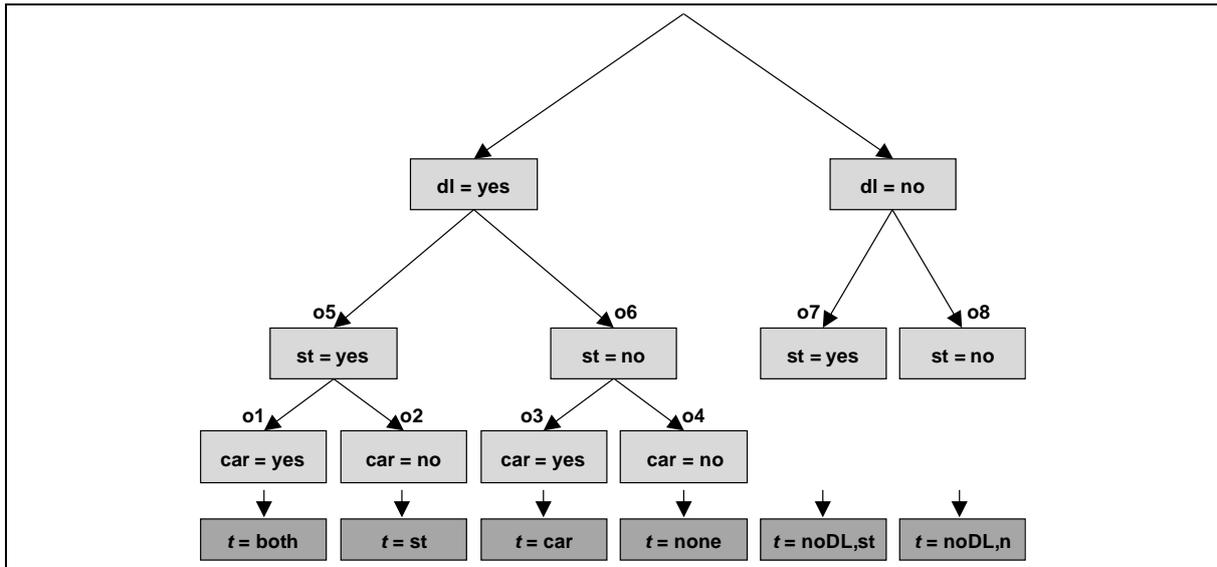


Figure 1 Hierarchic structure of MTO model

Besides the accessibility terms, two other independent variables are applied to describe the utility of each MTO combination: Firstly, the yearly costs of a season ticket depending on the person category and the price of an average personal car, and secondly, a term depending on the household composition referring to the number of cars in the household. The parameters of the model were calibrated on aggregated data for different areas classified by degree of urbanisation and using service elasticities and price elasticities from literature. For the application to a specific municipality, the MTO model has to be recalibrated by estimating its alternative specific constants using data on car density and level of season ticket ownership.

4 Application: Climate Protection Scenario for the Municipality of Stuttgart

To show the effects of integrated MTO modelling, the model was applied to the municipality of Stuttgart, the center of a metropolitan region in the south of Germany with about 630.000 inhabitants. It was calibrated on data of the year 2010. On this basis, two future scenarios were developed and compared. In the Base Scenario, population, household composition, income and license holdings slightly change compared to the calibration case. Furthermore, the composition of the vehicle fleet and the underlying vehicle technology are changing significantly. Especially the high share of electric vehicles causes a considerable reduction of vehicle costs. These conditions remain unchanged in the second scenario developed with the objective of achieving a reduction of greenhouse gas emissions by 95 % (Climate Protection Scenario). The implementation of several measures, such as pricing measures (costs of electricity, fuel, car acquisition and public transport use), the number of pedelecs, extension of the bicycle path network and an investment in the public transport system, was assumed for this purpose. Table 1 shows an extract of values changed between the scenarios to operationalize these measures.

Table 1 Variables describing transport supply and the assumed changes between the modelled scenarios (extract)

	Base Scenario	Climate Protection Scenario
Annual fixed and operating costs of a car	580 €/a	unchanged
Acquisition costs of a car	1,274 €/a	1,911 €/a
Average of distance-depending car travel costs	0.11 €/km	0.25 €/km
Price for public transport ride (average distance)	2.40 €	1.20 €
Bicycle travel speed (average)	12.5 km/h	20.8 km/h
Access and egress time for public transport (sum, average)	9.3 min	7.6 min
Headway of long-distance/short-distance public transport system	10 min / 60 min	7.5 min / 30 min

To illustrate the effects of different choice mechanisms implemented in the model, four model runs are compared: Base Scenario (B-Scenario), Climate Protection Scenario without MTO modelling (CP1-Scenario), Climate Protection Scenario only considering effects of acquisition costs for car and season ticket on MTO (CP2-Scenario) and Climate Protection Scenario also considering the effects of accessibility (CP3-Scenario). Figure 2 shows the results. In scenario CP1 MTO obviously remains unchanged. Nevertheless, the measures show considerable effect on mobility behavior and the vehicle kilometers traveled increase by 45 %. The models reaction on higher costs for car acquisition are relatively small. However, taking into account the effects of the measures on MTO in terms of accessibility leads to a remarkable change in vehicle ownership. Overall, due to effects on MTO, the reduction of vehicles kilometers traveled increases by about 40 % and the reduction of greenhouse gas emissions by about 20 %.

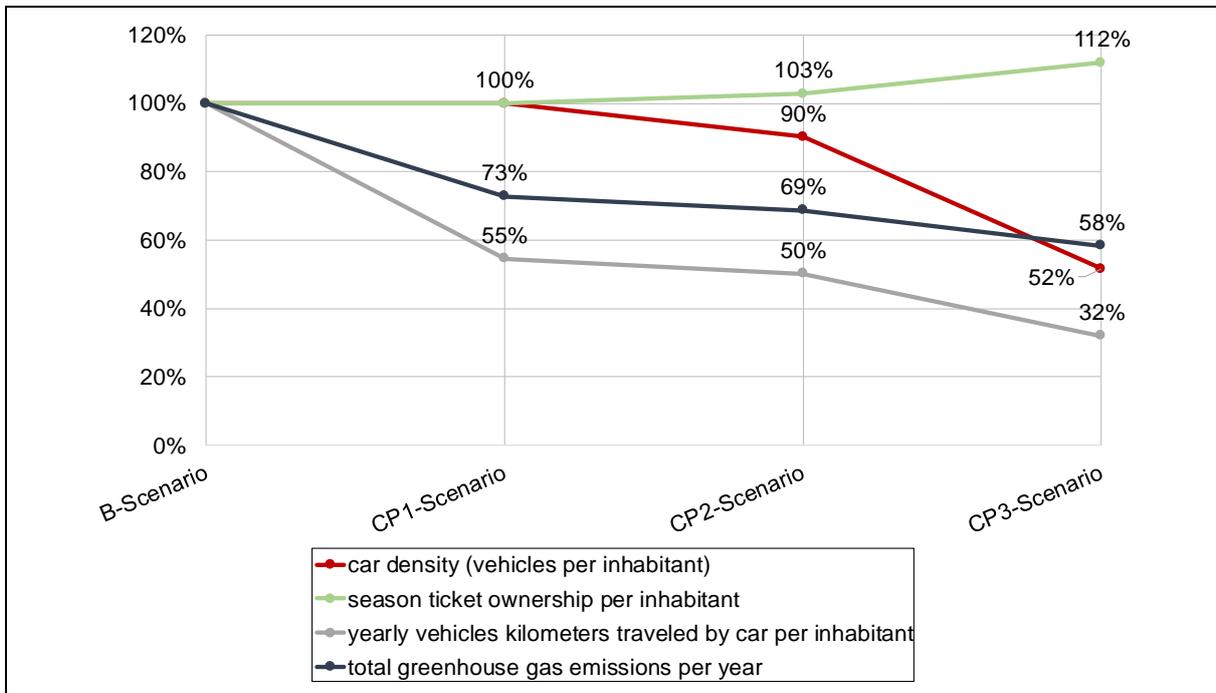


Figure 2 Results of scenario runs with and without considering effects of MTO

5 Conclusion and outlook

The scenarios show the importance of an integrated MTO modelling for strategic transport planning. Not taking into account the effects of accessibility on MTO choice means neglecting important possibilities of the modelled population to react to changes in transport supply. Due to the suggested indicator of accessibility, the illustrated approach allows the consideration of all modes of transport taking into account all trips of a person.

Nevertheless, a major simplification embodied in the model is to consider car ownership as a yes-or-no-decision that applies to an average car with average costs. This neglects the possibility of responding to changes in vehicle costs by adapting vehicle type choice. Although this makes the model specification and calibration considerably more difficult, further development will be focused on overcoming this shortcoming. Furthermore, it is intended to integrate the MTO model into a regular spatial transport demand model. Here, the challenge is to keep the computation time within a manageable range, since in contrast to the non-spatial model applied so far, load-induced feedback effects will then come into play.

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