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Towards an agent-based, integrated land-use transport modeling system

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Abstract

This paper reports on initial steps of an integration of the microscopic land-use simulation system SILO (Simple Integrated Land-Use Orchestrator) and the agent-based transport simulation system MATSim (Multi-Agent Transport Simulation). It is shown how information can be transferred from the land-use model to the transport model in an agent-oriented fashion and how MATSim can be used as a transport model within the SILO framework in lieu of an aggregate transport model, which SILO has been coupled with up to now. It is shown that results of the previous model structure can be reproduced by the new fully microscopic modeling system based on SILO and MATSim. It is discussed how an agent-based transfer of information can also be established in the reverse direction, i.e. from the transport model to the land-use model based on the implementation of a query architecture. Finally, it is discussed how an integration of SILO and MATSim can help addressing additional current demands for research.

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Keywords: integrated land-use transport modeling, land-use modeling, transport simulation, agent-based modeling, agent-based simulation

1. Introduction

Hansen, with his well-known work on accessibilities[6], established the concept that trip and location decisions co-determine each other.[1] The transport system determines how well locations for activity participation can be reached, which can trigger or hinder land-use development. The field of accessibility computation is concerned with the quantitative expression of this phenomenon.[6,5,24] The land-use system defines where trips originate and end, which affects the use of the transport system. This interrelationship has been widely recognized and is known as the *land-use transport interaction cycle*.[22] Over the past 60 years, a considerable amount of cross-disciplinary research has been undertaken to understand and analyze this relationship, which has established a long-standing tradition of *integrated land-use and transport (ILUT) models*.[22,23,8,1]

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In the traditional way of integration, the transport model provides zone-to-zone travel times (and sometimes travel distances and costs; often referred to as *skims*) that are used in the land-use model to calculate accessibilities, which influence land-use decisions. The land-use model, on the other hand, provides the locations of households and jobs, which are used by the transport model to derive trip origins and destinations.[4,21,18,20] With the increasing consideration of transport demand management policies – in contrast to previously prevalent *predict-and-provide*-based infrastructure enhancement policies – more sophisticated policy analysis questions have become relevant. Flextime workers are able to adjust their worktime – potentially also in response to current congestion conditions. Teleworkers may only need to travel to work once a week, reducing their commute burden substantially. Low-emission zones in city centers may reduce (or increase) the ease with which people can access city-center facilities, potentially dependent on time of day and on vehicle type (e.g. vehicle emission class).

It is obvious that such highly individualized conditions cannot be considered in traditional ILUT models. Recently, ILUT models have benefitted from disaggregate modeling methodologies such as microsimulation.[1] This paper presents an approach of developing a *fully microscopic integrated land-use transport model* by integrating the microscopic land-use model SILO (Simple Integrated Land Use Orchestrator) with the microscopic transport simulation model MATSim (Multi-Agent Transport Simulation). In this sense, the present study addresses several of the most prevalent issues in integrated land-use transport modeling, which Acheampong and Silva[1] summarize:

- There is the need to bridge the gap between the proliferation of activity-based travel demand models and their integration with operational ILUT models in practice.
- The capabilities of existing models need improvement with respect to integrating the environment and forecasting the impact of future urban policy responses on climate change and energy scarcity.
- Robust methodologies for measuring accessibility, the key concept that links land use and transportation, are needed to adequately evaluate the effects of land-use policies on transportation and vice versa.

In this paper, it is shown how MATSim can successfully replace an aggregate transport model that SILO has been coupled with until now. An agent-based transfer of information from the SILO to MATSim is established, which shows how the two models can be coupled in a methodologically sound way based on individual agents. Furthermore, the feasibility and some implementation details of a fully agent-oriented integration are pointed out. Conceptual advantages by allowing the land-use model to query the transport model for specific information are discussed.

The microscopic land-use model SILO. SILO (www.silo.zone) consists of three main modules: (1) The core module is the *household relocation* module, in which individual households consider moving to alternative dwellings subject to their available housing and travel budgets as well as to commute travel times for each worker in the household. Because SILO functions as a microsimulation in which households with their respective income and household members with their individual workplace are represented explicitly, the model is able to reflect monetary and time constraints explicitly.[12] (2) The *demography* model covers all relevant demographic events, including aging, marriage and divorce, birth of children, children leaving the parental household, death, car ownership, and change of employment status or workplace. (3) The *real estate development* module simulates developers who invest into new dwellings if demand is high. Developers imitate household location preferences to build the most marketable housing stock. Some dwellings deteriorate over time and may be demolished eventually. Other dwellings are renovated. This module also includes a price model that adjust housing prices upwards under high demand and downwards if demand for a given dwelling type in a neighborhood is low.

The agent-based transport simulation system MATSim. MATSim (www.matsim.org) is an agent-based demand adaptation and traffic assignment model. Each synthetic person (*agent*) in the model has one or more *plans*. A plan is a chain of activities (e.g. *home–work–shop–home*), including their locations and end times. Activities at different locations are connected by transport. The MATSim loop consists of the following important elements: In the *network loading* (also called *mobility simulation*), all selected plans are simultaneously executed in a synthetic reality, which, e.g. produces congestion. Next, all executed plans are *scored*, e.g. by a utility function, based on their actual performance. Finally, all synthetic persons are allowed to *replan*, e.g. by switching to another plan in their memory, or by generating a new plan, e.g. using other routes or other modes of transport. This loop is iterated until the system is sufficiently "relaxed" as determined, for instance, based on the development of agents' plan scores.

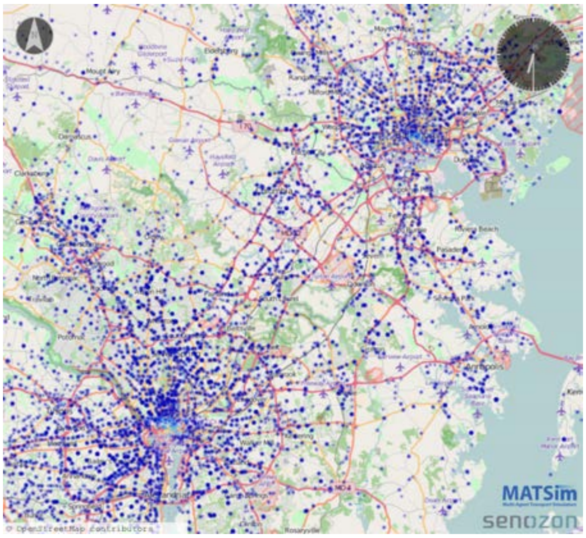

Fig. 1: Spatial distribution of home and work activities in the Baltimore-Washington metropolitan area based on the SILO land-use model.

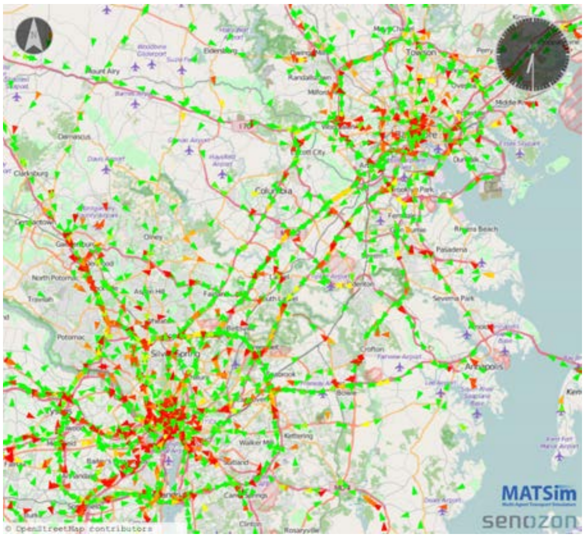

Fig. 2: Agents traveling in the MATSim transport system simulation.

2. Methodology: An initial version of an integration of SILO and MATSim

The latest version of SILO is the implementation for the state of Maryland (and vicinity) in the United States. In that implementation, SILO is coupled with the Maryland Statewide Transportation Model (MSTM),[11] which encompasses 1,892 traffic analysis zones (TAZs). Out of these, 1,588 are included in SILO as depicted in fig. 3. 10,683,182 persons, 4,153,836 households, 4,367,805 dwellings, and 5,979,254 jobs are contained in the model. This scenario is also used for the integration between SILO and MATSim in the present study. Besides information on the population, MATSim requires a transport network, which is created based on OpenStreetMap (OSM) data following established procedures.[26] The resulting network contains 188,747 nodes and 367,295 links. In this initial step, default values are used to set speeds and other network attributes. Required adjustments of these values for North America are deliberately left aside in this initial model integration approach. To date, only car traffic is considered.

Transferring Information from Silo to MATSim. As described in section 1, SILO is based on the simulation of decisions of the members of a synthetic population. Each such individual is represented by a Java object called `Person`. To establish an agent-based connection between SILO and MATSim, the following process is carried out at the end of each simulation year in SILO: With a probability of *scalingFactor*, a given SILO person is shortlisted to create a MATSim agent. A MATSim agent is created if the corresponding SILO person is (1) employed, (2) has a workplace within the study area, and (3) has the possibility to travel by car as determined based on a comparison between the number of cars and workers in the corresponding SILO `Household`. To account for people on holiday or sick leave, workers commuting at non-peak times, and commuters not using an available car option, the aforementioned probability to create a MATSim agent is multiplied with a value of $2/3$. Setting the *scalingFactor* to 0.01, this creates a 1% sample of all people commuting by car (26,980 agents) to simulate the morning and afternoon peak commute traffic in Maryland and vicinity. 1% samples have proven to be sufficient to observe plausible larger-scale traffic patterns.[13,14,19]

Via the SILO `Person` objects, the IDs of home and work zones of the selected SILO persons are retrieved. Next, a random coordinate which falls within the correct zone is determined and assigned as the home and workplace location of the agent, respectively. Every MATSim agent is then assigned with a home, a subsequent work, and a final home activity at its home and workplace locations, respectively. These activities are depicted by blue dots in fig. 1.

To create trips from that information, trip start times (= activity end times) are needed. In this preliminary approach, these times are chosen randomly based on uniform distributions between 6:00 and 9:00 for the morning and between 15:00 and 18:00 for the afternoon commute, respectively. The resulting morning traffic at 6:30 is depicted in fig. 2.

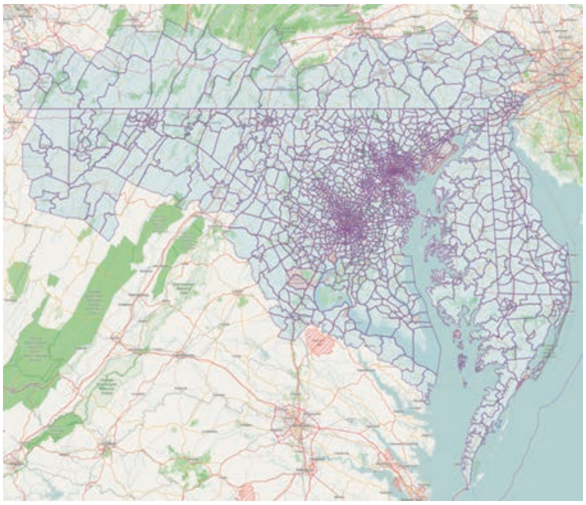

Fig. 3: Zones used in MSTM and SILO.

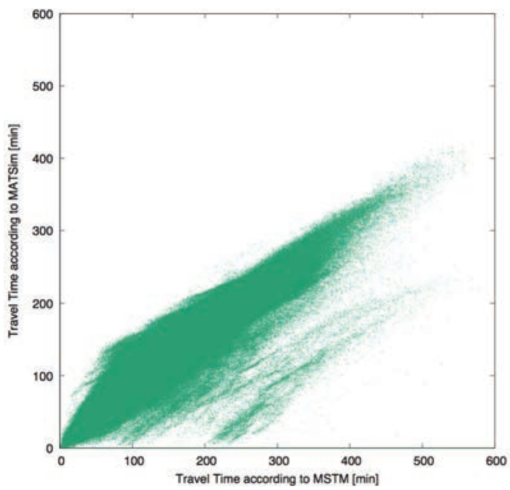

Fig. 4: Comparisons of zone-to-zone travel times according to MSTM and MATSim.

Transferring Information from MATSim to SILO. In contrast to the agent-oriented provision of information from SILO to MATSim, the provision of travel information from MATSim to SILO follows the traditional approach of information exchange that was described in section 1. SILO requires zone-to-zone travel times, which are in its latest previous implementation provided by MSTM, which operates on the same zoning system as SILO (see fig. 3).

For the present study, this way of providing travel information to the land-use model is replicated by using MATSim in lieu of MSTM. In MATSim, traffic-condition-dependent (= time-dependent) travel times can be computed using so-called least-cost-path trees in a computationally efficient manner. In the current implementation, n random coordinates of each zone are chosen and used to calculate n^2 time-dependent zone-to-zone travel times for each O-D relation. The average of these n^2 travel times is provided to SILO in a zone-to-zone travel time matrix replacing the travel time skims provided by MSTM in the latest previous version of SILO. They can be interpreted as rush hour travel times of a typical day on a given O-D relation. These travel times are used to compute zonal accessibilities in SILO. Individuals in SILO use these accessibilities while taking household relocation decisions.

3. Results

First of all, it should be stated that this initial integration between SILO and MATSim was much easier to achieve than a similar integration between UrbanSim and MATSim.* This is mostly due to the fact that both MATSim and SILO use the same programming language (`Java`), while UrbanSim is programmed in `Python` based on `C`.[15]

Fig. 4 shows a comparison of zone-to-zone travel times between MSTM and MATSim. As expected, a cigar shape can be observed confirming the similarity of the travel times yielded by the two different transport models. It can also be observed that travel times tend to be lower in MATSim. The authors assume that this is attributable to the fact that MATSim has not been calibrated for the scenario under consideration at this early development stage. In particular, default values for the creation of a MATSim tansport network based on OSM data have been left unchanged (see section 2), which may result in speeds that are systematically too high for the North American context.

Fig. 5 and fig. 6 depict congestion levels for a typical weekday at 8:00. While fig. 5 shows real-world observations, fig. 6 is based on model results from MATSim. It can be observed that congestion patterns are generally reproduced quite well by MATSim. That this is the case already in this uncalibrated stage of the scenario also reaffirms the high transferability of MATSim as a transport model.[25]

* The reported integration between UrbanSim and MATSim[17] was preceded by a prototypical integration at the end of 2008.

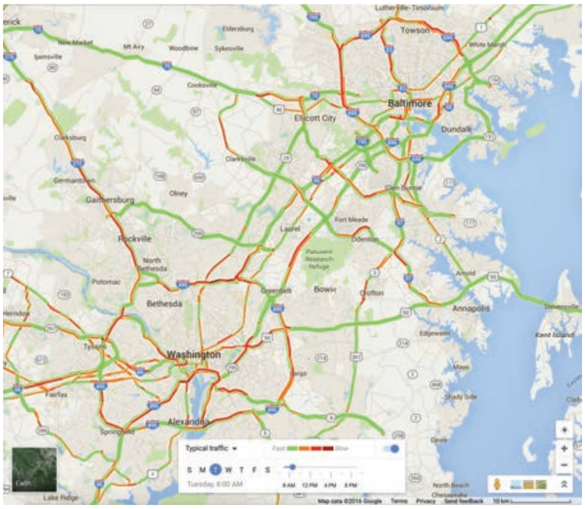

Fig. 5: Real-world traffic in the Baltimore-Washington metropolitan area on a weekday at 08:00 (Source: Google Maps).

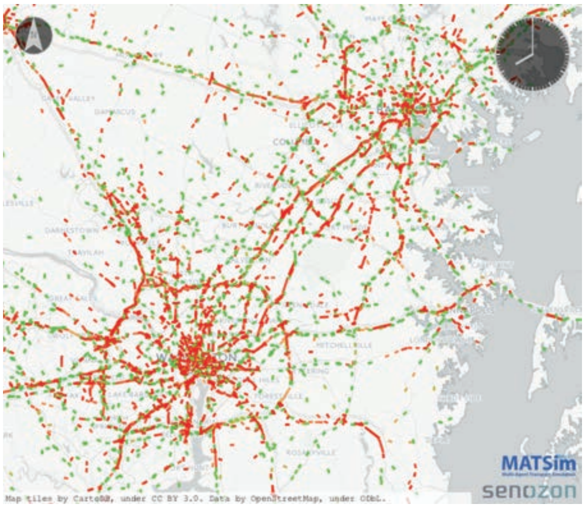

Fig. 6: Simulated traffic in the Baltimore-Washington metropolitan area on a weekday at 08:00 according to MATSim.

4. Discussion and outlook: Further steps of improving the integration of SILO and MATSim

While the transfer of data from SILO to MATSim has already been implemented in an agent-oriented way, this is not yet the case for the reverse direction, i.e. for the provision of travel data from MATSim to SILO. A first step of improvement may consist in computing the accessibilities already within the travel model.[16,17] Instead of scaling with the *square* of the number of zones like for the travel times matrix, accessibility information only scales *linearly* with the number of zones. This allows to feed back information at much higher spatial resolution.

Still, the currently used process of a *pre-emptive procurement* of all necessary information to the land-use model contradicts the concept of behavioral modeling (see enumeration of requirements in section 1). A major conceptual improvement to this would be to allow the land-use model to *query* the transport model for required information for a specific decision (= modeling step). In terms of household relocation, for instance, a person that just started a job close to a train station might want to look for a home close to a train station on the same train line, rather than just searching for a home within a large zone that provides good access to the person's workplace zone *on average*. Since it is impossible to provide such information pre-emptively for all possible questions that might be asked by a behavioral component of the land-use model, it seems more plausible to turn the established modeling philosophy upside down and to establish a *query architecture* between the land-use model and the transport model. By this, the land-use model would be enabled to query the transport model for very specific information that is relevant for a person with specific attributes (e.g. a flextime or teleworker; cf. section 1) that may be much less relevant for other people (e.g. a worker with rigid work hours). Based on experience with the interplay of SILO and MATSim to date, the authors expect this to be much easier to implement than this would be with UrbanSim and MATSim (mainly due to the fact that SILO and MATSim are both written in `Java`).

In order to improve activity timing (see section 2) and also to be able to model land-use transport dependencies in terms of secondary activities (e.g. shopping or leisure), it would be beneficial to include a scheduling module for overall *daily activity-travel patterns* like CEMDAP[3] or FEATHERS[2]. Based on the authors' previous experience with integrating such models with MATSim, the general feasibility of such an integration is proven.[25]

Finally, it has to be pointed out that already the present integration allows environmental impact modeling of land-use policies (see enumeration of requirements in section 1) since MATSim is already equipped with, e.g. an emission modeling tool[10] and a noise calculation tool[9]. The intended deeper, fully agent-oriented integration of SILO and MATSim would also allow to base smaller-scale location choice decisions on such information.

5. Conclusion

It was shown how MATSim can successfully replace an aggregate transport model that has been coupled with the microscopic land-use model SILO until now. An agent-oriented transfer of information from the land-use model to the transport model has been established. Based on this experience, the feasibility and some implementation details of a deeper, fully agent-oriented integration were pointed out. In particular, conceptual advantages by allowing the land-use model to query the transport model for specific information required to model decisions within the land-use model in a behaviorally sound way were discussed. Based on the fact that SILO and MATSim are both programmed in Java and the authors' current experience of coupling the two models, the feasibility of establishing a *fully agent-oriented integrated land-use transport modeling system* based on SILO and MATSim was shown. Furthermore, the potential of addressing currently-discussed requirements on new ILUT models like environmental impact analysis as well as potential model enhancements by considering full-day activity-travel patterns were addressed.

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