

# An Activity-based Travel Demand Model of Switzerland Based on Choices and Constraints

*Short paper for hEART 2019*

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## 1. Introduction

Travel demand models are used to predict traffic volumes on the infrastructure and user benefits from new service concepts. Most travel models applied in practice today simulate aggregated travel flows, i.e. they are of macroscopic nature. In contrast, we present a microscopic model, which simulates each traveller as an individual entity.

The model is called SIMBA MOBi. It has been developed over the past two years by SBB (Swiss Federal Railways). As far as we know, this is one of the first microscopic models that is developed inside a transport operating company in Europe and applied to support real world business decision making. It is person-based, multimodal, simulating 24 hours of the average weekday (Monday through Friday) and covers the entire country of Switzerland, urban, rural and intercity. While it is possible to derive a parameter set also for Saturdays and Sundays, using the same model structure, this effort has not yet been undertaken as most capacity constraints in the rail and road systems are observed on weekdays.

SIMBA MOBi starts from a synthetic resident population of Switzerland, constructs activity plans and travel plans for each person, balancing for each traveller both the individual preferences as well as constraints. Preferences are represented by discrete-choice models for tour and activity frequency, destination and mode choice. Constraints are represented in the plan adjustment and scheduling steps, using time budgets with a rule-based approach, which assures plan integrity and consistency. Finally, 24-hour dynamic network flows for cars and public transport are simulated using the agent-based software MATSim. Hence, the model is microscopic through all model steps.

In this paper we focus on the travel demand module, called MOBi.plans. The population synthesis and the agent-based traffic flow simulation are not covered in this paper.

## 2. Previous related work

Since the origins of computer-based travel demand models in the 1960s until today, the mainstream of transportation planning models that are used in practice has been a macroscopic (i.e. aggregated) approach, based on several sequential steps (see Boyce and Williams, 2015). Later, the idea of activity-based transport models (ABM) emerged and was put into practice in the 1990s. For a

historical review see Bowman (2009) or Rasouli and Timmermans (2014). Today there are several approaches of ABM, who differ in their focus and in terms of how far they have advanced to be used in real world applications. The following overview presents those ABM approaches that have influenced the authors in the development of *SIMBA MOBi*.

The North-American school of microscopic ABMs follows an econometric approach. Important representatives who have managed to get ABM up and running in practice for several major U.S. cities in the 2000s, are Bowman and Ben Akiva (2001), Vovsha, Bradley et al. (2004), Bhat et al. (2004). A comprehensive presentation of the methodology is given by Castiglione et al. (2015). We borrowed many concepts from this school for the generation of synthetic individual day-plans for each member of a population, using a system of discrete-choice models from the generation of tours and activities to the choice of modes, destinations and locations.

Other mainly academic ABMs can be defined as rule-based. We have drawn ideas from the work of Roorda et al. (2008) for plan scheduling. We found few sources regarding the implementations of time budgets in travel demand models; a rare example is Moeckel et al. (2019), using budgets of travel time.

Agent-based models emerged in the 2000s with a focus on large-scale and network-wide microscopic traffic simulation. *SIMBA MOBi* applies the open source software *MATSim* (Horni et al., 2016), which for over a decade has been in use to model Switzerland for research purposes (Meister et al., 2008). *MATSim* connects supply and demand in a network equilibrium. In addition to route search, agents can also reschedule time and mode choices. The *MATSim* software does not yet include modules to generate daily activity plans.

An earlier practice of tour-based models (Axhausen, 1989; Fellendorf et al., 1995) has a record of many real-world applications already in the 1990s, mainly in German-speaking countries. It was made available as part of the commercial *PTV VISUM* software. The aggregated calibration methodology of this approach was adapted for *MOBi.plans*.

Building on all the approaches mentioned above, we developed a model that is activity-based and microscopic and at the same time responsive to socio-economic shifts and to changes in transport supply through all model steps.

### 3. Methodology and structure of the model

The objective of *MOBi.plans* is to synthetically generate an individual daily plan for each resident of Switzerland, as represented in the synthetic population. Each individual plan contains:

- the permanent location of primary activities, which are work and education, i.e. workplace and/or educational institute
- the desired number and kind of activities a person wishes to perform in a day
- the pattern of how those activities are bundled in tours
- the sequence of tours and the sequence of the activities within each tour
- the exact geographic location where each activity will be performed
- the mode choice for each tour or subtour
- the duration and time of day for each desired activity

Figure 1 depicts an example of a plan with all its components.

**Figure 1** Example of a full-day plan with all its components

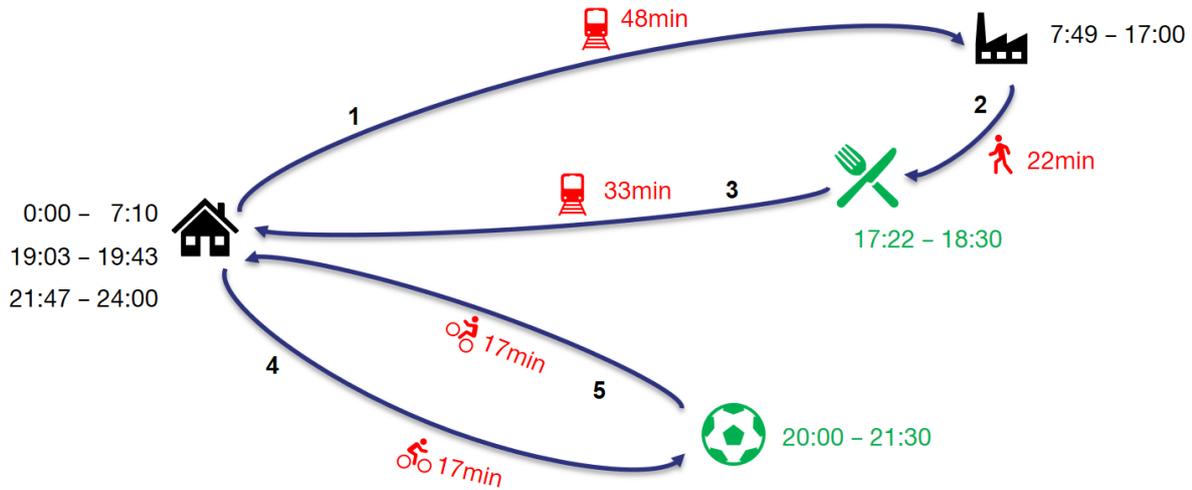
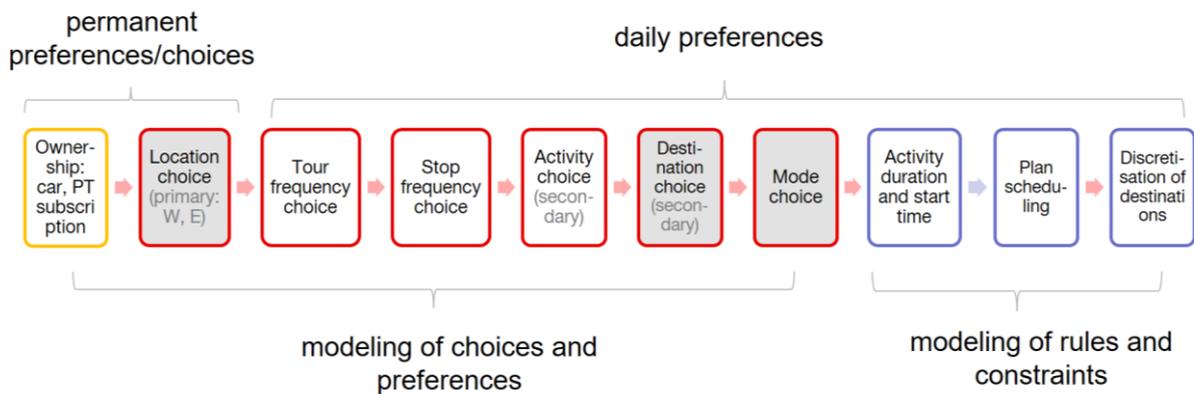


Figure 2 shows the sequence of model steps taken to construct the plans. Technical details of each of these steps will be described later in the paper.

**Figure 2** MOBi.plans model steps



### 3.1. Car availability and PT subscription

A first model step determines car availability and PT subscriptions (i.e. yearly or monthly public transport passes) for each person in the population. Both are very important person attributes with a strong impact on mode choice and destination choice. In the existing case, these attributes are determined by choice models and then corrected based on small-area control variables (Danalet and Mathys 2018). For the application of the model in forecasting, it is planned to integrate accessibility measures for the prediction of mode availability.

## 3.2. Location choice

Location choice assigns permanent locations (work place and/or school place) to each person who is in a status of employment or education. Being responsive to changes in level of service (LOS) is a crucial requirement of the model. This is achieved with a nested model structure, where the logsum (or maximum expected utility) of trip-based mode choice informs location choice about the service quality of all modes to each location. Additional additive utility terms (shadow prices) in the higher level of the location choice explain regional preferences which cannot be explained alone by physical attributes of travel or LOS measures. The LOGIT formula of location choice is identical to the one used in destination choice see (3.4).

## 3.3. Tour and activity generation

The estimation of the number of activities per person and how these activities are bundled into tours follows the American approach of discrete-choice-based ABM as described in Bowman and Ben Akiva (2001) and Castiglione et al. (2015). It involves discrete choice models for tour frequency, subtour frequency and stop frequency.

A tour is defined as a sequence of trips that begin at home and end there again. Our model does not allow for ending a tour at location different from home. Four different types of tours are modelled, the first two being considered primary tours and the latter two secondary:

- Work tour
- Education tour
- Business tour
- Other tour

Work and education are primary activities. Both work and education are related to permanent locations and considered the dominant activity in their respective tours. On a tour, there will be additional intermediate stops for secondary activities. Our model uses the following secondary activity types:

- Leisure (L)
- Shopping (S)
- Business (B)
- Education as non-primary activity (EC)
- Accompany (A)
- Other (O)

An overview of the tour and stop frequency models is shown in Table 1.

All these models are multinomial LOGITs. The perhaps most important property of the generation models is their ability to forecast changes in the mobility of individuals in reaction to mode availability, to changes in transport supply (by means of accessibility) and to demographic shifts (e.g. by means of the age variable). As an example, Table 2 shows the LOGIT utility parameters of tour frequency for “other tours” (tours without primary activity). Age and employment level are included as piecewise-linear variables, without a base (or “dummy”) variable. For employment there is an additional dummy variable (employment level =0), which has special meaning: being “true” when someone is unemployed and zero else.

**Table 1** *Tour- and Stop Frequency Models*

|                                  | Tour frequency          |           |                           |       | Sub tour frequency | Stop frequency  |                                 |   |
|----------------------------------|-------------------------|-----------|---------------------------|-------|--------------------|-----------------|---------------------------------|---|
|                                  | Number of primary tours |           | Number of secondary tours |       |                    | On primary tour | Number of stops on primary tour |   |
|                                  | Work                    | Education | Business                  | Other | Outbound           |                 | Inbound                         |   |
| Constant                         | X                       | X         | X                         | X     | X                  | X               | X                               | X |
| Employment level                 | X                       | X         | X                         | X     | X                  | X               | X                               | X |
| Main occupation is student/pupil |                         | X         |                           | X     | X                  |                 |                                 |   |
| Age                              | X                       | X         | X                         | X     | X                  | X               | X                               | X |
| Is in management                 |                         |           | X                         |       |                    |                 |                                 |   |
| Presence of kids in HH (<18)     | X                       |           |                           | X     | X                  | X               | X                               | X |
| Car available                    | X                       |           | X                         | X     | X                  | X               | X                               | X |
| Public transport subscription    | X                       | X         | X                         | X     | X                  | X               | X                               | X |
| Car distance to primary location | X                       | X         | X                         |       |                    | X               | X                               |   |
| Number of total tours            |                         |           |                           |       | X                  | X               | X                               | X |
| Number of primary tours          |                         |           |                           | X     |                    |                 |                                 |   |
| Is a work tour                   |                         |           |                           |       | X                  | X               | X                               |   |
| Is a business tour               |                         |           |                           |       |                    |                 |                                 | X |
| Accessibility home location      | X                       | X         |                           | X     |                    | X               | X                               | X |
| Accessibility work/edu location  |                         |           | X                         |       | X                  |                 |                                 |   |

**Table 2** *LOGIT coefficients: choice of tour frequency for “other tours”*

|   | Number of other tours per day |           |           |           |
|---|-------------------------------|-----------|-----------|-----------|
|   | 0                             | 1         | 2         | 3         |
| Constant                                    | 0.000                         | +1.861*** | +1.603*** | -0.140    |
| Employment level = 0%                       | 0.000                         | +0.051    | -0.229    | -0.276    |
| Employment level: 1% - 39% <sup>1</sup>     | 0.000                         | -0.008*   | -0.011*   | -0.007    |
| Employment level: 40%-79% <sup>1</sup>      | 0.000                         | -0.014*** | -0.017*** | -0.026*** |
| Employment level >= 80% <sup>1</sup>        | 0.000                         | -0.005*   | -0.017*** | -0.020*** |
| Age < 18 <sup>1</sup>                       | 0.000                         | -0.022    | -0.047*   | -0.038    |
| 18 <= age < 25 <sup>1</sup>                 | 0.000                         | -0.078*** | -0.059*** | +0.059*   |
| 25 <= age < 65 <sup>1</sup>                 | 0.000                         | -0.002    | -0.000    | -0.003    |
| 65 <= age < 75 <sup>1</sup>                 | 0.000                         | -0.019*   | -0.016    | -0.061*** |
| Age > 75 <sup>1</sup>                       | 0.000                         | -0.048*** | -0.091*** | -0.099*** |
| Presence of kids in the HH (<18)            | 0.000                         | +0.035    | +0.256*** | +0.554*** |
| Is student                                  | 0.000                         | -0.726*** | -0.625*** | -0.882*** |
| Is apprentice                               | 0.000                         | -0.390*** | -0.154    | +0.303    |
| Is pupil                                    | 0.000                         | -0.727*** | -0.587*** | -0.453    |
| Car available                               | 0.000                         | +0.452*** | +0.854*** | +1.053*** |
| PT subscription                             | 0.000                         | -0.094**  | -0.141*** | -0.230*** |
| Number of primary tours                     | 0.000                         | -0.807*** | -1.850*** | -2.566*** |
| Accessibility of home location (multimodal) | 0.000                         | +0.023*** | +0.039*** | +0.032*   |
| Accessibility * car_available <sup>2</sup>  | 0.000                         | -0.035*** | -0.032*** | -0.015*** |

Number of observations : 38149

Rho-square : 0.22

Footnotes:

<sup>1</sup> piecewise linear variable

<sup>2</sup> interaction term of 2 variables

\*  $P \leq 0.05$

\*\*  $P \leq 0.01$

\*\*\*  $P \leq 0.001$

After these generation models are computed for each person, the secondary activities are specified in each tour. As a result, complete activity chains are now determined for each tour (e.g. home-work-shop-home). The set of all activity chains results in a skeleton of each person’s plan. In the following steps, this skeleton is completed with destinations, modes and timing.

### 3.4. Destination and mode choice

Knowing precisely number and type of activities each agent performs in each tour, the next step is choosing the destination of each secondary activity and the mode for each trip between activities. For this purpose, destination probability matrices for each activity type and different demand strata are estimated following the same method as in location choice (see 3.1).

The probability of choosing mode  $m$  on the origin-destination pair  $ij$  is:

$$P(m|ij) = \frac{\exp(V_{ijm})}{\sum_k \exp(V_{ijk})}$$

The expected maximal utility (EMU) of mode choice is then:

$$EMU_{ij} = \ln \left\{ \sum_m [\exp(V_{ijm}/\theta)] \right\}$$

Mode choice depends on various variables such as travel time, distance and other level of service measures (see Table 3). To inform destination choice about the level of service of all modes, mode choice is nested into destination, by including  $EMU_{ij}$  (the expected maximal utility of mode choice) into the destination choice utility:

$$V(j|i) = \ln(A_j) + \theta \cdot EMU_{ij} + \lambda_j + \lambda_{ij}$$

With:

- $EMU_{ij}$ : maximum expected utility of mode choice from  $i$  to  $j$
- $A_j$  : = the socio-economic attraction of zone  $j$
- $\lambda_j$  := shadow price of destination  $j$
- $\lambda_{ij}$  := shadow price of origin-destination pair  $ij$

For calibration purposes, it is important to extend the destination utilities with shadow prices. Finally, the probability of choosing destination  $j$  under the condition of starting in origin  $i$  is:

$$P(j|i) = \frac{\exp(V(j|i))}{\sum_k [\exp(V(k|i))]}$$

**Table 3** Variables used in mode choice utility  $V_{ijm}$

| mode            | constant | travel time | access/egres (parking search) time | service frequency | number of transfers | parking cost | distance |
|-----------------|----------|-------------|------------------------------------|-------------------|---------------------|--------------|----------|
| walk            | x        | x           | -                                  | -                 | -                   | -            | -        |
| bicycle         | x        | x           | -                                  | -                 | -                   | -            | -        |
| PT              | x        | x           | x                                  | x                 | x                   | -            | x        |
| car - driver    | x        | x           | x                                  | -                 | -                   | x            | x        |
| car - passenger | x        | x           | x                                  | -                 | -                   | x            | x        |

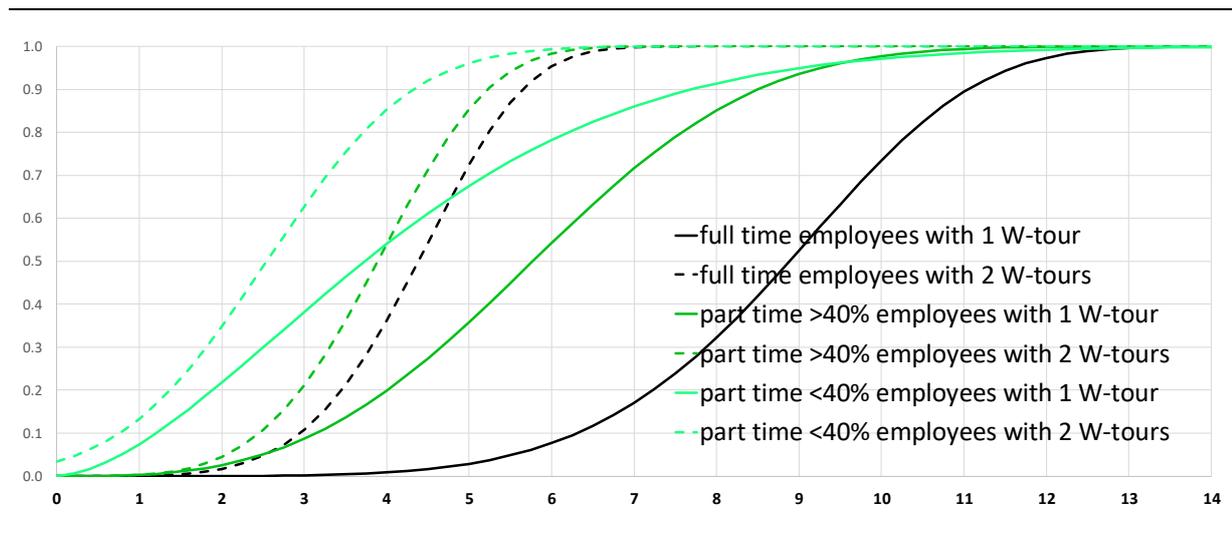
However, choosing the exact destination for each stop is not as straightforward as in location choice. Since an intermediate tour stop lies between two pre-defined locations, “rubber banding” is used to consider both trip origin and primary location (i.e. work place) in the choice of the intermediary destinations. Note that at this stage of the model, there is no interaction between the destination choice decisions of multiple tours. In some cases, this might result in unrealistically high travel time which violates time budgets and hence plan integrity. This issue will be treated at a later model stage (see 3.6).

### 3.5. Desired activity duration and activity start times

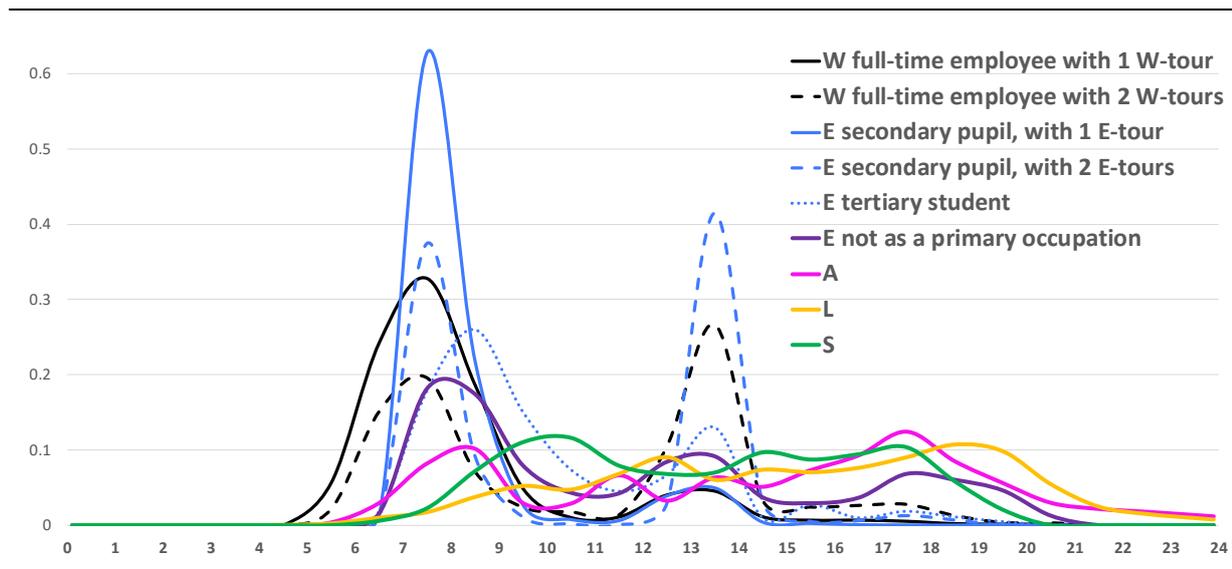
In a similar approach to the one taken by Hörl (2017), activity durations and desired activity start times are determined based on probability distributions that were derived from the travel diary survey. The distributions distinguish several demand segments that are specific to:

- the type of activity
- socio-economic attributes of the person
- the frequency of an activity in one plan (e.g. the workplace is visited once or twice)

**Figure 3** *Examples of probability distributions of desired activity duration*



**Figure 4** *Examples of probability distributions of desired activity duration*



### 3.6. Adjustment of plan components based on time budgets

The integrity of the plan requires that each plan must fulfil the following constraints:

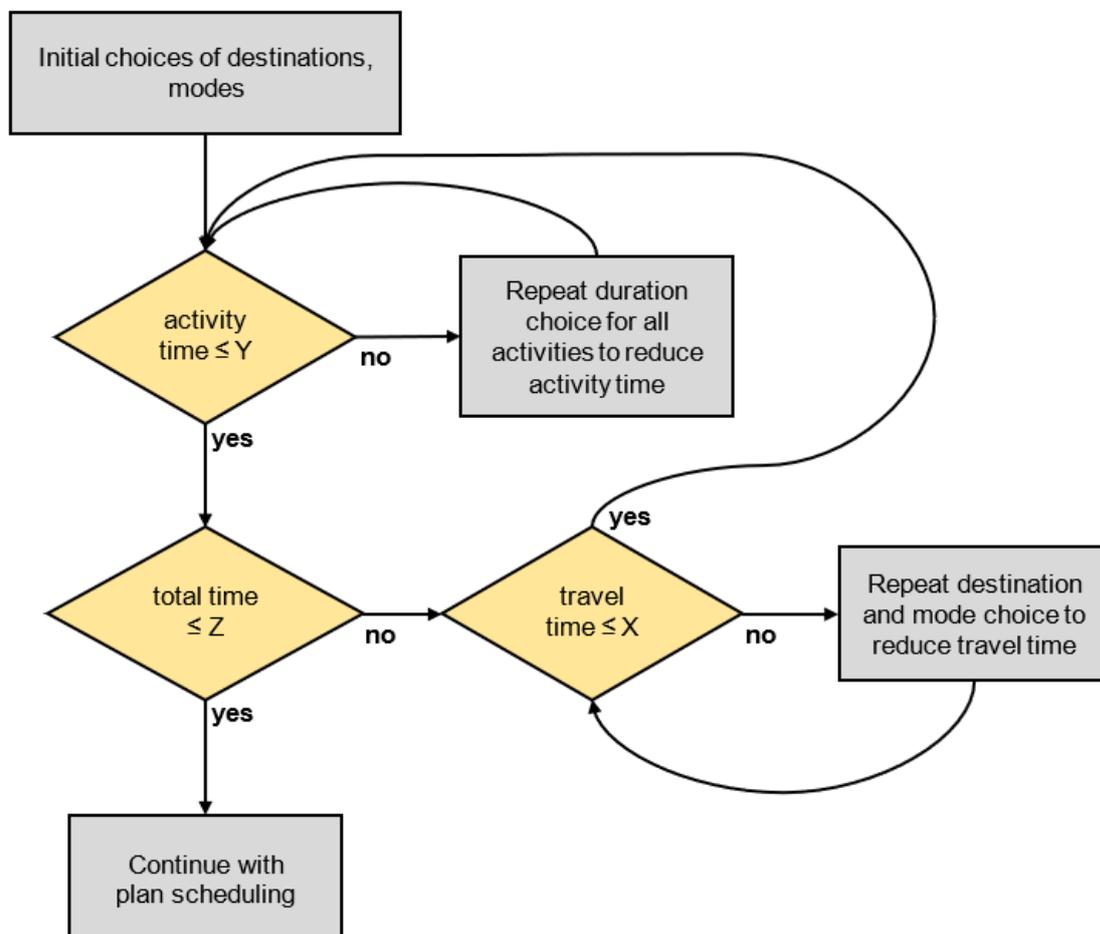
1. All activities must start between 0:00 and 24:00 hours (apart from the last home activity).
2. An agent can perform only one activity or one trip at a time.
3. The total of travel time shall not exceed the time budget X.
4. The total of activity time shall not exceed the time budget Y.
5. The total time spent on activity and travel episodes shall not exceed the total time budget Z, with  $Z = X + Y$ .

While constraints 1 and 2 will be enforced in the scheduling step (section 3.7), the step of plan adjustment will ensure that constraints 3 through 5, i.e. the time budgets are satisfied. To satisfy time budgets, the following changes can be performed:

- Redo the step of activity duration choice and so modify the durations of all activities.
- Redo the step of destination choice with the aim to obtain travel times that fit into the travel time budget.

We observed that 83.5% of the persons do not need an adjustment of the original preferences in their respective plan. Of the 16.5% who need adjustment, 8.2% adjust only activity durations, while the other 8.3% adjust also their destinations and modes. Note that the permanent locations of work and school places are not adjusted. Only the destinations of secondary activities, which are considered day-to-day choices, are reviewed. The following figure shows a simplified view of plan adjustment algorithm:

**Figure 5** *Rule-based plan adjustment algorithm*



### 3.7. Scheduling procedure

The scheduling procedure takes the activity chains (and so the sequence of activities in each tour), and the adjusted durations and travel times of all activities as they come out of step 3.6. Travel times between activities are looked up for each individual trip as a function of travel start times. With these inputs given, the scheduling procedure itself follows the principle of an “outward” approach described in Castiglione et al. (2015), with the rationale that priority is given to the primary activities and their durations, and that secondary activities and travel episodes are added before and/or after the primary activities. The procedure is given here in a simplified form:

*Order the activity chains according to priorities*

*Repeat min. m and max. n times:*

*For all tours:*

*“Step 1”:*

*Choose start time for the primary activity (or main activity)*

*Block time slots needed for the duration of primary activity*

*“Step 2”:*

*Block time slots needed for travel times to/from secondary activities*

*Block time slots needed for duration of secondary activities*

*Between tours, block a minimum of 30 minutes for the home activity*

*Compute objective function depending on time-of-day probability distributions*

*Keep schedule if it has a higher objective value than previous best schedule*

*If reached m and all activities start between 0:00 and 24:00: break*

*Else: continue*

*If not succeeded (exceeded n): discard the lowest tours in the priority order.*

*“Step 3”:* assign all remaining time slots to the home activity”

The above algorithm will discard tours from the schedule, if they do not fit into the 24 hours of the day. This is the last resort to assure integrity of the plans. But these cases are extremely rare (less than 4 ‰ of all trips), thanks to the step of plan adjustment (3.6), which is quite effective to assure that the timing constraints can be met by the scheduling procedure.

**Figure 6** *Example of the rule-based plan scheduling*

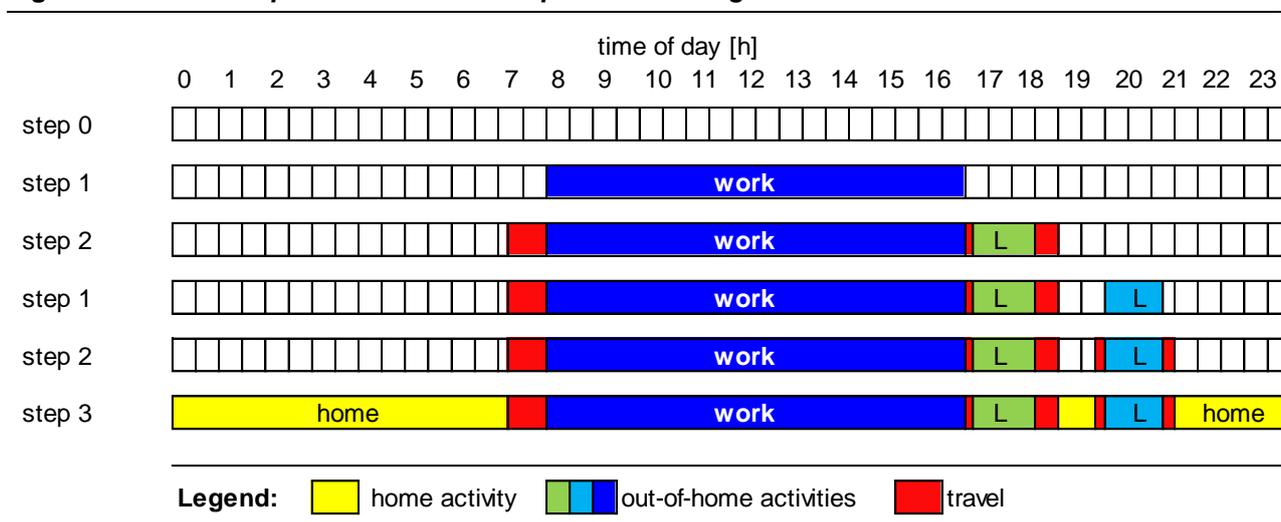


Figure 6 above illustrates the scheduling procedure for the example that was given at the introduction of the paper in Figure 1. This particular agent obtains a day schedule packed with activities and travel and spends only a short time at home between his/her two tours. It is a realistic plan, not untypical for younger “singles”, who have less motivation to spend time at home during the day than people in larger families would have.

### **3.8. Spatial discretisation**

After the scheduling step, all plans are precise in time. Start and end times of activities and travel times are given in hours, minutes and seconds of clock time. The spatial precision however is still mixed at this time. While home locations have precise coordinates, locations of primary and secondary activities are still based on the 8000 zones that were used in location and destination choice.

In the final step of the demand model, the activity locations are broken down from zones to geographically precise coordinates. The synthetic population provides facilities, which can be businesses, other institutions or households. These facilities are precisely geo-coded. The discretisation step chooses randomly for each activity of each agent one facility among all facilities in the destination-zone that are open for the respective activity. The random draw respects weights which correspond to the attractions  $A_j$  in destination choice: e.g. number of jobs in a work facility for activity work, school enrolment for education, number of jobs in retail for shopping.

We feel that this discretisation method is very effective for our model: The zonal system, which was defined by the Swiss Federal Government for travel modelling purposes, has a fine granularity with in average 1000 inhabitants. In urban areas, zones are small and accessibility to the transport network is homogenous across the zone, and hence random distribution of destinations can be independent of mode availability. In rural zones with less density however, there are significant differences of accessibility between the facilities within one zone. E.g. destinations can be 50m or 2000m from the next public transport stop. But, land use policies in Switzerland require facilities to be concentrated “in the village”, which is realistically represented in our synthetic population, and public transportation stops are also always located in the village center. Still, some agent’s plans who have chosen public transportation will obtain a destination of the trip that is not suitable for this mode. In that case, mode choice will be corrected during agent-based traffic flow simulation (see 3.10).

### **3.9. Complementary exogenous travel demand**

The activity-based demand model covers the travel of the resident population of Switzerland. To produce comprehensive traffic on the networks, exogenous demand is developed from the best available sources. The exogenous demand includes international rail travel, border crossing road traffic, airport travel by non-residents, travel by tourists and visitors (both road and rail).

### **3.10. Agent-based network simulation**

Endogenous plus exogenous demand is fed into an agent-based network simulation with MATSim, which implements a spatially fully disaggregate multimodal assignment (Horni et al. 2016). The traffic flow simulation is not described in this paper, having been calibrated earlier (Scherr et al. 2018, Rieser et al. 2018). The use of agent-based simulation requires strong plan integrity in space and time, as stated also in Vovsha et al. 2016. We have achieved this integrity of plans with the scheduling algorithm described in sections 3.6 and 3.7.

From the agent-based network model we also derive LOS-indicators, which are computed from/to discrete locations and then aggregated from/to zones to become input of MOBi.plans.

During the agent-based flow simulation in MATSim, each traveller will not only optimize route choice. Based on his/her individually experienced network conditions, also mode choice, activity duration, and departure time are adjusted.

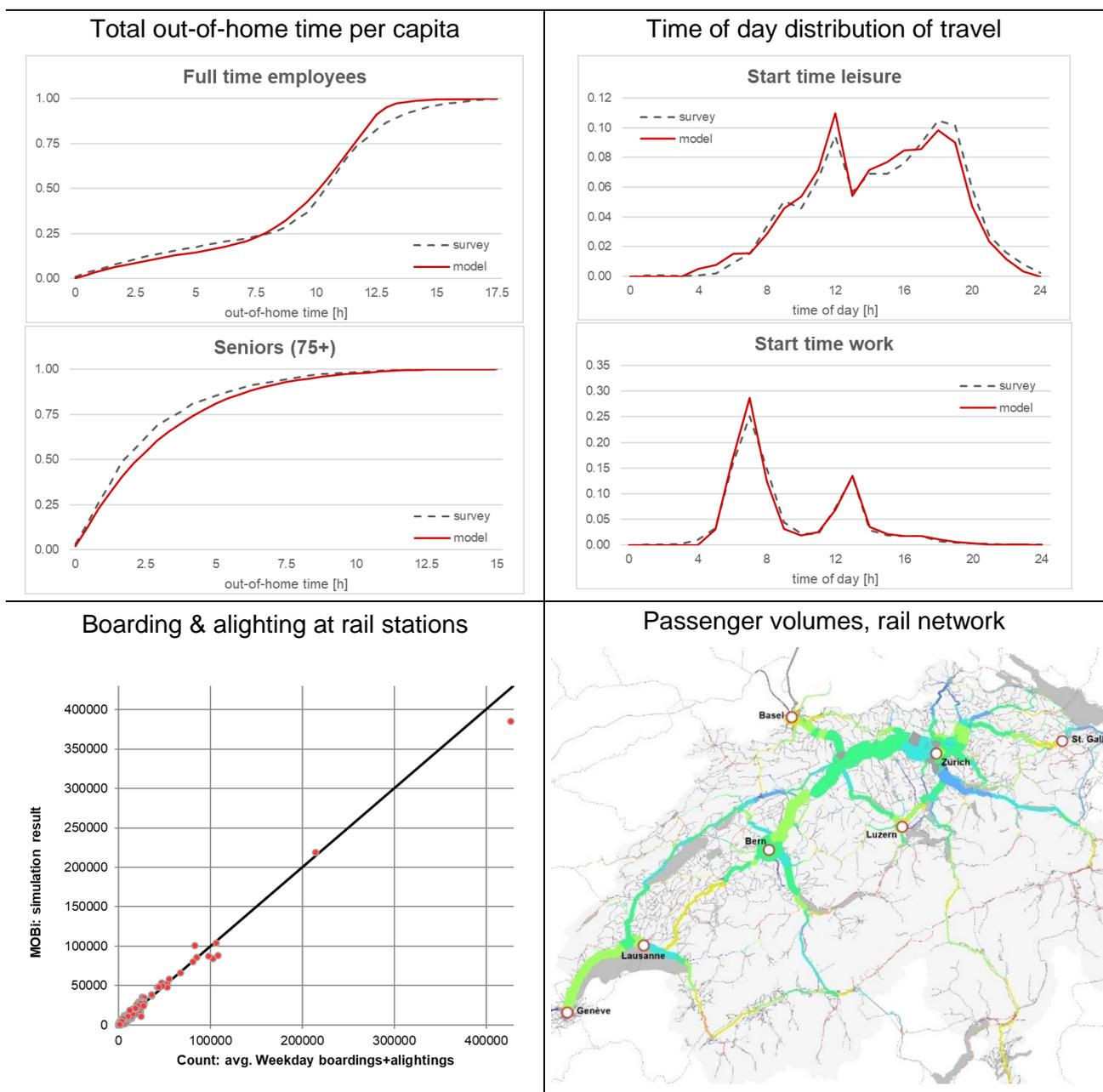
## 4. Results and conclusions

In May 2019, the model calibration was completed for the existing state. At the time of the conference, a set of first pilot applications and sensitivity tests will be completed, and the experience will be presented.

### 4.1. Validation

The model is validated in comparison to comprehensive travel statistics that include the national travel diary survey, national rail OD-survey, rail counts, other public transportation counts, road traffic counts, and SBB corporate data. In the following Figure 7 we show a few examples of validation.

**Figure 7** *Examples of model validation*



## 4.2. Summary: main properties of the model

The properties of the model SIMBA MOBi can be summarized as follows:

- Activity-based approach
- Microscopic simulation through all model steps: from generation to network flow simulation
- High resolution of time and space
- Use of aggregated zones in intermediary steps, while the final demand has exact geographic locations for all destinations in a plan
- Person-based simulation, taking household properties in consideration in persons' decisions, but not modelling household interactions explicitly.
- Representation of 24 hours of the average weekday
- Strong integrity of the time and space sequence of activities and travel along 24-hour plans
- A focus on the representation of variables (person attributes and transport LOS) that explain travel choice for or against public transportation.
- A strong effort in model calibration to allow for the analysis of travel volumes and capacities on a transportation project level.

## 4.3. Conclusions

Based on our experience we state that microscopic activity-based models are ready for practice. We have achieved model calibration to a goodness of fit as it is expected in the practice of macroscopic models. Microscopic models today require more staff time and computer resources than conventional models. Some of the reasons are: complexity of the approach, increased amount of data and parameters, software tools still being under development in terms of functionality and user friendliness. We continue to work on improving usability and computational efficiency. On the other hand, there is a lot of benefit from microscopic modeling. The high geographic and socio-economic granularity of travel demand allows for analyses that were unthinkable with conventional models. Among those are: traveler composition according to multiple attributes, coverage of all legs of travel from door to door, time-dynamic outputs over 24-hours, analysis of all public transportation stops without the limitation to major stations. Further, we expect increased possibilities in forecasting future mobilities: Agent-based traffic flow simulation enables the integration of new travel modes and the activity-based demand model allows for changes in activity and travel patterns of future populations (e.g. "active seniors" perform more activities and longer trips than the same age group does today).

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