1. INTRODUCTION

For certain professions, it has become popular to work at least part-time from home. Telework allows more flexible schedules, may reduce the burden on commuting and may also offset costs for office space for the employer. According to the German federal statistics bureau, almost every other employee works at least occasionally from home, and 10 percent of all German employees work regularly from home. In the European context, Germany’s share of teleworkers is just below the average, with the Czech Republic and Denmark leading the list of teleworking countries with 15.2 percent and 14.4 percent, respectively (Welz and Wolf, 2010).

The impact of telework shows a two-sided sword. On the one hand, teleworkers do not need to commute to their work place, at least not on a daily basis. Thereby, many trips can be eliminated, particularly during peak hours. On the other hand, empirical studies have shown that, at least in part, teleworkers compensate by making additional other trips. They may decide to go shopping at a grocery store further away because they have “saved” the time they otherwise would have spent to travel to work. Last but not least, housing locations may be affected. While traditional workers will search for housing locations within a reasonable distance to work, teleworkers are more flexible in housing search and often will select more remote areas, where housing is cheaper. Those areas, however, tend to be more car-dependent.

Transport modelling is a powerful method to understand what-if relationships. It allows transport planners to understand the impacts of telework policies in a simulation environment before telework becomes more mainstream. Transport modelling also allows to test the effects of possibly costly policies and infrastructure projects before they are implemented in reality. Existing operational models are insufficiently prepared to reflect the impacts of teleworking on transport demand as they are unable to model rebound effects of teleworkers who engage in alternative travel if they do not need to commute to work. This research aims at filling this gap and at developing approaches to model the impacts of telework on transport and land use.
2. LITERATURE REVIEW

The impacts of telework are ambiguous. For example, Mokhtarian (2004) found that telework may reduce vehicle-kilometres travelled by eliminating commute trips, though at the same time teleworkers may compensate commute-time savings with additional recreational travel. Mokhtarian and Varma (1998) found that telework reduced vehicle-miles travelled by 11.5 percent, even though the number of person trips increased slightly on telework days. Kitou and Horvath (2003) concluded that telework may lower selected emissions because of reduced commuting, however, some emissions (in particular N2O and CH4 emissions) may increase because of added activity at home. In addition, the theory of constant travel time budgets (Zahavi, 1982; Zahavi, 1979) suggests that many teleworker could use the commute time saved through telework to do other trips, such as driving a longer distance to the preferred grocery store or making additional leisure trips. Furthermore, workers who only need to visit the office one or two days a week may decide to move further away from their workplace to enjoy lower housing costs or a larger house, which may offset any travel savings from telecommuting.

Integrated land use/transport models have been developed since the 1960. Initial approaches, such as Lowry’s Model of Metropolis (Lowry, 1964) or the DRAM/EMPAL model (Rosenthal et al., 1972), were fairly coarse and not based on behavioural theory. Later models can be grouped into two approaches: bid-rent models and discrete choice. The bid-rent theory was introduced by Alonso (1964) and states that land prices are an immediate result of the bid-auction process between land owners and land users. In contrast, the discrete choice approach -initially developed for housing choice by Nobel Laureate McFadden (1978)- models land being bought or rented with no instant effect on the price. Rather, urban development is driven by utilities for land owners and land users and discrete decisions are modelled. Martínez (1992) compared the two approaches and concluded that both lead to very similar results. Good overviews of operational land-use/transport models are given particularly by Hunt et al. (2005), Wegener (1994; 2004) and Timmermans (2003).

3. INTEGRATED LAND-USE TRANSPORT MODELING

The transport system (shown on the top of Figure 1) provides travel times under current congestion, which is used in land use models (bottom half of Figure 1) 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, travel times.

![Figure 1: Land use/transport feedback cycle (Wegener, 2004)](image)

This feedback cycle is represented explicitly in this research. Workers who telework have different travel behaviour, and thereby, different housing preferences. The full representation of the land use/transport feedback cycle helps understanding the impact of telework on transportation and land use.

Transport modelling is a powerful method to understand what-if relationships. It allows transport planners to understand the impacts of telework in a simulation environment under different rates of acceptance. In this research, a modelling suite is developed that allows analysing the impacts of telework on transport and land use. The transport model MATSim (www.matsim.org) will be integrated with the land use model SILO (www.silo.zone). Traditionally, land-use and transport models are coupled by using aggregate accessibilities, or mode choice logsums in advanced cases (Timmermans, 2003). As both SILO and MATSim work microscopically, this model setup allows considering actual travel times experienced by individuals (Moeckel and Nagel, 2016). Travel time to work is treated as a real constraint in housing location choice. For example, a worker who leaves for work at 9 am will see a different level of congestion than a worker who needs to be at work by 6 am. The availability of modes may be different for the two workers as well. Another worker who commutes by bus will only consider transit travel times while auto travel times are mostly irrelevant. The individually experienced travel time can be considered in household relocation in SILO. However, regular teleworkers...
may care less about or disregard entirely travel time to work entirely in their location choice.

Mokhtarian and Salomon (1997) developed a model to choose whether someone telecommutes or not. Bailey and Kurlan (2002) analysed literature to understand who telecommutes, finding that male professionals and female clerical workers prevail. Those findings will be used to implement telework in the SILO/MATSIm modelling suite. By accounting for daily schedules that respect Zahavi’s travel budgets, it will be possible to quantify the impacts of individual choices to telework on travel and housing location choice. Different scenarios will model varying acceptance rates to telework a certain number of days per week. Indicators to measure the impact of telework will include vehicle-kilometres travelled, mode share and degree of urban sprawl.

4. DATA ANALYSIS

This research will develop a modelling suite that allows analysing the impacts of telecommuting on transport and land use. The modelling suite represents travel demand, traffic assignment and land use changes explicitly. All models are developed as a microsimulation, meaning that households, persons, dwellings and jobs are represented individually. For this purpose, a synthetic population of households, persons, dwellings and jobs was created from aggregate data using the Iterative Proportional Updating algorithm Konduri et al. (2016) for the Munich Metropolitan Area. Individuals in the synthetic population do not replicate individuals in the real world, as such detailed data are unavailable, and the privacy of individuals needs to be protected. Instead, the synthetic population resembles the real population only on the aggregate. The share of different household sizes and income levels are replicated exactly, and even the distribution of household sizes within each income category matches observed data. However, individuals are created synthetically and do not attempt to replicate specific individuals in the real world.

An important benefit of synthetic populations is that an almost infinite number of household or person attributes can be added (Donnelly et al., 2010). For this research, employment industry will be an important additional attribute for each worker, as government employees or professional services workers are much more likely to telecommute than employees in manufacturing or health industries. Based on employment industry, individuals are assigned a probability to telework. Data of a German household travel survey (Mobilität in Deutschland 2008) and German micro census were used to estimate the probability of a worker to telecommute.
Probabilities were generated to select whether a worker telecommutes on a given day or not. To simplify matters, workers who are selected to telecommute will work from home the entire workday. In reality, some workers may go to the office in the morning and continue work from home in the afternoon. For the purpose at hand, however, such rare behaviour may be simplified as “person commutes to work and works full day.” The fact that part of the workday is spent at home does not affect the time spent on traveling to and from work, nor does this affect the available remaining time for other activities. Hence, it is only relevant for this model whether someone works from home the entire day or works in the office any portion of the day. Figure 2 shows the share of respondents by occupation who reported no work trips.

The 40,848 records used for this graph only included survey responses for weekdays (Monday through Friday) and from persons who reported not to be on holiday or sick leave. Still, 27% of all full-time employees reported to have done zero work trips on the day of the survey. While some of them will work on weekends, and therefore, could have gotten the day of the survey off, the majority of these workers are assumed to have worked from home on that day. Of part-time employees, 42% reported no work trips on the survey day. Obviously, having a 60% position does not necessarily mean to work 60% every day, but most would work 3 out of 5 days and stay home for two days. Those who are unemployed, take care of the households or children, retirees

Figure 2: Share of workers that reported no work trips on a given day (Source: Own analysis of the household travel survey “Mobilität in Deutschland” 2008)
and children going to school have—as expected—almost no work trips. They make a few work trips, as some of them might be looking for work, and a trip for an interview or to the unemployment office would be counted as a work trip.

A second dataset was analysed to confirm findings on telework. The microcensus Germany was used to compare the number of workers who responded to work mainly or occasionally from home by 86 occupation types. These types were aggregated for improved readability to 27 main categories shown in Figure 3. The numbers on the bars show the number of respondents. Occupations were sorted by the frequency of working at home, where “mainly” was weighted twice as high as “occasionally.”

The highest share of working at home is held by workers in agriculture. Supposedly, many farmers have an office at home and do most of the farm’s management from home. Pastoral care and teachers work a lot from home as well, presumably to prepare for their work at church or school. Publishers and artists have an almost equal share of working from home. The next three categories, justice/police, consulting and engineers tend to have higher education, require less supervision and often work fairly independently, key prerequisites to being able to work from home. Occupations at the bottom of Figure 3 show professions that usually require to work on site, such as a sales

Figure 3: Share of workers working mainly, occasionally or never from home (Source: Own analysis of the micro census Germany, 2000)
person in a shop, a construction worker on a construction site, or cleaning personnel working on site.

5. MODEL IMPLEMENTATION

Based on the person characteristics occupation, age and gender, the probability to work from home will be selected for each individual in the synthetic population. In trip generation, this probability will be used to select whether an individual makes a work trip or not. The number of work trips, in turn, may affect the number of non-work trips, as according to Zahavi (1982) travellers tend to have a fairly static travel time budget that changes only slowly over time. Doing fewer work trips will lead to additional non-work trips. Moreno and Moeckel (2016) developed a model to estimate remaining travel time budgets after fulfilling work trips. A person making fewer (or no) work trips because she is working from home is likely to spend additional time on other trips, such as going to a grocery store that is further away or fitting in an additional trip to meet with a friend.

At the same time, telecommuting influences location choice of households. The probability to work from home will be used to assess the relevance to find housing near work. Figure 4 shows as an example the average work trip length frequency distribution in the Washington, D.C. metropolitan area.

![Figure 4: Trip length frequency distribution for work trips (Source: Own calculation based on Washington/Baltimore household travel survey from 2007)](image-url)
SILO has been built to respect this average trip length frequency distribution when looking for a new housing location. In most cases, the work location(s) of all household members are a given constraint when the household starts looking for a new place to live. Those who need to show up at work every day will take the trip length to work as a serious constraint in housing choice. This constraint has been reflected explicitly in the land use model SILO (Moeckel, 2017). For a given dwelling that a household considers for relocation, the frequency of the corresponding commute distance (shown on the y-axis of Figure 4) is used to adjust the utility of this apartment. In other words, a dwelling in a commute distance of 37 min would be seen about twice as favourable as a dwelling with a distance of 50 min. While SILO considers many other location choice factors, the distance to work is a key constraint in housing search.

For a household member who telecommutes 100 percent, this home-to-work-distance constraint is eliminated completely. For a person who telecommutes 4 out of 5 days, the relevance of the workplace location is reduced to 20 percent. For example, it would be conceivable to work in a Munich office once a week and live in Vienna the remainder of the week, which would make a 260 min commute by car once a week. It would be unlikely, on the other hand, that this person lived in Los Angeles, because distance still matters if occasional presence in the office is necessary. Depending on the share of time a person telecommutes, the distance-to-work constraint it gradually weakened, and eliminated for full-time telecommuters. As a consequence, telecommuters are more likely to move to suburban and rural areas, everything else being equal.

6. CONCLUSIONS

The proposed modelling suite will be the first model environment that is fully capable of representing the impacts of telecommuting. Not only the effects on travel behaviour will be modelled, but also the impact on population distributions and urban sprawl. Given that both SILO and MATSim are built as microscopic models, in which each synthetic person and household is simulated individually, the impact on congestion and urban sprawl by telecommuters and non-telecommuters can be distinguished.

Given advances in technology, working from home will become even more relevant in the future. Web meeting software has become more powerful, internet connections become faster through microfiber cables, smart phones allow for constant connectivity with colleagues, and cyber gloves allow even people working with their hands, such as doctors or artist, to work remotely.
Assessing its impact on transportation and land use will become even more important.

7. REFERENCES


