mobiTopp – A Modular Agent-based Travel Demand Modelling Framework

Nicolai Mallig*, Martin Kagerbauer, Peter Vortisch

Institute for Transport Studies, Karlsruhe Institute of Technology, Kaiserstraße 12, 76131 Karlsruhe, Germany

Abstract

mobiTopp is an agent-based travel demand modelling framework designed in a modular fashion, so that exchange of individual modules is easy. This offers the possibility to start with quite simple models and implement the system in practice while at the same time providing the opportunity to develop more sophisticated models for research that can eventually be transferred into practice. Also, practical experience with the system can drive the need for further research. So the system helps bridging the gap between research and practice.

The paper presents a detailed overview of mobiTopp’s structure and its modules. The practical applicability for large-scale simulations is demonstrated by an example of a study involving about 2.5 million agents.

Keywords: microscopic travel demand model, agent-based simulation, modelling framework, mobiTopp

1. Introduction

mobiTopp is an agent-based travel demand model system that is based on the principle of multi-agent-simulation. This means every person of the planning area is represented in the computer as a virtual person, a so-called agent. Each agent is modelled in the context of his household. In addition each agent receives a complete activity schedule for a whole week consisting of a sequence of activities with the attributes: day of the week, purpose (activity type), duration and planned starting time of the activity. Based on this schedule the agents carry out their activities during the course of the week. For each activity they perform a destination choice and a mode choice. Afterwards they make the trip to the (new) location and carry out the activity. The simulations run chronologically and simultaneously for all agents. The simulations make essential use of household travel surveys such as the German Mobility Panel [1]. Ideally a comprehensive travel survey is carried out in the study area. Otherwise the data of national travel surveys can be used as fall-back or to complement smaller surveys [2].
The idea of agent-based travel demand modelling has more than 30 years of tradition in transportation research [3], although the term agent-based was not used at that time. The early agent-based travel demand models typically only covered the first 3 stages of the classical four-step model. One of the first agent-based models covering the complete range of the four-step model was TRANSIMS [4], however the focus was on the microscopic traffic flow simulation heavily used to generate optimal plans for the individual agents through an iterative process. MATSim [5] started as a reimplementation of TRANSIMS, focussing initially on motorized traffic and it is probably nowadays the most widespread agent-based model. The development of mobiTopp [6] started in 2000, originally with the idea of short-term traffic forecasts and real-time use in telematic applications. However its use has shifted afterwards to transport planning for large-scale scenarios, currently only covering the first 3 stages of the four-step model. A different approach is adopted by ALBATROSS [7] focusing on synthetic activity schedule generation in a hierarchical manner and using decision-trees instead of models based on utility theory for the diverse decisions. ALBATROSS is complemented by the Aurora/FEATHERS models [8] that emphasise short-term dynamics and within-day rescheduling.

This paper is structured as follows. Section 2 gives an overview of the mobiTopp system from the perspectives of modular structure and program flow. Section 3 presents mobiTopp’s modules in more detail and in their contexts within the mobiTopp system. Section 4 gives a short presentation of a project where mobiTopp has been successfully applied and Section 5 discusses the experiences gained by the application of mobiTopp and points out some directions for further development.

2. The mobiTopp system

2.1. Structure

The mobiTopp travel demand modelling framework is modularized in order to offer the possibility to start with relatively simple modules and to replace them later with more sophisticated ones as necessary. This makes a pragmatic approach for practical application possible, while at the same time challenging research with difficulties identified during application. The use of empirical data from travel surveys in the modules helps to keep their structure simple while still modelling complex behaviour. Figure 1 shows mobiTopp’s overall structure. It consists of the two main modules setup and simulation, each one making use of several submodules. The setup module contains the submodules population synthesis, activity schedule generation, fixed destination allocation, allocation of car ownership and commuter ticket ownership. The simulation module contains the submodules destination choice and mode choice.

2.2. Program Flow

The simulation consists of two phases: the setup phase modelling long-term decisions and the simulation phase modelling travel behaviour. The setup phase encompasses the population synthesis, the allocation of activity schedules, the allocation of fixed destinations for work place or school place and the allocation of car ownership and commuter ticket ownership. In the simulation phase the travel behaviour of all agents is modelled chronologically in time steps of 1 minute over the whole analysis period. The simulation process is schematically shown in Figure 2. For every time step it is checked which agents just have finished an activity or a trip. For each agent having finished an activity the next trip is prepared: the agent performs a destination choice for the next activity followed by a mode choice. Subsequently the agent makes the trip taking a car out of the household’s car pool if applicable. An agent having finished a trip immediately starts performing his activity, so the starting time of the activity typically differs somewhat from the planned starting time. However an explicit rescheduling is not done. If an agent has returned home with a car, the car is returned to the household’s car pool. After handling all agents finishing an activity or a trip, the time is incremented and the process is repeated for the next simulation time step.

The result of the simulation is a list of trips, containing every trip and activity for each agent in the planning area over the whole analysis period. The list contains the relevant information (agent id, source zone, destination zone, mode, day of the week, time of the day, duration, purpose) for all the trips and associated activities performed. This output offers flexible opportunities for analysis and can be aggregated to the level needed, for example hourly O-D matrices differentiated by mode.
3. The modules

3.1. Setup module

The setup module consists of the submodules for population synthesis, the activity schedule generation, the allocation of fixed destinations for work and education and the modelling of car ownership and commuter ticket ownership. The population synthesis module is applied for each traffic analysis zone. The other modules are then applied for each agent of the resulting population.

3.1.1. Population synthesis

Currently only one population synthesis module exists. It uses a two-stage process similar as described in [9] with a reweighting of the households in the first stage and a (weighted) random sampling of complete households from the travel survey data in the second stage. Complete household means here that all attributes of the household and all persons belonging to the household with their attributes are taken and form a virtual household in the synthesized population.

Main input for the population synthesis is the household travel survey data and the demographic data. The demographic data on the household level as Cartesian product of household size with 4 levels (1, 2, 3, 4 or more persons) and number of cars per household with 3 levels (no car, one car, two or more cars) defines 12 household types. For each of these 12 household types the corresponding number of households is randomly drawn from the household travel survey data while the probability for each household within each class (household type) is determined by the characteristics of the persons belonging to the household. The probabilities for the households within each class are calculated by an iterative adjustment approach: First an equal weight is assigned to each household. Based on these weights and the proportions of the 12 household types, the distributions (age, employment type) at person level are calculated. The results are compared with the given input data. Then the household weights are adjusted based on the ratio of calculated distributions to the given distribution and the process is repeated until a good match is achieved.

For each of the 12 household types the required number of households is sampled randomly from the travel survey data using the calculated household weights. Sampling a household includes all persons belonging to it. The synthesized population is the union of all persons belonging to the sampled households. For each synthesized person, from now on called agent, attributes are assigned according to the household travel survey, including car availability, commuting distance and ownership of a commuter ticket. In addition each agent inherits the complete activity schedule (all activities with the attributes weekday, purpose, duration, planned starting time) from the person of the travel survey.
3.1.2. Activity Schedule Generation

Currently the existing activity schedule generation module is completely based on the empirical data of the household travel survey. The complete activity schedule of the corresponding person of the travel survey is assigned to the agent. As the current population synthesis module draws complete households from the survey data, it is assured that the activity schedules are consistent even at the household level.

3.1.3. Car ownership

Within the existing population synthesis module, car ownership is modelled implicitly. As the number of cars per household is one of the variables that determine the household type and the number of households in each class is given as input for the population synthesis, car ownership is defined as a by-product of population synthesis. Person level attributes relating to car availability (e.g. personal car, shared car within household) are inherited from the travel survey. So the current car ownership module just assigns the number of cars of the corresponding household in the travel survey.

3.1.4. Fixed destinations

Destinations for work or education are typically not chosen on a trip-by-trip basis. Instead they remain fixed over a long period of time. Therefore these destination choices are modelled in the setup phase and remain fixed during the chronological simulation. The fixed destination module is based on existing so-called commuting matrices, basically O-D matrices for work and educational trips. In Germany the commuting matrices for work trips can be derived from statistical data of the Federal Employment Agency which is available at the level of municipalities and have to be disaggregated further to traffic analysis zone level as needed. Otherwise these matrices can be generated externally for example by use of a gravity model. Based on the employment type of the agent several fixed destination types are distinguished: work, primary education, secondary education, tertiary education and vocational school. For each a different matrix is used.

Given that the distribution of fixed destinations is already determined by the externally given matrices, the main aim of this module is to assign the destinations in a way that they are compatible with the activity schedule of the agents. This means that an agent having an activity schedule that is based on short commuting trips should get a destination close to his residence while an agent with an activity schedule based on long reported commuting distance should get a destination with a long distance from home.

3.1.5. Commuter ticket ownership

Commuter ticket is modelled on a person level. It is assumed that all commuter tickets are personalized tickets used exclusively by the owner. Currently two modules for commuter ticket ownership exist: one directly based on the empirical data of the travel survey and the other based on a logit model. Within the empirical data based model commuter ticket ownership is directly inherited from the travel survey data. This model is intended as a simple model that yields reasonable results when not much other information is available. The logit based model is based on the attributes region, employment type, car availability, sex and number of cars per person. It can be calibrated for a known total number of commuter tickets in the study area or for different forecast scenarios, each characterized by a different number of commuter tickets.

3.2. Simulation

The simulation module is the central module of the mobiTopp framework and is responsible for the execution of the simulation. This mainly includes the management of the agents, namely the start and end of activities and trips and the management of cars. See Section 2.2 and Figure 2.2 for more details. The main work is done in the submodules destination choice and mode choice. The typical simulation period is one day, however a simulation period up to one week is possible.

3.2.1. Destination choice

Based on the location type of the activity – fixed or flexible – the destination choice method is different. In case of an activity with fixed location i.e. home, work or education, the predetermined location for this activity is used. In case of an activity with flexible location (e.g. leisure or shopping), a destination choice model is used to determine the next destination.
There are currently two destination choice models implemented in mobiTopp, a simple gravity model and an gravity model that takes into account not only the generalized costs to the destination zone, but in addition the generalized costs for returning to the next fixed destination based on the ideas described in [10].

The model has the following form:

\[ p_{ij} = \frac{A_{ij}}{\sum_{k=1}^{N} A_{ik}} \]  

with \[ A_{ij} = \frac{G_{j}^z\alpha_z e^{\beta_z (t_{ij} + t_{jn}) + \gamma_z (c_{ij} + c_{jn})}}{I} \]

where \( i \) is the zone of current location, \( p_{ij} \) the probability of choosing zone \( j \) as destination (given current location \( i \)), \( G_{j}^z \) the opportunities for activity type \( z \) in zone \( j \), \( t_{ij} \) the travel time from zone \( i \) to zone \( j \), \( c_{ij} \) the travel cost for travelling from zone \( i \) to zone \( j \), \( n \) the next fixed destination (for activities home, work or education), \( I \) the monthly income and \( \alpha_z, \beta_z, \gamma_z \) are model parameters for activity type \( z \).

3.2.2. Mode choice

mobiTopp models the following modes: walking, bike, public transport, car passenger and car driver. For mode choice a multinomial logit model is used. The utility function is freely definable, only restricted by the availability of data. The choice set of available modes depends on the situation and on the mode used on the trip before. If the agent is at home all modes are available given the agent has a driving license and there is a car available in the household. Otherwise the choice set consists only of the other modes. If the agent is not at home and the last mode used was car driver or bike, only the mode last used is available. If the agent is not at home and the last mode used was walking, public transport or car passenger, then the choice set consists of these three modes.

3.2.3. Route choice

Route choice is currently not modelled within the mobiTopp system. Instead the trip file generated by mobiTopp is aggregated to hourly O-D-matrices which are used for traffic assignment in VISUM. The resulting travel time matrices are fed back into mobiTopp.

4. Application

The mobiTopp system has been successfully applied to the Stuttgart Region, consisting of the city of Stuttgart and the surrounding districts, encompassing more than 2.7 million inhabitants. The study area has been divided into 1 012 traffic analysis zones. The division into zones, the travel time, cost and commuter matrices and the structural data have been borrowed from an existing macroscopic model [11]. For population synthesis, activity schedule generation and parameter estimation of the different modules, a recent household travel survey [12] has been used. Only persons aged 6 years and above where modelled, resulting in roughly 2.5 million agents. The model has been calibrated to match trip length distributions by activity type and modal split by employment type. The duration of a simulation run of one simulation day was about 11 hours on an upper level desktop PC\(^1\).

The resulting output contains 7.8 millions of trips made by 2.3 millions of agents. To give an example of the results the travel demand profiles over time for trips entering or leaving the inner city of Stuttgart are shown. Figure 3 shows the trips entering the city differentiated by the modes public transport, car driver, and car passenger. Figure 4 shows the corresponding travel demand profile for the opposite direction. The morning and the evening peaks are clearly visible. The morning peak for the traffic entering the inner city is notably greater than the evening peak while for the traffic leaving the city the evening peak is more pronounced than the morning peak. This reflects the fact that there are more commuters from outside having their workplaces in the inner city than inhabitants of the inner city having their workplaces outside. Remarkable is the large morning peak for public transport indicating the large capacity of the public transport system.

\(^1\)Intel Core i7 950 @ 3.07GHz, 24 GB RAM
5. Discussion and Future Work

With the simulation of a large-scale scenario within a reasonable time frame and providing meaningful results, mobiTopp has demonstrated its qualities in practical application. The heavy use of empirical data from travel surveys in several submodules worked well. In the case of commuter ticket ownership, the results from the module using empirical data only did not match the number of sold commuter tickets in the Stuttgart region, however the problem was easy to fix by plugging in a logit-based commuter ticket module. So the approach of implementing a modular system, starting with simple modules and replacing them later as needed by more complex ones seems suitable.

Future improvements will include an improved module for the distribution of fixed destinations to reduce the need for externally generated matrices and to improve the ability to forecast. The implementation of a departure time choice module will weaken the dependence on empirical activity schedules and eventually pave the way for the integration of a synthetic activity schedule generation module. The integration of space-time constraints will be straightforward by removing alternatives not reachable within the given constraints from the choice sets for destination and mode choice. The integration of a route choice module will allow dynamic feedback within the mobiTopp system.

References

[1] M. Wirtz, T. Streit, B. Chlond, P. Vortisch, On new measures for detection of data quality risks in mobility panel surveys, in: 92nd Annual Meeting of the Transportation Research Board (TRB), Washington, DC, 2013.
[2] D. Zumkeller, B. Chlond, M. Kagerbauer, Regional panels against the background of the German Mobility Panel: An integrated approach, in: 8th International Conference on Survey Methods in Transport, Annecy, France, 2008.
[3] M. Poeck, D. Zumkeller, Anwendung einer maßnahmeempfindlichen Prognosemethode am Beispiel des Großraums Nürnberg, in: Workshop der Deutschen Verkehrswissenschaftlichen Gesellschaft: Policy Sensitive Models, Gießen, 1976.
[4] L. Smith, R. Beckman, K. Baggerly, TRANSIMS: Transportation analysis and simulation system, Tech. rep., Los Alamos National Lab., NM (United States) (1995).
[5] B. Raney, K. Nagel, An improved framework for large-scale multi-agent simulations of travel behavior (2004).
[6] S. Schnitberger, D. Zumkeller, Longitudinal microsimulation as a tool to merge transport planning and traffic engineering models—the mobiTopp model, in: European Transport Conference, Strasbourg, 2004.
[7] T. Arentze, H. Timmermans, A learning-based transportation oriented simulation system, Transportation Research Part B: Methodological 38 (7) (2004) 613–633.
[8] T. Arentze, H. Timmermans, D. Janssens, G. Wets, Modeling short-term dynamics in activity-travel patterns: from Aurora to FEATHERS, in: Innovations in Travel Demand Modeling, Transportation Research Board, 2006, pp. 71–77.
[9] K. Mueller, K. Axhausen, Hierarchical IPF: Generating a synthetic population for Switzerland, in: ERSA conference papers, European Regional Science Association, 2011.
[10] V. Waßmuth, Modellierung der Wirkungen kehrsreduzierender Siedlungskonzepte, no. 60 in Schriftenreihe des Instituts für Verkehrswesen, Universität Karlsruhe (TH), 2001.
[11] J. Schlaich, U. Heidl, R. Pohlner, Verkehrsmodellierung für die Region Stuttgart – Schlussbericht, unpublished (2011).
[12] Verband Region Stuttgart, Mobilität und Verkehr in der Region Stuttgart 2009/2010 – Regionale Haushaltsbefragung zum Verkehrsverhalten, no. 29 in Schriftenreihe Verband Region Stuttgart, 2011.