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Agent-based integrated land use/transport models: a study on scale factors and transport model simulation intervals

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Abstract

Modern agent-based models often suffer from long runtimes (computation times). While quite a few studies deal with runtime issues in transport models, there is less research with respect of agent-based, integrated land-use transport (ILUT) models. This paper examines how the transport model interval in an ILUT model suite affects runtime and results. In addition, the possibility of scaling the synthetic population, which is a common approach in agent-based transport models, is tested on the land-use side. Results suggest that transport models do not necessarily need to run every one or two years and larger intervals like five years lead to similar results. However, if intervals are too long, there error of estimated travel times in the years between transport model updates become larger. Scaling the land-use population does not result in large reductions of runtimes if the transport model population is kept uniform. Thus, scaling the land-use model population can be used to actually model every agent individually in the transport model. On the other hand, if the transport model population is scaled down with respect of the land use model, runtimes can be improved. In both cases, the results of the land use model appear to be stable in when using smaller population sub-samples, as far as the resolution of the analysis is not too small.

Keywords: integrated lan the furund-use transport modeling; agent-based models, sampling rate;

1. Introduction

Fully integrated land use/transport models offer high fidelity for scenario analysis, but computational runtimes may increase dramatically. This is all the more concerning in agent-based models that tend to have longer runtimes than comparable aggregate models. There are several studies that developed methods to improve the runtime of agent-based transport models, such as decreasing time step resolution [12], macroscopic travel time estimation [1], reduction of assignment computation time by using surrogate models [4], improving the efficiency of computation [2] or scaling the synthetic population by using a sample of the full population [7].

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The easiest and most widely used method to reduce computational runtime is scaling the population to a sample. While the effects of scaling in a queue-based transport simulation like MATSim have been analyzed in previous studies, sampling has not been tested in integrated land use/transport models yet. The impact of scaling of the synthetic population in land use models is largely unknown.

As transport models (to simulate one day) tend to run slower than land use models (to simulate changes over the course of one year), most integrated land use/transport models run the transport model in selected years only. Intervals range from running the transport model every third year (e.g. [11]) to every twenty years (e.g., [3]). Even though the frequency of the transport model has a substantial impact on model runtimes, there is no systematic study of the influence of transport model frequency on model results.

This paper examines the impacts of scaling the synthetic population in an integrated land use/transport model. The impact on model runtimes and on model results are discussed. In addition, different intervals for transport model execution in between land use years are analyzed.

2. Modeling suite

In this paper, the FABILUT (Flexible, Agent-Based Integrated Land-Use/Transport) modeling suite is employed [9, 13]. The suite consists of the land use model SILO (Simple Integrated Land use Orchestrator) [8] and the transport simulation MATSim [5]. A tight integration was made possible as both models are open-source and written in Java. SILO uses a synthetic population consisting of households, persons, dwellings and jobs [10]. From one simulation year to the next, SILO models demographic changes (such as marriage, birth and death), real estate developments (such as construction, renovation, housing demolition) and household relocation. Every household of the synthetic population is microscopically simulated. An important part of the household relocation utility is a reasonable representation of commute travel times and accessibilities of locations, both of which are updated by MATSim that is executed in pre-selected years. In such transport model years, the current state of the synthetic population in SILO is converted into MATSim agents which are used to simulate traffic flows in MATSim.

MATSim is an agent-based transport simulation in which agents aim to maximize their personal *score* for a given daily plan [5]. A plan may consist of multiple activities throughout a day and can include, for example, going to work, shopping or staying at home. To increase their score, agents try to minimize time spent traveling and still conduct their desired activities. MATSim uses an iterative approach to let agents learn and adapt to their daily schedule. In every iteration, agents execute their current selected plan. In the subsequent scoring step, every agent scores its last executed plan. After scoring, a certain share of agents is selected to adapt their plan by adjusting travel behavior, e.g. by re-routing based on current travel times. This procedure is repeated until no agent can unilaterally increase its score anymore. Once the transport model has finished, updated travel times are fed back to SILO by either providing a skim matrix that contains averaged zone-to-zone travel times or by feeding back the MATSim router to allow agents in SILO to route individually at their specific time and position [6].

The runtime of the FABILUT modeling suite can be anywhere between a few hours and a few days - depending mostly on the size of the scenario, the interval of transport simulation runs, the spatial resolution of the network and the scale factor of the population. As the size of the scenario and the frequency with which the transport model is run are relevant factors of the overall runtime, this paper examines the consequences of (a) using different intervals between transport model runs and (b) scaling down the synthetic population at different rates.

3. Study area and setup of scenarios

The FABILUT modeling suite is implemented for the metropolitan region of Munich. The study area was delineated based on commuter flows and includes the core cities Munich, Augsburg, Ingolstadt, Rosenheim and Landshut, and every nearby municipality from where at least 25% of all workers commute into those core cities.

We choose a base scenario that forecasts demography, job market and household relocation changes from the base year 2011 to the future year 2041. The initial year was selected because of the availability of census data and to allow for model validation in the current year 2019. A synthetic population was generated for 2011 that is updated in SILO on a year-by-year basis. The base scenario is set up with constant population and job growth rates of 0.5% per year. The years in which the transport model is run are selected individually by the user. In the past, the transport model

Table 1: Simulations with uniform transport model population size (S_ are simulated scenarios)

SILO scale factor	Silo agents	MATSim scale factor (vs. land use model	MATSim agents	Transport model interval		
				2 year	5 year	15 year
100%	4,400,000	5%	119,000	S1	S2	S3
50%	2,200,000	10%	119,000			S4
20%	880,000	25%	119,000			S5
10%	440,000	50%	119,000			S6
5%	220,000	100%	119,000			S7

Table 2: Simulations with down-scaled transport model population size (S_ are simulated scenarios)

SILO scale factor	Silo agents	MATSim scale factor (vs. land use model)	MATSim scale factor (vs. reality)	MATSim agents	Transport model every 15 years
100%	4,400,000	5%	5%	119,000	S3
50%	2,200,000	5%	2.5%	59,000	S8
20%	880,000	5%	1%	24,000	S9
10%	440,000	5%	0.5%	12,000	S10
5%	220,000	5%	0.25%	6,000	S11

was only run every 12 years due to runtime constraints. Given that the Munich metropolitan area grows in population and employment, travel times may change noteworthy in 12 years. One motivation of this paper was to overcome this shortcoming. To simplify the model setup for this paper, no changes are implemented in the car and public transport networks during the simulation period.

Traditionally, SILO works with the full synthetic population. For this paper, we added a method to scale down the population in SILO. The method is applied before the start year, and randomly selects households (and all their members) to the predefined scale factor. Vacant jobs and dwellings are randomly sampled too, and land availability is reduced proportionally. In the years when the transport model runs, the SILO population (independently of whether it was scaled before the start year) is scaled to the MATSim scaling factor and converted into MATSim agents. The two scaling factors are independent from each other. The MATSim population is assigned to a network of a capacity reduced by the product of both scale factors (e.g. a 50% scaling factor in SILO and a 10% scaling factor in MATSim represents $50\%x10\% = 5\%$ of the reality, thus the network capacity is reduced to 5%).

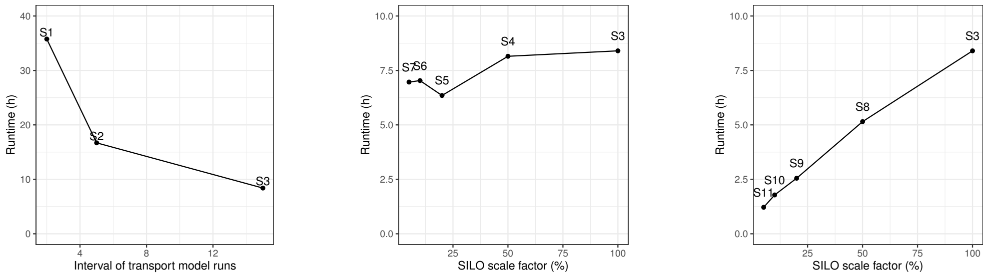
The paper compares different model runs that vary in their set up in three dimensions. Firstly, by using different parameters regarding the frequency with which the transport model is run (interval in years between successive transport model runs). Secondly, by changing scaling factor of the land use model (percent of the synthetic population that is simulated by the land use model SILO) and lastly by additionally scaling the transport model MATSim.

In previous applications of the FABILUT modeling suite, the land use model represented 100% of the population, and the transport model typically was set to simulate 5% of the agents. The capacity of the network was scaled accordingly to 5%. This configuration will be used as the reference configuration. For the objective of the paper, we propose two sets of simulation setups. For the first one, the number of agents simulated by the transport model is kept constant, and only the land use model population is scaled (see Table 1). The second model setup scales down both the land use and the transport models, as show in Table 2. Here, the transport model represents always a 5% of the land use population, therefore its simulated population is progressively smaller.

4. Findings

Simulation results of scenarios defined in Tables 1 and 2 are evaluated by comparing (a) runtime of the entire modeling suite, (b) Number of households by region and year (to test stability of model results, we selected 4 different regions, i.e. counties, of decreasing population to analyze different area types) and (c) Commute times by region and year, defined as the time by car between home and job location. The average is calculated for the region of residence.

Figure 1a shows that –as expected– an increase of the frequency in which the transport model is run results in longer runtimes of the entire suite. The effect is nearly linear with respect to the number of times the transport model



(a) Transport model interval (b) Uniform MATSim population (c) Reduced MATSim population

Fig. 1: Runtimes. The labels indicate the simulated model configuration, as defined by Tables 1 and 2. Note that the vertical scale of (a) is different from (b) and (c).

is run (it runs three times in S3, seven times in S2 and 16 times in S1). Figure 1b shows the different SILO scaling factors. As the MATSim scaling factor was adjusted inversely to the SILO scaling, there is no significant change of the transport model duration. Very small savings are derived from a small SILO population, and the outlier of S5 is assumed to be caused by random variation. However, if we reduce the population of the land use model SILO in conjunction with a reduction of the population of the transport model MATSim, the runtime is reduced significantly (Figure 1c) from 8 h (S3) to approximately 1 h (S11).

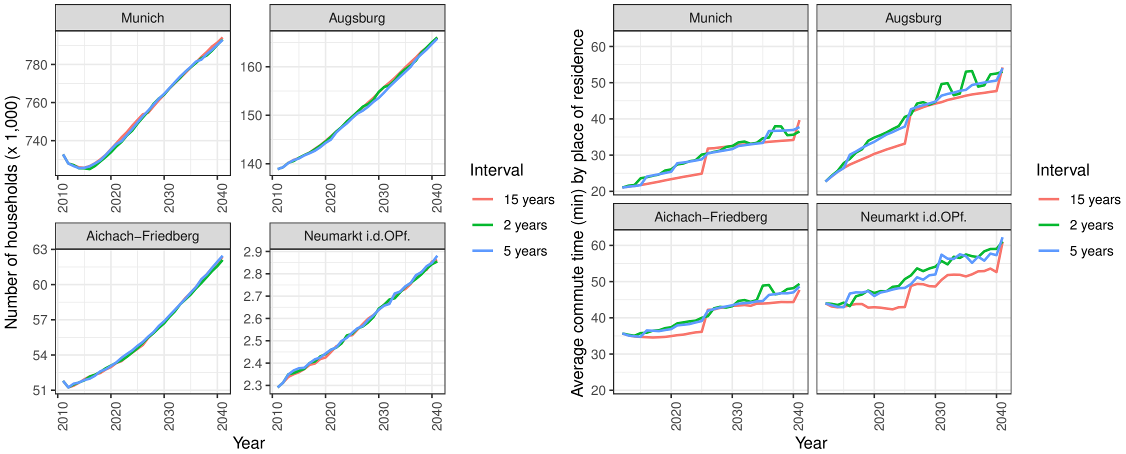
Figure 2 shows the land use and transport indicators for the settings with different intervals between transport model years. Regarding the spatial and temporal distribution of the population (Figure 2a), no significant changes between model setups are detected. This suggests that scaling SILO to smaller populations does not affect too much model results and that scaling agent based land use models is an appropriate method to reduce runtime. The comparison of average commute times (Figure 2b), however, shows a significant impact of the frequency with the transport model is run. While the average commute time at the end of the simulation is very similar for the three settings, but the evolution along the simulated period differs. When the interval is 15 years, there is a transport model run in 2011, 2026 and 2041. Accordingly, the average commute time in the years between transport model runs differs significantly more than for settings in which the transport simulations are conducted more frequently. The differences between running the transport model every 2 years and every 5 years are much smaller. With the smallest tested interval of two years, we observe unstable results, as commute times oscillate at successive transport simulations.

The Figures 3 and 4 compare results for scenario in which SILO is scaled. In the first case, the transport model scale is adjusted to maintain a uniform population size, in the second, it is scaled as well. The results in terms of population distribution (sub-figures a) and in terms of commute times (sub-figures b), are similar in both approaches. The differences in the count of households across different scale factors are minimal for mid-sized counties (such as Aichach-Firedberg (bottom-left)). For larger counties (top), the use of smaller scale factors for SILO results in smaller household counts. This is a yet unknown consequence of scaling the synthetic population of SILO, as it does not appear in the base year but in later years, and differences over the course of time. For very small areas, the differences across scale factors are due to random variation of the scaling process. Commute times only differ significantly for small counties due to the randomness of the scaling process.

5. Conclusions

Based on the results of the paper, we observed that different intervals between transport model runs produce different forecasts of commute times. Too long intervals reflect jumps in the average commute time, since the effects of land use changes (relocation) on transport are neglected until the transport model runs. Too short intervals show average times going up and down. The relocation models in SILO do not have memory, because it was designed under the assumption that the transport models would not run frequently. Therefore the changes in transport situation every few years can trigger households to relocate too frequently.

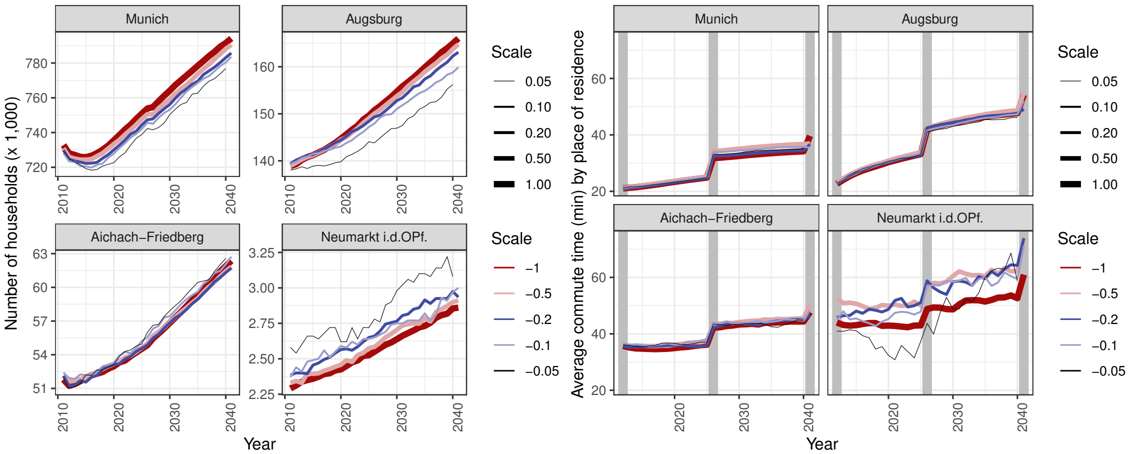
In relation with the scale, using a sub-sample for the land use model is effective to reduce the runtime, but only if the transport model is scaled as well. For land use analyses, where the function of the transport model is to generate



(a) Number of households

(b) Commute time

Fig. 2: Scenarios with different transport model intervals



(a) Number of households

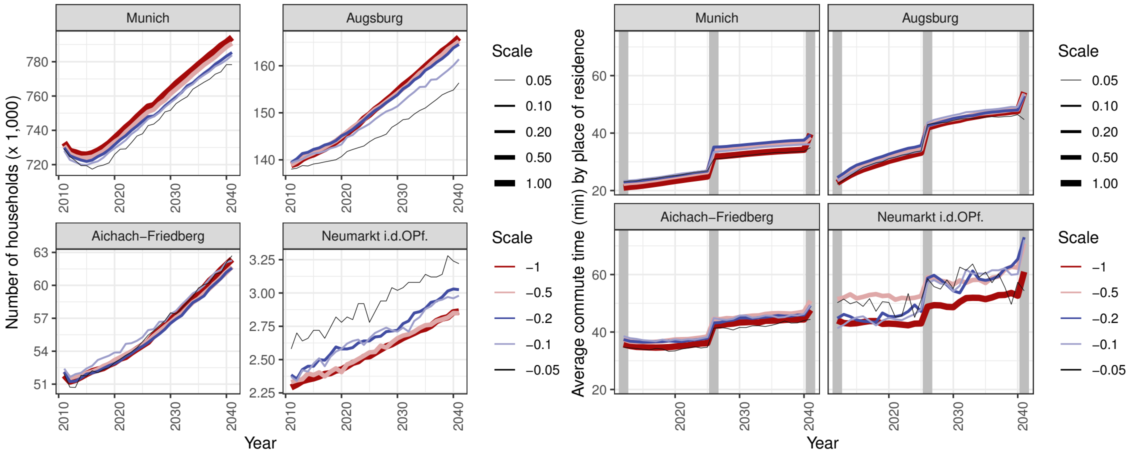
(b) Commute time

Fig. 3: Scenarios with uniform transport model population

travel time matrices, the use of transport simulations of 1% or less were acceptable. On the other hand, if the land use model is scaled down, but the transport model population size remains constant, there is no benefit for runtime. But, if every agent of the land use model is simulated by the transport model (e.g. in the case SILO was scaled to 5% and MATSim to 100% of SILO) there is an equivalence 1:1 between the models. This opens new opportunities for the integration of land use and transport, since land use decisions may depend on actual travel patterns of the agent, and not only in travel time information, unrelated to persons, possibly improving current research [6].

However, we also detected some shortcomings of the scale process. First, the accuracy of the results at small areas is lower, due to random effects. Second, the microscopic output of the land use model (events of relocation, marriages, etc.) cannot be analyzed individually, since no information is provided for the non-simulated events (that belong to the non-simulated sample). Third, the scale of the transport model has to be smaller or equal to the land use one. Therefore, the transport model cannot simulate more agents than the land use model.

Although the results of the paper cannot assess the validity of the simulation results, the output of scaled scenarios was found to be, with certain restrictions, equivalent to the output of the full-scale ones. Consequently, such smaller and faster model runs are crucial at the mode development phase.



(a) Number of households (b) Commute time

Fig. 4: Scenarios with reduced transport model population

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