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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Benefits of Integrating Microscopic Land Use and Travel Demand Models: Location Choice, Time Use & Stability of Travel Behavior

Rolf Moeckel[a]*, Michael Heilig[b], Tim Hilgert[b], Martin Kagerbauer[b]

[a] *Technical University of Munich, Arcisstr. 21, 80333 Munich, Germany*
[b] *Karlsruhe Institute of Technology, Kaiserstraße 12, 76131 Karlsruhe, Germany*

Abstract

The land use/transport feedback cycle has been described since decades. The transport system provides travel times under congested conditions, which are used in land use models to assess the desirability of locations. Based on where people live and work, demand for travel is derived which leads to updated congestion, and hence, new travel times. There is a renewed interest in combined land use and travel demand models, as new trends, such as telework or driverless vehicles, are expected to have substantial influence on land use/transport interactions. Modeling the impact of such scenarios simply cannot afford to leave the land use forecast static and unaffected by changes of the transportation system. The research presented in this paper proposes a new way of integrating a land use model with a travel demand model. Traditionally, land use models provide location and employment information of the synthetic population for the travel demand model, and the transport system feeds back accessibilities as one of many location factors to the land use model. For improving the cause-and-effect correlation of travel demand and land use models an integrated approach is worthwhile. The project, however, will be the first to microscopically integrate these models at the agent level. Individual activity schedules will influence individual household relocation. Vice versa, changes of the housing location, location of work and school places and the likelihood to conduct telework will influence activity patterns for a household. Representing both systems in integrated land use/transport models results in more reasonable sensitivities than provided by models that represent only one domain. What has not been accomplished before is a microscopic integration of travel demand and land use models. Even projects that integrated microscopic land use models with activity-based models did not improve upon the integration step, but merely linked two microscopic models in a traditional way through accessibilities, and thereby, missing out on some of the opportunities offered by microsimulation. This project will integrate the two existing models SILO and mobiTopp. Both are agent-based models and work with synthetic populations that represent the agents microscopically. The microscopic integration will allow for a better representation on land use/transport interactions.

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* Corresponding author. Tel.: +49-89-289-22699.
E-mail address: rolf.moeckel@tum.de

Keywords: Agent-based model, activity-based model, land use model, land use/transport integration

1. Introduction

The land use/transport feedback cycle has been described since decades (Forrester 1969). The transport system provides travel times under congested conditions, which are used in land use models to assess the desirability of locations. Based on where people live and work, demand for travel is derived which leads to updated congestion, and hence, new travel times.

Many integrated land use/transport models, however, remained in an early research exploration stage or are abandoned after a few years due to high complexity or non-operationality (Wagner and Wegener 2007). There is a renewed interest in overcoming implementation issues, as new trends, such as telework or driverless vehicles, are expected to have substantial influence on land use/transport interactions. Modeling the impact of such scenarios simply cannot afford to leave the land use forecast static and unaffected by changes of the transportation system.

The idea of this project contains a new way of integrating a land use model with a travel demand model. Traditionally, land use models provide location and employment information of the synthetic population for the travel demand model, and the transport system feeds back accessibilities as one of many location factors to the land use model. For improving the cause-and-effect correlation of both models, the demand and land use, an integrated approach is worthwhile. There are a few attempts to couple microscopic land use models with microscopic transport models (e.g., Waddell et al. 2010, Strauch et al. 2005). The project, however, will be the first to microscopically integrate these models at the agent level. Individual activity schedules will influence individual household relocation. Vice versa, changes of the housing location, location of work and school places and the likelihood to conduct telework will influence activity patterns for a household. Moreover, upcoming driverless vehicles may influence location choice of households and/or mode choice because of new travel time perceptions or activity options while traveling. The following state-of-the-art focuses on land use models, activity-based travel demand models and the integration thereof.

2. State of the Art

2.1. Integrated land use transport modeling

Lowry's Model of Metropolis (Lowry 1964) is often considered to be the first computer model that truly integrated land use and transportation. The Lowry Model assumed the location of basic employment exogenously and generated an equilibrium for the allocation of non-basic employment and population. Over the last five decades, this popular model has been implemented many times (e.g., Batty 1976, Mishra et al. 2011, Wang 1998). At least equally influential was Forrester's Theory of Urban Interactions (Forrester 1969). Even though it was an aspatial model, his research on interactions between population, employment and housing has influenced the design of many spatial land use models developed ever since.

Putman (1983) developed the Integrated Transportation and Land Use model Package (ITLUP), which led to the frequently applied DRAM and EMPAL models. Wilson's Entropy Model generated an equilibrium by maximizing entropy of trips, goods flows or the distribution of population (Wilson 1967).

The MEPLAN model developed by Echenique, Crowther, and Lindsay (1969) is an aggregated land-use transport model that used the basic concept of the Lowry model as a starting point. The model can simulate a variety of both land-use and transport scenarios. Another modeling approach using the Lowry model as a starting point is the TRANUS model (de la Barra and Rickaby 1982) that simulates land use, transport, and its interactions at the urban and regional scale.

Martínez (1996) developed a land-use model under the acronym MUSSA in which location choice is modeled as a static equilibrium. MUSSA used the bid-auction approach based on the bid-rent theory where consumers try to achieve prices as low as possible and not higher than their willingness to pay. In the bid-rent theory, first introduced by Alonso (1964), land prices are the immediate result of the bid-auction process. In contrast, the discrete-choice approach - initially developed for housing choice by McFadden (1978) - models land being bought or rented with no instant effect on the price.

Wegener (1982) developed the IRPUD model as a fully integrated land-use transport model. The household location choice is microscopic, simulating every household individually. The IRPUD model was one of the few early approaches that contradicted the common assumption that land-use models shall reach an equilibrium at the end of each simulation period. Land-use development aims at equilibrium constantly, but due to a continuously changing environment and slow reaction times of households, businesses, developers and planners, this equilibrium stage is never reached. The price of a new dwelling and the commute distance to the household's main workplace are accounted for as true constraints in location choice. Similarly, the Metroscope model for Portland, Oregon (Conder and Lawton 2002) compares expenditures for housing, transportation, food, health and all other expenses to ensure that household budgets are not exceeded.

PECAS (Hunt and Abraham 2009) is another land use model that represents an equilibrium of competing demand for developable land. Households relocate based on available floorspace, prices, accessibilities and other location factors. PECAS combines this bid-rent approach in a spatial economic model with a microscopic land development model. DELTA (Simmonds 1999) combines an economic model for relocation of households and jobs with a long-distance migration model.

Orcutt et al. (1961) proposed to simulate individuals, called microsimulation, rather than modeling population at the aggregate. A few influential microscopic land use models have been developed, including ILUTE (Salvini and Miller 2005), UrbanSim (Waddell 2002), ALBATROSS (Arentze and Timmermans 2000), PUMA (Ettema et al. 2007), SimDELTA (Simmonds and Feldman 2007) and LUSDR (Gregor 2006). All these models use an aggregate transport model. An exception is the ILUMASS model (Wagner and Wegener 2007). However, the microscopic integration between land use and transport never became operational.

Probably, the first true integration of microscopic land use and transport models was developed by (Waddell et al. 2010) for San Francisco. Kii et al. (2016) identified new challenges for integrated land use/transport models to be climate change mitigation, energy scarcity, social conflicts and new technologies, such as autonomous vehicles or shared mobility services. Good overviews of operational land use/transport models are given particularly by Acheampong and Silva (2015), Hunt, Kriger, and Miller (2005) and Wegener (2014).

2.2. Activity-based travel demand models

Activity-based models care for the actual purpose of making a trip, which is doing an activity (Vovsha, Bradley, and Bowman 2005). Bowman et al. (1998) summarize the theory underlying activity-based travel demand models: Travel demand is a derived demand from doing activities. Activity scheduling decisions are constrained by various aspects, i.e. time, space, capability, coupling or authority. Furthermore, both urban development and transportation system performance may affect decisions and may lead to scheduling adjustments.

Activity-based travel demand models aim at modeling travel behavior as close as possible to real behavior by incorporating as many constraints as possible. At the same time, however, the complexity of the models needs to be manageable.

Within the last decades, the concept of activity-based travel demand modeling increased in importance for transport planners. There are model implementations used in practice all over the world and research activities still work on improvements of these models. Evolving from trip-based to tour-based models and then connecting tours to schedules, the state of the art today is the simulation of activity schedules (Ben-Akiva and Bowman 1998). Initial studies from the 1970's and 1980's focused on descriptive empirical research and investigated the basic principles and constraints of travel behavior and the fact that travel is a derived demand from the desire of conducting activities at different locations (Hägerstrand 1970, Chapin 1974). Later, different subgroups of activity-based models were developed. One important group are utility-based econometric modeling approaches. They are based on the theorem of utility-maximization, which originated from consumer choice theory. The first models developed based on this idea date back to the 1970's. They are trip-based and were developed for Washington, D.C and the San Francisco Bay Area. Later, models were built on basis of tours (see implementations for the Netherlands (Daly, van der Valk, and Van Zwam 1983) and Stockholm (Algers et al. 1996)). A more enhanced review on trip and tour based models is given by Ben-Akiva and Bowman (1998). Finally, Bowman proposed the development of daily activity schedules (Bowman

1998, Ben-Akiva and Bowman 1998). This idea goes beyond the concept of single tours and simulates activities throughout the day. The main idea of Bowman's approach has been widely used in different activity-based models for metropolitan planning organizations, such as in Portland, Oregon and San Francisco or Sacramento in California (Bradley and Bowman 2006). The most commonly used activity-based models are based on Bowman's approach, including simMobility (Adnan et al. 2016), CEMDAP (Bhat et al. 2004) and CT-RAMP (Davidson et al. 2010). Currently, models usually cover a modeling period of one typical weekday. The mobiTopp model extends the daily schedule to an entire week (Hilgert et al. 2017).

Beside econometric models, there are also rule-based computational process models. STARCHILD (Recker, McNally, and Root 1986) was probably the first model within this group and the ALBATROSS (Arentze and Timmermans 2000) framework is another well-known model. A more comprehensive review of this group can be found in Pinjari and Bhat (2011). Often, models tend to combine different aspects rather than belonging to exactly one group of models. Activity-based models have proven to be successful in evaluating peak spreading and congestion pricing (Donnelly et al. 2010). By splitting time of day into finer temporal units than traditional models do and by considering the context of trips, the time-of-day analysis is more complete. The ability to represent individual values-of-time was found to be a major advantage in modeling congestion pricing scenarios (Erhardt et al. 2008, Sall et al. 2010). Another important advantage of microscopic modeling approaches is that the model design allows for the model to be more easily extended in the future (Vovsha, Petersen, and Donnelly 2002). Because of the disaggregate nature of these models, it is actually quite easy to add a new descriptive variable to the model system. In an activity-based model, it is as simple as adding a column to a table, whereas in a trip-based model, it involves further segmentation of trip matrices, which can quickly become unwieldy. Further, the ability to simulate individual travelers greatly enhances the types of policies that can be tested. This also allows integrating new kinds of transport and mobility services, e.g. in the area of sharing economy or autonomous vehicles (Heilig, Mallig, et al. 2017, Heilig, Hilgert, et al. 2017).

2.3. Traditional integration approach of land use and transport models

Land use models provide spatial data of population and employment. Commonly, these socio-demographic data are aggregated to zones (called Traffic Analysis Zones, or TAZ). These data are used in the transport model to generate travel demand. Conversely, the transport model provides zone-to-zone travel times that are used to calculate accessibilities that affect location choice of population and employment. This has been visualized in the famous land use/transport feedback cycle shown in Figure 1. Details have improved over the last 50 years, but in practical applications, the land use/transport integration methods have remained unchanged (Shahumyan and Moeckel 2016).

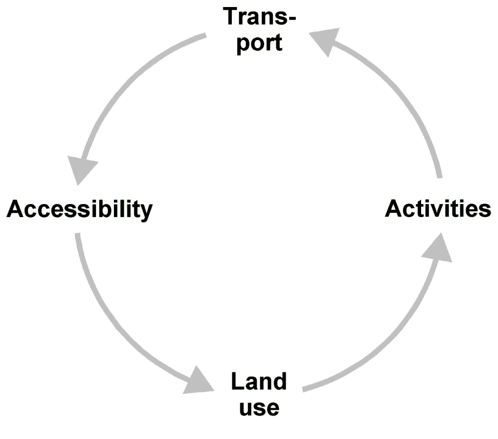

Figure 1: Land Use Transport Feedback Cycle (Wegener and Fürst 1999)

Traditionally, integrated models were used to analyze, for example, the impact of zoning policies, alternative growth scenarios or pricing scenarios. Nowadays, the implications on equity issues, energy usage and environmental impacts are explored as well. For such scenarios, the traditional aggregate implementation of land use and transport models tends to be insufficient. Newer model applications describe agents microscopically, however, the integration of land use and transport is done in the aggregate in all known operational models.

3. Shortcomings of existing approaches

None of the integrated models developed so far fully explores the potential of microscopically integrating land use and transport models. To represent the impact of autonomous vehicles on household location choice, activities while traveling need to be modeled in addition to activities conducted at the trip destination. It has been hypothesized that autonomous vehicles would encourage households to move further away from their workplaces because one could work while traveling, which would make commuting less onerous. Only if activities conducted while traveling are modeled explicitly, the impact on location choice (and other activities conducted throughout the day) can be modeled plausibly.

Stability over time is another aspect that commonly receives little attention. For transport models that focus on modeling one day, this aspect is less relevant. When simulating travel behavior over longer periods, such as one entire week, it gains increasing importance. mobiTopp (Mallig, Kagerbauer, and Vortisch 2013) has been designed to simulate travel behavior for one week scenarios. No model is known that would address the stability of travel behavior over several years, even though a tight integration with a land use model allows tracking activity schedules of the previous year. Instead, all known existing integrated land use/transport models recreate activity patterns from scratch every simulation period. Somewhat of an exception are ALBATROSS (Arentze and Timmermans 2000) and ILUTE (Salvini and Miller 2005), as both conceptionally implemented the idea of learning over time. Yet neither one is fully operational for scenario analysis. True agent-based modeling assumes that agents may learn over time and remember their travel behavior of the previous year. Integrating an activity-based travel demand model with a land use model that incrementally updates every household from year to year allows remembering how agents behaved in a previous year, and thus, allows influencing the behavior in future years. So far, no fully operational integrated land use/transport model has realized this learning capability.

Last but not least, the location of activities of all household members should have an impact on household location choice. Some models account explicitly for the travel time to work of the head of household (Wegener 1982) or of all household members (Moeckel 2017a), but no model is known to take into account other common destinations in location choice, such as which neighborhood the parents live in or which doctors, gyms or stores are frequently visited. An integrated land use/transport model that keeps track of activities from year to year would allow to explicitly take such common activity locations into account when simulating household relocation.

4. Framework

Land use and transport interact with each other as described in the literature review. Representing both systems in integrated land use/transport models results in more reasonable sensitivities than provided by models that represent only one domain (Wegener 2004). What has not been accomplished before is a microscopic integration of travel demand and land use models. Even projects that integrated microscopic land use models with activity-based models (Waddell et al. 2010) did not improve upon the integration step, but merely linked two microscopic models in a traditional way, and thereby, missing out on some of the opportunities offered by microsimulation. This project will integrate the two existing models SILO and mobiTopp. Both are agent-based models and work with synthetic populations that represent the agents microscopically. The microscopic integration will allow for a better representation on land use/transport interactions.

The idea is organized in four major tasks (see Figure 2). The first work package (WP) focuses on the integration of mobiTopp and SILO. This rather technical task defines and implements the interface to pass data between the two models. Most importantly, this interface will ensure that both models work with the same synthetic population. It is intended to integrate the two models tightly, which will allow to pass synthetic households back and forth between the two models without time-consuming writing to and reading from the hard drive.

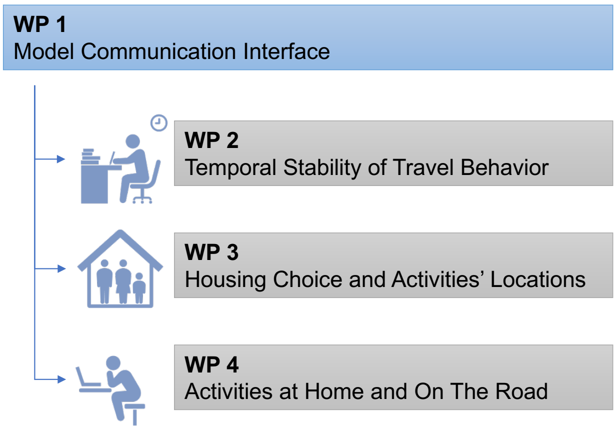

Figure 2: Organization of work packages (WP) to integrate mobiTopp and SILO

WP 2, 3 and 4 build on the tight integration developed in WP 1. Each of the WP 2 to 4 further enhances the integration between mobiTopp and SILO and very specifically applies this integration to improve selected model capabilities.

WP 2 will help to model more realistic temporal stability in travel behavior. Instead of recreating travel behavior from scratch every year, mobiTopp will keep relevant parts of the activity patterns from the previous year unless SILO indicates major changes. If, for example, a child was born or a new job was started or travel times have changed noteworthy, travel behavior will be adjusted by mobiTopp accordingly. For many households, however, various aspects of the activity patterns will remain the same from one year to the next, reflecting the more realistic travel behavior that people tend to see the same family members or shop in the same stores from one year to the next (at least if the surrounding facilities and the transport supply do not change).

WP 3 considers the spatial distribution of activity locations when choosing a new housing location. It has been shown empirically that many households move to new dwellings that tend to be close to the previous dwelling (Schätzl 1996). Households with many activities in the neighborhood are assumed to be more attached to the old housing location with a higher probability to find a new dwelling in the same area. Households with activities that are more spread across town will be assumed to be less attached to their neighborhood and more open to move to other parts of town. Instead of arbitrarily assuming that most households find a new dwelling in the same part of town, this task will reflect activity patterns when asserting how attached a household is to a given neighborhood.

Last but not least, WP 4 adds activities that are performed at home or while traveling. Traditionally, such activities have been ignored in travel demand models. With an increasing trend of telework and the future ability to get things done while traveling in autonomous vehicles, such non-traditional activity locations become more important to model the impact on travel behavior and housing location choice. On public transit, this combination of travel and conducting activities (such as doing emails) can already be observed today. With autonomous vehicles on the horizon, this behavior will become more important to represent in our models.

Land use models simulate the transition from one time period to the next, while travel demand models typically model an average day (or an average week, as implemented by mobiTopp). Figure 3 visualizes the workflow. Accordingly, mobiTopp will be revised to use the results simulated by SILO for each simulation year as an input. The resulting activity schedules and location choices from mobiTopp are then passed back to SILO for the simulation of housing location choice in the following years. This process is executed iteratively on a year-by-year basis.

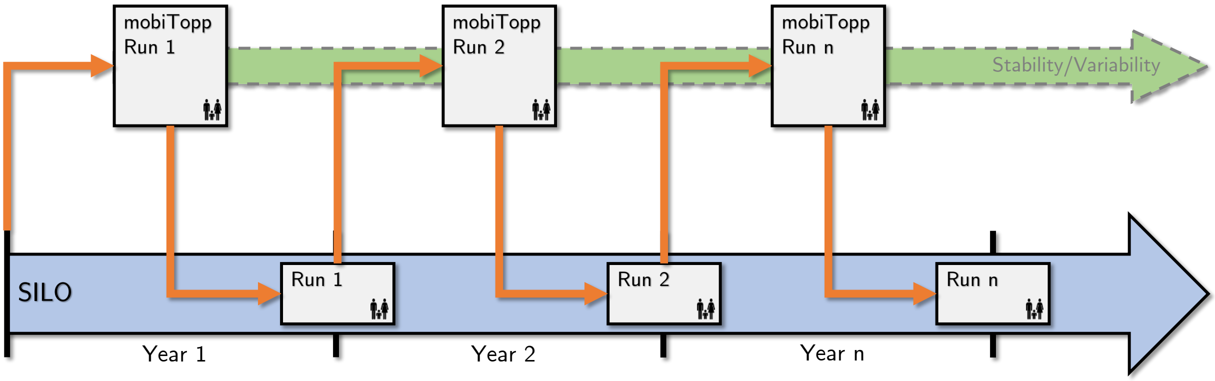

Figure 3: Model flow integration: While mobiTopp simulates travel demand for one typical week, SILO simulates land use transitions from one year to the next

5. Expected Benefits

After realizing the model integration (WP1), we anticipate three major improvements that relate to WP2, WP3 and WP4:

- Stability and variability of travel behavior: Maintaining consistency in travel behavior over years. To achieve consistent travel behavior between years, personal histories of agents provided by the land use model will be applied in the travel demand model. As all other existing travel demand models, mobiTopp currently does not consider agents' personal history, but rather travel demand is recreated from scratch every year. In this project, mobiTopp will be revised to ensure that the stability and variability in travel behavior (activity patterns, destination and mode choice) is modeled explicitly from one year to the other. Parts of the activity schedules and locations may not change from one year to the other unless there is no "big" change (e.g., change of occupation status) provided by the land use model. Panel survey data will be analyzed to evaluate changes and stability in behavior over certain time periods and to evaluate aspects of activity schedules that change from one year to the other. This type of data is rare, which is one reason why this stability over time is commonly not represented in travel demand models. In Germany, however, the German Mobility Panel survey (Eisenmann et al. 2018), which is conducted under the guidance of KIT, provides such information. The German Mobility Panel collects travel behavior data over the course of one week of about 2,000 households every year since 1994. Every household is asked to participate for three consecutive years, which allows for analyses of the stability and variability of travel behavior over time.
- Housing location choice affected by regular activities: Represent appropriate proximity in household relocation. Households tend to find new dwellings close to their previous dwelling (Schätzl 1996). This is commonly explained by the fact that households like to keep in touch with their old neighbors, have their preferred grocery stores and doctors, and prefer neighborhoods they know rather than moving to an unknown neighborhood. Unless major transitions occur (in particular change of job), most households that relocate tend to stay in the same neighborhood or neighborhoods that are relatively close to the previous housing location. Instead of adding an arbitrary factor that drives households to select a new dwelling in relative proximity to the former dwelling, activity patterns provided by mobiTopp will be analyzed. Households that conduct most activities in relative proximity to their home location will be assumed to have a stronger tendency to stay in the same neighborhood after relocation. Households with activities all over town will be less prone to stay in relative proximity to the previous housing location. Data of a household relocation survey by the city of Munich may be used to analyze the relevance of closeness of activities for selecting a new neighborhood.
- Time Use: Interaction between activities at home or while traveling and location choice. To further improve the prediction of location for activities and travel behavior, it is important to integrate activity types that are often ignored in transport models, namely activities conducted at home or while traveling. Since travel demand models

are mostly based on trip-based travel surveys, information about in-house activities are underrepresented. It is relevant to know what activities people conduct at home, such as telework or online shopping, as it might influence out-of-home activities, too. People working at home have no commuting trips, which likely influences other travel behavior throughout the day (Bowman 1998). For example, they may be more flexible in timing their shopping trips or leisure activities. This is relevant for two reasons. First, empirical studies have shown that telework may have an impact on housing choice, and housing location choice may influence the probability to telework (Ory and Mokhtarian 2006). Secondly, the simulation of traveling by transit or autonomous vehicles requires to account for activities conducted while traveling. Some workers may decide to move further away from work and spend part of their commute working on a laptop. Given that both SILO and mobiTopp are designed as agent-based models, occupation and education levels can be represented explicitly for each individual worker. This information can be used to assess which workers might be eligible to conduct part of their work while traveling. While there is no observed data on travel behavior with autonomous vehicles, accounting for activities while traveling will be mostly based on time use data for transit commutes. For modeling autonomous vehicle travel, this will be a major theoretical improvement to plausibly model the tendency to travel by autonomous vehicles and its impact on housing location choice. The time-use survey conducted by the German federal department of statistics contains information about all activities (including concurrent activities) during a day in 10-minute intervals and will be used in addition to travel behavior surveys to analyze telework and activities while traveling.

6. Conclusions

Activity-based models are in operation since two decades and have become fairly sophisticated today. While most researchers have focused on improving (also important) details in activity generation, the fundamental interactions with land use have been largely ignored. Noteworthy exceptions are San Francisco (Waddell et al. 2010) and Atlanta (unpublished) in practice as well as ALBATROSS (Arentze and Timmermans 2000) and ILUTE (Miller and Salvini 2001) in academia. However, the integration between activity-based travel demand models and land use models has been limited to traditional accessibilities. The framework presented in this paper is probably the first integration that truly works at the micro level. This microscopic integration of land use and activity-based models will allow to simulate temporal stability of activities over years, household relocation can be influenced by activity locations and activities conducted at home and while traveling can be simulated explicitly.

The jury is still out how important the integration of land use and transport actually is. There is convincing theoretical foundation (Hansen 1959, Hägerstrand 1970, Wegener, Gnad, and Vannahme 1986), while others have found limited relevance in econometric analyses (Timmermans 2007). Yet it is conceivable that modeling the interaction between land use and transport will only become more relevant with new technologies. Telework, which is on the rise in most countries (Moeckel 2017b), may have an important influence on housing location choice (Ory and Mokhtarian 2006) and other travel (Wang and Law 2007). Autonomous vehicles may entice people to move away farther from their work place, or a further revitalization of our cities may happen if parking issues in city centers are resolved. To model such interactions, land use and transport models do not only need to be coupled, but a microscopic integration between the two is required.

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