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# Creating an integrated agent-based travel demand model by combining mobiTopp and MATSim

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**Abstract**

In the past years, the travel demand model mobiTopp has undergone substantial developments towards a full agent-based travel demand model. Until now, mobiTopp covers the generation of a synthetic population with synthetically generated activity plans, different models for ownership of cars or transit passes, destination choice models for long- and short-term destinations, and various mode choice models. However, it still does not contain a dynamic traffic assignment procedure for motorized traffic. On the other side, MATSim's origin is a traffic flow simulation used for a dynamic traffic assignment, and in the past years, extensions for destination and mode choice have been developed on a fundamental or experimental basis. As the strengths of both models are in different parts of a travel demand model, it suggests itself to combine both instead of redeveloping the missing parts in both models. Therefore, this paper presents our approach of integrating mobiTopp and MATSim to build a full travel demand model.



*Keywords:* travel demand model; traffic assignment; agent-based; mobiTopp; MATSim;

## 1. Introduction

Travel demand modeling has made much progress during the last fifty years. The highly dynamic agent-based models of today have not much in common with their static and macroscopic ancestors. However, this transformation is not the result of a paradigm shift, but rather the outcome of an ongoing evolution. Perhaps the most significant change was the shift from the aggregate zonal view to the so-called disaggregate models [8], which focus on the individual activities and the related trips and model the corresponding decisions based on Multinomial Logit Models [14]. Thus the full methodology of the rational choice theory was available for travel demand modeling.

The extension from trips to tours led to further minor improvements. Another breakthrough was the introduction of the so-called *daily activity schedule* [5]. This approach was the first theoretically sound methodology of modeling travel demand over a complete day while being operated at the same time. Conceptually, the daily activity schedule is

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a discrete choice model, where the choice set consists of all possible activity programs, which are possible given the modeled choice dimensions. A choice probability is calculated for each activity program. The daily activity schedule is operationalized by a hierarchy of Multinomial and Nested Logit Models, such breaking it down and making it tractable. Totals can be calculated by applying the hierarchy of models to a representative sample of the population and aggregating the resulting probabilities. This approach is known as *sample enumeration*. For many years, these disaggregate modeling technique based on a hierarchy was widely used. Due to the focus on activities, these models are also called *activity-based models*.

A further step was using microsimulation for travel demand modeling, a technique used before mainly in traffic flow simulation [18]. With microsimulation in travel demand modeling, the hierarchical structure of the activity-based models is kept, but it is used differently. Instead of propagating the probabilities of the individual models down to the leaves, the probabilities are used to simulate several distinct decisions. For each simulated person, a decision is simulated on each level of the hierarchical structure. This decision is made as a random draw from the distribution given by the probabilities of the model on this level. Only the selected branch is followed further down to the next level. Totals are calculated by summing over the results of the different decisions of the different people instead of aggregating the probabilities.

The term *multi-agent* was first used in travel demand modeling in the context of TRANSIMS [6]. The term *agent-based* was used for MATSim [15], which started as a reimplementation of the traffic flow simulation of TRANSIMS. A common feature of both models is a microscopic traffic flow simulation as a central component, which can be used for traffic assignment. While TRANSIMS traffic flow simulation is based on cellular automata, the one contained in MATSim is queue-based.

The border between microsimulation and agent-based simulation is blurry. Taking Bonabeau's [4] definition of agents as entities that act and make decisions independently and interact with each other, microsimulation models like the New York model [18] qualify as agent-based. Each person is modeled as an individual entity. The people make decisions for destination choice and mode choice. In this model, the agents interact regarding destination choice. Each destination has a limited capacity and is no longer available for other agents when this capacity is reached.

Most of the activity-based microsimulation models lack a microscopic traffic assignment procedure. As replacement often a macroscopic traffic assignment, like EMME/2, is used. This has the drawback that the complete model is no longer fully agent-based.

In recent years, there were several projects aimed at developing fully integrated travel demand models from scratch, for example, Polaris [17, 1] or SimMobility MT [11]. However, developing a new model from scratch is very ambitious and needs lots of resources. A more pragmatic approach is using an existing model for travel demand in the narrower sense and combining it with an agent-based dynamic traffic assignment model. One of the first applications of this approach was the coupling of the Tel-Aviv model with MATSim [3]. In this application, MATSim was used as a replacement of an external static traffic assignment tool and the coupling was done manually. A more recent application combines CEMDAP with MATSim [19] but follows a slightly different strategy. In this case, CEMDAP is used to calculate a set of activity plans for each agent. MATSim is used for dynamic traffic assignment, but can additionally choose between the different precalculated plans.

The approach here is similar to the approaches outlined above but uses a tighter coupling. We use mobiTopp to model the demand in the narrower sense and use MATSim for dynamic traffic assignment. As both frameworks, mobiTopp and MATSim, are available as open-source software, they can be tightly coupled: MATSim agents are directly created from within mobiTopp. The MATSim simulation is started from within mobiTopp as well and the resulting travel times are directly fed back to the next mobiTopp iteration.

In the following sections, we give a short overview of the relevant parts of mobiTopp and MATSim, followed by the description of their integration. As proof of concept, we use an existing mobiTopp model for the greater region of Stuttgart, where the integrated MATSim dynamic traffic assignment replaces the external static traffic assignment. Finally, we compare the results of the integrated mobiTopp–MATSim model with the results of the static traffic assignment of the original mobiTopp implementation.

## 2. The mobiTopp model

mobiTopp [12, 13] as an agent-based travel demand model, models every person, household and car of the study area. People are modeled as agents who make decisions autonomously, individually and situation-dependent based on the current situation or the interaction with other agents. In mobiTopp, every agent has an assigned activity program for a whole week. While they carry out their activity programs, the agents decide where an activity will take place and which mode will be used to arrive at the location. Both decisions, destination choice and mode choice, are based on discrete choice models. Currently, mobiTopp has no dynamic traffic assignment model for individual traffic. Due to this, there is no direct interaction between cars.

mobiTopp consists of two stages: initialization and simulation. During initialization, the long-term aspects of agents and households are modeled. This includes population synthesis, generating all agents and households based on structural data. During this stage, locations for fixed activities (home, work, education), the ownership of private cars and transit passes, and the activity programs for each agent are modeled. An activity program is an ordered set of activities containing the type, the preferred start time and the duration of each activity. Currently activity programs can be assigned based on a travel survey or based on actiTopp [9], a combination of various logit models to generate synthetic activity programs. The simulation of the travel demand during the simulation stage is based on these long-term decisions. In this stage, the travel behavior of all agents is simulated simultaneously. By applying the destination and mode choice models sequentially for each trip of an agent, all agents are simulated over one week.

During destination choice, two types of activities are distinguished: activities at fixed locations (work, education, and at home) and flexible locations (e. g., leisure, and shopping). Activities with fixed locations have predefined locations modeled in the initialization stage. Due to this, no destination choice is made for such activities during the simulation stage. For activities with flexible locations, a destination choice on the level of traffic analysis zones (TAZs) is made. The default implementation of the destination choice model is a discrete choice model taking into account the travel time and travel cost from the current location to the potential destination together with the travel time and travel cost from the potential destination to the next fixed location (e.g., to the workplace, or back home) [13].

For each trip, agents in mobiTopp select the main transportation mode. The default implementation contains the following five modes: *walking*, *cycling*, *public transport*, *car as driver*, and *car as passenger*. The actual choice set for each situation consists of a subset of these five modes, based on a set of rules. When starting at home, all modes are available for an agent as long as the agent owns a driving license. Bike ownership is currently not modeled in detail, and it is assumed that every agent owns a bike. Due to this, every agent can at least choose between cycling, walking, public transport and car as a passenger. The current location of an agent and the mode used on the last trip are the most influential factors for mode restrictions. If an agent is not at home and the mode on the last trip was car as driver or cycling, the choice set is limited to the mode of the last trip. The agent is forced to use the same mode until coming back home. Otherwise, when an agent starts at home using one of the modes walking, public transport, or car as a passenger, the agent can switch between these three modes. The actual mode choice decision is made by a Multinomial Logit Model using the choice set of the available modes. The utility function of the Multinomial Logit Model contains variables like distance, travel time, travel cost, transit pass and sociodemographic variables.

## 3. The MATSim model

MATSim is used as dynamic traffic assignment model. It is based on the interaction of agents with a network by using a queue simulation approach for a single day. Agents undergo an iterative process to find a suitable assignment of the demand to the given supply. This iterative process is split into three parts. Each iteration starts by simulating the demand on the network, continuous by scoring the executed daily plan, and finishes by choosing a plan for the next iteration.

During the simulation, each agent executes the initially selected plan or the one selected at the end of the last iteration. All agents are processed simultaneously. The default traffic flow simulation uses a first-in-first-out (FIFO) queue to model each link in the network, while taking into account various attributes of the link such as free-flow speed, link length, allowed modes, and others [10]. After the simulation, a score is calculated for the executed plan of each agent by assigning an utility value to each activity and trip of the plan. Typically, activities provide a positive utility, while traveling provides negative utility.[7]

After scoring the executed plan, each agent selects the plan to be executed in the next iteration. The agent can choose between selecting one of the existing plans or generating a new one. Generation of a new plan is made by modifying a copy of an existing plan using so-called *innovation strategy modules*. MATSim provides as default strategy modules that can change the end time of activities, the route, and the mode of trips. Other innovation strategies exist to change, e.g., the destination of an activity.[10]

## 4. Methodology

mobiTopp and MATSim are fully integrated to generate a complete processing chain for travel demand and supply simulation. First of all, mobiTopp is used to generate a synthetic microscopic population based on structural data. An approach based on iterative proportional fitting [2] is used to match the households of the travel survey with the structural data. Agents with various attributes like gender, age, transit pass, car ownership, and household relations represent the population. For each agent, a fixed home and work or school location will be chosen. The home location is determined by the travel zone for which the household has been generated. The work or school location will be selected based on the distance reported in the travel survey and commuting matrices. In the next step, activity programs for all agents are generated and assigned.

After this, the population is simulated by mobiTopp for one day to generate the initial plans with locations and activity durations for all activities of each agent together with the used modes for MATSim. MATSim is afterward used as a dynamic traffic assignment model to assign the demand to the given network. For this purpose, mobiTopp converts the network and all plans using the mode car as a driver to data structures of MATSim and starts a MATSim simulation of several iterations.

During the MATSim iterations, the agents are only allowed to change their routes by using the *ReRoute* innovation strategy. Destination, mode and time choices are modelled by mobiTopp and are considered as fixed during the iterations. After the dynamic traffic assignment, the resulting link travel times in MATSim are aggregated to hourly travel time matrices to be used as an input for the next mobiTopp iteration. Due to this, the processing chain contains two feedback loops. The inner loop of MATSim optimizes the route choice. The outer loop of mobiTopp and MATSim takes into account the effects of changing travel times for destination and mode choice. Figure 1 shows an overview of the processing steps. The results of the dynamic traffic assignment are afterward analyzed according to traffic volumes on links over the whole day by comparing them to traffic volumes collected by automatic traffic counters.

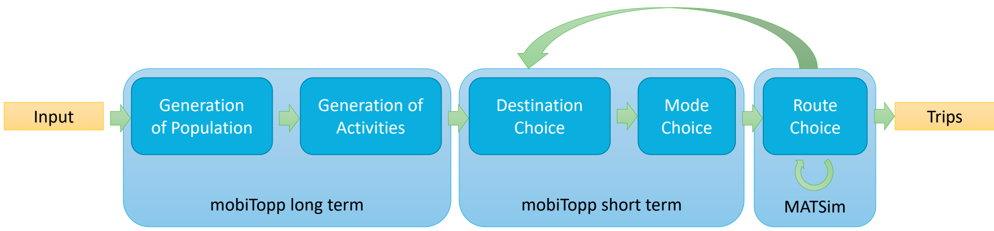



Fig. 1: Processing chain after coupling mobiTopp and MATSim.

### 4.1. Adaption of mobiTopp

Various adaptions to mobiTopp are necessary to couple both models. First of all, destinations have to be based on coordinates instead of TAZs, the road network may contain incorrect links and has to be cleaned up, and external traffic has to be added as it influences travel times on links.

mobiTopp by default models locations of agents on the level of TAZs while MATSim uses exact locations presented by the nearest network link. Therefore, for each destination, an agent could choose, an exact location is determined. The locations are randomly spread within the developed area of each TAZ and are tied to the nearest link. Home locations are concentrated in residential areas.

In MATSim an agent travels from link to link. Therefore, for each origin-destination pair of links, a valid route must be available in the network. This is ensured by cleaning the network before assigning any location to a destination. The cleaning is done by finding all links connected to each other using variations of Dijkstra's search algorithm on the road network. As a starting point, the center point of the first TAZ is used, and all TAZs are connected to the network using the connectors. All links which are reachable from the first TAZ remain in the network.

Spreading the locations all over the TAZ has the effect, that connectors of the TAZ will not be used by agents living and moving inside the study area. However, agents may also travel to destinations far out of the study area. In these external TAZs, the road network is typically missing. Exact locations cannot be calculated for those TAZs. Instead, the center point of the external TAZ is used as the destination. The connectors of the external TAZs are therefore modeled as links in the MATSim network. As MATSim typically does not know connectors, they should not influence the behavior of agents. Therefore, the connectors are converted given their specified travel time and a predefined free-flow speed. The capacity is set a magnitude higher than on regular links avoiding congestion on connectors.

In mobiTopp all agents of the study area are modeled. People living in the external TAZs traveling into the area or through the area (external traffic) are not modeled, as they do not affect the choices of agents modeled by mobiTopp. In dynamic traffic assignment, every car on the road increases the traffic load resulting in a change of the travel time. Neglecting external traffic in such models will result in incorrect volumes on links and due to this in different travel times. Therefore, external traffic is explicitly modeled in MATSim.

Origin-destination matrices for external traffic are used as input. The matrices only contain the number of trips between origin and destination regardless of the activity type. The relationship between trips and an activity program of a single person cannot be reconstructed from these matrices. Because of this, each trip of an origin-destination matrix is modeled as a single agent traveling only one way, called external agent. An external agent starts at the center point of an external TAZ and travels to an exact location inside the study area or vice versa. Exact locations are selected randomly inside the internal TAZ. External agents also travel between center points of external TAZs. These external agents are generated only for MATSim, where they interact with the other agents during traffic assignment.

## 5. Application to a real-world scenario

The presented approach of coupling mobiTopp and MATSim to create an integrated travel demand model has been successfully applied to the region of Stuttgart. The region contains the city of Stuttgart and its surrounding districts with a total of 2.7 million inhabitants. The study area is divided into 1012 TAZs. An 1% sample of the inhabitants is simulated over a single day. The input data for mobiTopp and MATSim has been taken from a macroscopic model [16]. For the dynamic traffic assignment, 307 845 links open for individual motorized traffic are converted from the macroscopic model to MATSim. Another 339 links are not reachable and due to this, not converted. From calibrating the macroscopic model, traffic counts from 544 count stations were available.

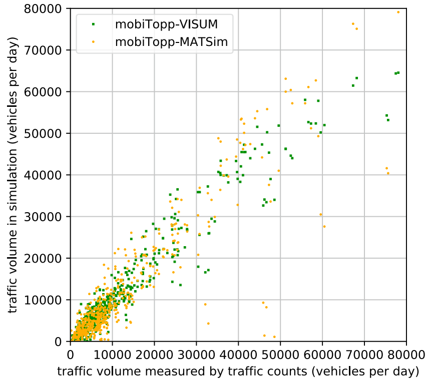
The integrated approach used mobiTopp version 0.1.1 and MATSim version 0.7. Using 100 iterations in MATSim, it took 45 hours for the whole simulation. The runtime can be split up into 30 minutes for the population synthesis, eight minutes for the simulation in mobiTopp, and 44 hours for the dynamic traffic assignment in MATSim. The remaining time is used to load and convert data between the models. The simulation has been run on an Intel Core i7 3820 (3,6GHz), Windows 7 and 64 GB of RAM of which the simulation used 25 GB. The number of threads used by MATSim was not limited by the configuration.

The focus of this work was to integrate both models technically. Therefore, no calibration of the MATSim model has been done. Figure 2a shows the correlation between the traffic volumes of the different models and the data of the traffic counts. The first model uses the demand generated by mobiTopp and the traffic assignment of PTV VISUM (mobiTopp-VISUM), while the second approach is the integrated one (mobiTopp-MATSim). It can be seen, that the results of both are similar. However, there are outliers with nearly no traffic volume in the integrated approach, but high traffic volumes in the real world. Some of those are located at entry and exit links to the car park at the airport. The car park attracts all traffic in the real world, while the destinations are spread within the TAZ in the model.

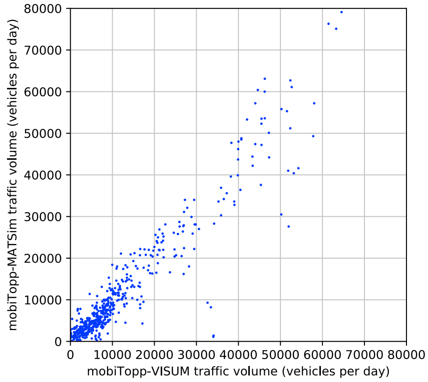
Figure 2b shows, the correlation between the traffic volumes of the mobiTopp-VISUM approach and the mobiTopp-MATSim one. It shows that links in MATSim with low volumes tend to have higher volumes in PTV VISUM, while for the rest of the links the traffic volumes of both approaches correlate more or less to each other.

## 6. Discussion and future work

The presented approach integrates the travel demand model mobiTopp with MATSim, used as tool for dynamic traffic assignment. The integration is technically working as it has been applied to the region of Stuttgart. The two feedback loops ensure that changes in travel time due to increased volumes on links are taken into account. The inner loop is the standard MATSim loop, while the outer one feeds the newly generated travel times from MATSim into the destination and mode choice models of mobiTopp. Due to this, it should be possible to build a model from scratch by using travel times of the empty network in the first iteration and update the travel times with the outer feedback loop. However, this has currently not been tested and is open for future investigation. The comparison with volumes measured by traffic counters shows that both approaches lead to comparable results.




(a) Comparison of the model using mobiTopp and VISUM, and mobiTopp and MATSim against data of traffic counts.




(b) Comparison of the model using mobiTopp and VISUM, and the model using mobiTopp and MATSim.

Fig. 2: Comparison of daily traffic volumes.

We will further investigate the calibration of the integrated model and make a more detailed comparison and analysis of the two approaches from a transportational point of view.

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