SUSTAINABLE URBAN MOBILITY AND COMMUNTING IN BALTIC CITIES

GUIDANCE FOR TRANSPORT MODELLING AND DATA COLLECTION

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1. INTRODUCTION

Motorized traffic and its consequences are a major burden of the modern society. It is one of the major sources of greenhouse gases and other pollutants. It generates noise and is harmful to life. And, mobility is increasing, yielding in more traffic, jams, and increasing its impacts. A comprehensive view at the environmental burdens of traffic can be found in [1].

While counting for traffic globally, such issues can as well be found within the partner cities of the SUMBA project. To cope with these issues, the administrations of these cities aim at increasing the share of active transport modes and at fostering intermodality – the combination of different modes of transport along a single way [2]. To help the administrations and the decision makers with this task, different documents and document templates are developed within the project, including SWOT analyses, commuting masterplans or a benchmarking scheme. In addition, the guidelines at hands addressing the modelling of mobility, transport, and traffic were prepared.

But why should mobility or traffic be modelled? In the past, the solution chosen most often for coping with increasing traffic was to build new roads or to extend existing ones for reducing congestions. This was meant to yield in an increase of the travelling speed and a reduction of emissions. Yet, by making private motorised transport more attractive by extending the infrastructure capacities, such solutions often ended in an extended use of private vehicles, and at the end in bigger jams. Because bigger roads make travelling by car more comfortable, larger distances are driven what forces urban sprawl and subsequently a further increase of traffic.

Meanwhile, powerful tools capable to predict the outcomes of traffic measures exist, including the measures' secondary effects, such as an increase in motorised individual transport, reallocation of built infrastructure, etc. The tools are capable to consider different modes of transport and to replicate the users' reactions when mobility offers are changed or when implementing regulatory measures.

Having the capability to predict the effects of measures, transport modelling tools go beyond a static representation of the current state like the one generated by geographic information systems (GIS). But modelling tools also help in understanding the current situation. Thereby, they help in creating and validating sustainable urban mobility plans (SUMPs) or strength-weaknesses-opportunity-threads (SWOT) analyses. They help in benchmarking the traffic system, in closing the gaps of partially missing data about the situation on the roads, and in pointing out bottlenecks in the infrastructure or in the supply of mobility options.

Yet, different approaches for modelling transport exist, and it may be complicated to choose the right one for supporting the planning of actions. This document introduces nowadays' transport modelling concepts and compares existing software solutions available for this purpose. Not only major commercial applications are presented, but available mature open source solutions as well. In addition, the document describes the data needed for building a model for a given city or region, shows where such data can be retrieved from, and how missing data can be generated. In addition, use cases are given, which help in choosing the right model or model class.

We want to thank the SUMBA project partners for reading this document and for proposing extensions and improvements.

2. TRANSPORT MODELLING: TASKS AND METHODS

Human mobility behaviour is a complex topic, including a large number of decisions taken at different levels under consideration of own needs, capabilities and constraints. They are influenced by the availability and the price of mobility offers and the distribution of places of inhabitancy and of the activity locations within the respective region. For outlining this complexity and for partitioning it into easier understandable sub-problems, the next sub-section outlines human mobility by discussing the origins of traffic within a city during a common day. As well, aspects of traffic that take place less often are outlined. Subsequently, a justification for modelling transport and traffic is given, followed by a description of approaches, models and methods used for replicating human behaviour and the resulting traffic on the roads.

2.1 Human Mobility

Let us start with a view at the traffic that takes place within a city or within a region during a usual day.

Figure 1: Traffic within a city (source: unsplash.com).

Most of the involved persons travel by purpose – to get to a certain place for performing a desired or needed activity. Beforehand, they choose the mode of transport to use. Some of the activities, such as the visited school or the work place, have a fixed location. But some other may be chosen from a set of alternatives, like, for example, the shop to buy daily goods at. Most decisions are often taken well in advance, but some may as well be taken at a random point in time. When performing a trip, the persons interact with their environment, including other persons and vehicles and the infrastructure.

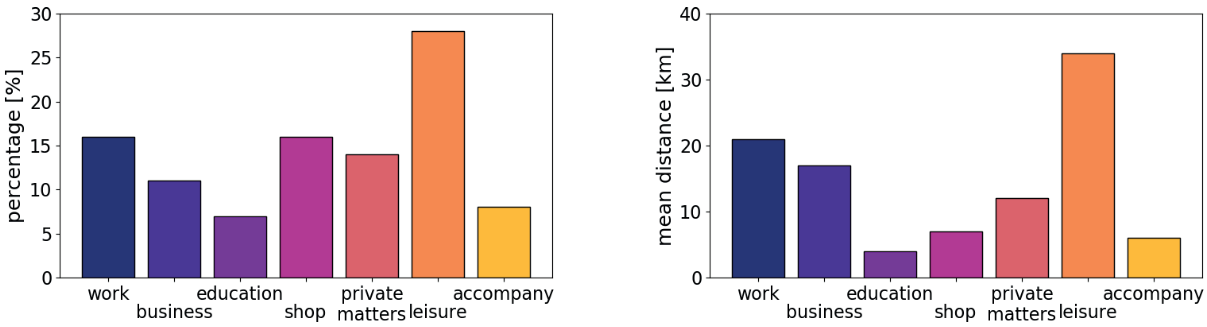

Figure 2: Shares of trip purposes in Germany; left: in percentage of performing a purpose, right: in respectively covered average distances (source: [3]).

But traffic is not only shaped by private persons' daily mobility. Further actors can be found, such as freight transport, or emergency or administrative services. And, private persons take decisions that influence their mobility and subsequently traffic on longer time scales as well, including the choice of a work place or the place of inhabitancy, or the purchase of mobility options, such as buying a car or an annual ticket for public transport.

In the following sub-sections the outlined aspects of mobility, transport, and traffic are described more detailed.

2.1.1 Available Modes of Transport and Their Choice

The major modes of transport, which are as well regarded in transport modelling, are walking, bicycling, using the public transport, and driving an own vehicle. In the following, we will use the abbreviations PT for public transport and MIT for motorised individual traffic. In addition, one may as well find the modes of co-driving a car, using a regional train, and, increasingly as the number of available offers grows, using car sharing. One may notice that further modes of transport exist, e.g. bike sharing, ride sharing or other micro-mobility options like e-scooters, yet they are not regarded in mobility models very often.

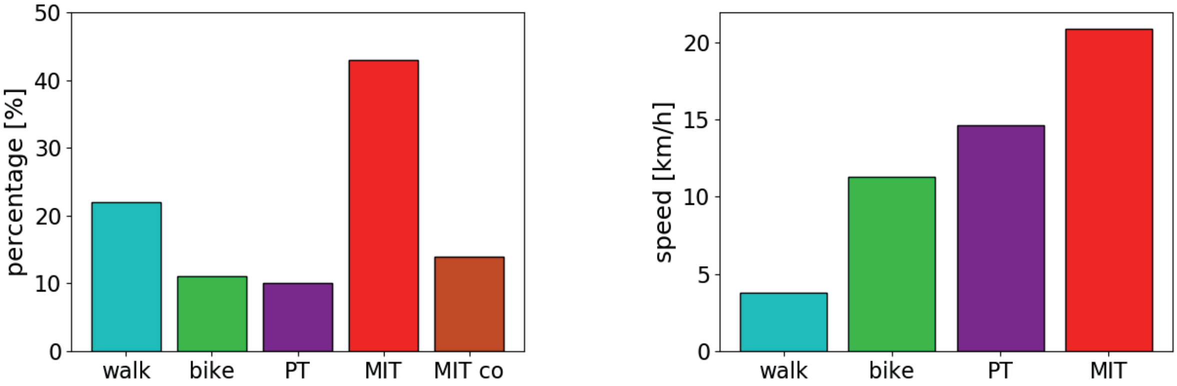

Figure 3: Left: modal split in Germany[1] in percentage of using the mode; right: avg. speeds of different modes of transport (source: [3]).

The personal choice of a mode of transport depends on a large variety of factors. Some of them, such as costs, distance, or travel time can be clearly measured for obtaining explicit dependencies between them and the probability to use the respective mode of transport. Some other constraints and limitations – one e.g. cannot carry large goods on a bicycle – can be named. But there is also a large number of other characteristics of and attitudes towards transport modes, which cannot be directly measured and which are matter to subjective preferences or abilities.

MIT is often preferred due to its flexibility in comparison to public transport that operates fixed routes and schedules. MIT is usually faster than the other individual modes of transport, namely biking and walking. As well, MIT gives its users a feeling to be in a private, owned room and to be secure against the surrounding. And, owning a vehicle is still often treated as a status symbol. But MIT is relatively expensive if all costs, including taxes, insurances, repair costs, etc. are considered. And the more persons use an own vehicle, the lower the average velocity of MIT is usually due to jams and due to longer time needed to find a parking space, what increases the times needed to access and egress the vehicle.

As long as no dedicated lanes or tracks exist, public transport shares the same space as MIT and thereby faces the problem of congestion as well. City-rail or metros running on separate tracks do not face this issue and are often faster than MIT. Public transport is also often cheaper then MIT. Yet, due to fixed routes and time plans, public transport is less flexible than individual transport solutions, especially in sparsely populated sub-urban regions. In addition, the access and egress times and distances needed to get to and from the used public transport carrier are usually higher than for MIT. In some areas, e.g. in sparsely populated suburbs, a profitable PT can be hardly offered. In such areas, people depend on their own mobility options, may it be a bike or an own car. One can also find other reasons which make public transport unpopular, including bad reliability, limited capacities, dirtiness, or lesser personal safety.

Naturally, walking is often possible, but some city designs or long blocks pose additional detours or have a bad walking infrastructure making walking unnecessarily long and uncomfortable. And walking is of course only feasible for short distances and only if no heavy goods must be carried. Similar aspects also count for using a bicycle. Often, an infrastructure appropriate

1 *Please note that the modal split is different for different region types and cities.*

for using a bicycle is missing, and the necessary sharing of the road space with MIT can make bicycling dangerous. In the wish to increase the usage of active modes of transport, these issues are currently well-discussed. E.g. the Copenhagenize index[2] shows how well different cities are suitable for biking. Similar approaches attempt to make cities be passed by walking in a convenient way [3] [4]. In addition, one can find attempts for designing “cities of short distances” that are more favourable for walking and biking.

Besides investigating single modes of transport, increasingly their combination along a single journey, called intermodality, got into focus. The combination of different modes of transport promises to reduce the overall burden of traffic by increasing the use of bikes and public transport. In parallel, it promises travel times and flexibility similar to those of MIT. To a major degree, intermodality can only be built upon a good public transport system and by offering comfortable possibilities of interchanges between the different transport modes.

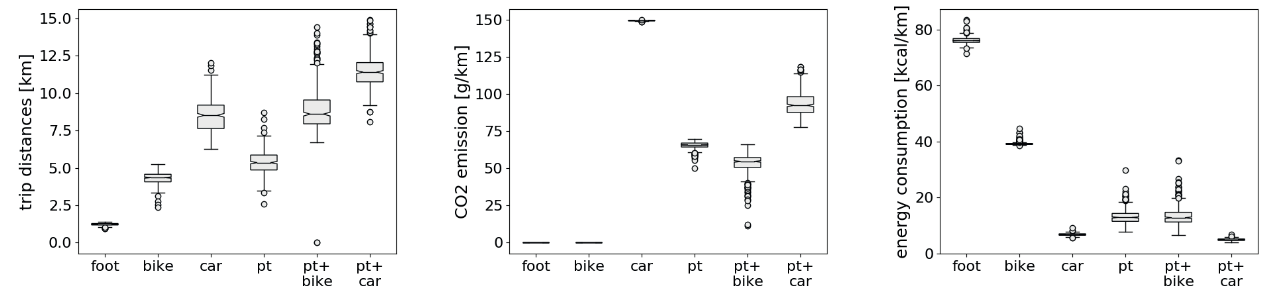

Figure 4: Performance indicators of different mono- and intermodal modes of transport computed for the city of Berlin for ways between home and work locations in 30 minutes; from left to right: avg. distances, CO2 emissions, personal energy consumption.

One may note that current research increasingly addresses the needs of different user groups, which differ in their possibilities to use existing transport options. Some modes of transport are not usable by all due to personal impairments, inabilities, missing documents, low income, classical or digital illiteracy, etc. Thereby, one of nowadays’ goals when planning transport solutions is to leverage these issues and to offer what is called an “inclusive”, easy to access mobility for all types of users.

2.1.2 Participating in Traffic

Planning of where to perform needed activities and how to access them is but only the first step of mobility and just a prerequisite for traffic. While following this daily activity plan using the chosen mode(s) of transport, persons entrain the respective carriers and use the available transport infrastructure. All the named different modes of transport have different on-road dynamics. Models that replicate the traffic within a city have to take these differences into account and replicate them accordingly, including possible interrelations.

In cities, the average velocity of MIT is mainly reduced by traffic lights. Still, traffic lights are the most performant possibility to deal with crossing traffic streams, in terms of throughput, price, and safety. Traffic lights can be optimized to the current traffic situation adapting the green times to the amounts of vehicles coming from the different directions and by introducing “green waves” or adaptive algorithms. As well, methods for prioritizing public transport or heavy goods vehicles can be employed.

On motorways or highways, the travelling speed is mainly reduced by the need to keep a safe distance to the vehicles ahead. Traffic counts show a clear relationship between the amount of vehicles on a road and the respective average velocity. Additionally, traffic degenerates to a state of a jam when a certain amount of vehicles is reached.

2 https://copenhagenizeindex.eu/
3 http://www.designforwalkability.com/walkability-principles
4 https://www.walkscore.com/

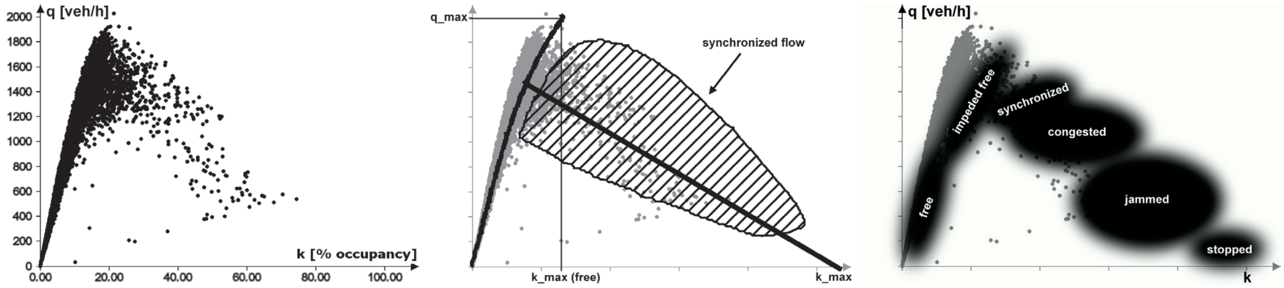

Figure 5: The so-called fundamental diagram of traffic showing the flow q in dependence to the traffic density k; from left to right: original data, interpretation by Kerner [4], interpretation by Kim & Keller [5].

In any case, for a proper representation of the situation on the roads, models for the progress of a vehicle through the road network are needed, regarding the available infrastructure and interacting with signals. Often, public transport and heavy goods vehicles are treated as special cases of motorised transport that in comparison to passenger cars need an adaptation of physical attributes only. But bicycling and walking follow other dynamics and need thereby dedicated models for describing their on-road dynamics. Especially when dealing with heavy bicycle traffic or when the share of motorised two wheelers is high, like it is the case in Asian countries, models that mimic the co-share of a single lane by multiple vehicles are needed.

2.1.3 Other Traffic Sources

Conventional transport planning focusses mainly on passenger traffic. Yet, freight transport gains increasingly in interest, including models for computing the amounts of goods, route schedules, or the allocation of disposition centres. The motivation lies partially in the increase in ecommerce which comes along with additional rides and blocked lanes when goods are being delivered to the final customer. Also, logistic companies increasingly support the optimization of their distribution journeys using transport models.

What is usually not regarded when modelling traffic are rides of specific organizations or services, such as the police, emergency vehicles, city cleaning services, etc. As well, a transportation model usually describes the mobility, including traffic, in the regarded area only. Commuter traffic or traffic that passes the modelled area has to be derived from other sources and added to model as external data. In such cases, this representation of additional traffic may be not sensitive to changes applied to the model. Thereby, it is necessary to choose the size of the modelled region well, including all areas that may be affected by measures that shall be simulated.

2.1.4 Long-Term Mobility Decisions

As seen, the daily mobility is composed by a set of circumstances and personal decisions, including each person's mobility needs and possibilities, plans about how to perform the daily activities, and the person's short-term actions during the journey. Yet, the daily behaviour is only one aspect of human mobility, as human beings interact with the urban structure and available mobility offers on other time scales as well.

On a medium-scale of months up to few years, one may find decisions about purchasing certain mobility options, such as a public transport season ticket, an own car, a car sharing membership, a bike, etc. As well, some activity locations are planned to be accessed frequently during a longer time period, including, e.g., often visited shops or leisure activity locations, are chosen on a non-daily base. On a long term, the place of inhabitancy may be changed for being capable to access the work place in a convenient way – or vice versa. Such non-daily human decisions are replicated by specific models. Usually, the information generated by these models that describes a situation in a future point in time is used as input to mobility or transport models that resemble daily traffic.

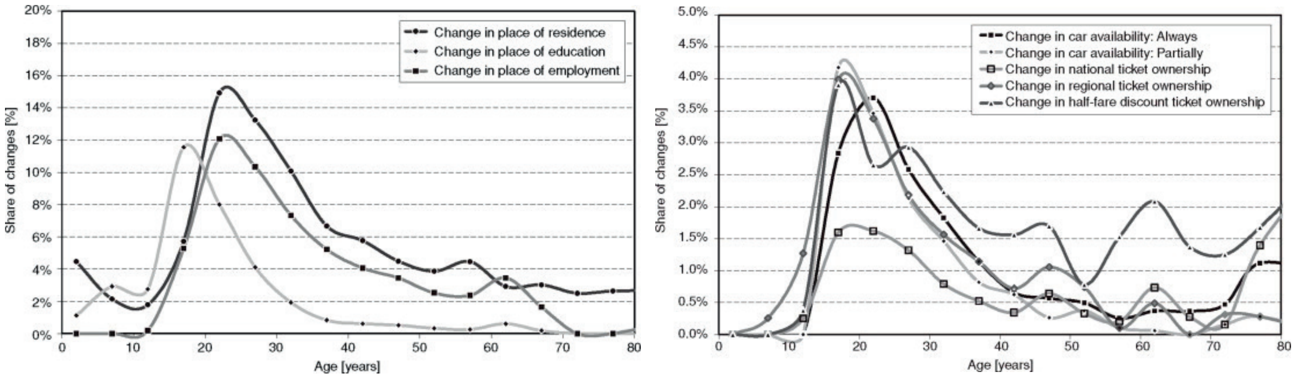

Figure 6: Changes in the place of residence (left) and the availability of mobility options (right) over life time (from [6]).

While being constrained by the urban structure, mobility and traffic shape the urban form as well. Building new roads induces additional traffic, due to the allocation of commercial and housing offers along these roads and due to the improved possibility to cover larger distances. Thereby, increasing accessibility of motorised individual traffic results in the growth of cities to sparsely populated areas with long ways, known as "urban sprawl" [7]. And vice-versa, urban sprawl induces additional traffic, increasing traffic problems.

2.2 Why Modelling?

But why should one try to replicate traffic or even mobility using models or simulations? There are different reasons. At first, a valid representation of the current situation helps in understanding what is happening. Existing infrastructure bottlenecks or shortcomings can be identified and explained. As well, traffic models usually come with a visualization component which helps in presenting the situation on the road or found issues to a broader audience.

But simulations of mobility or traffic are capable to go beyond the representation of the current state on the roads. Because they use models for representing human behaviour in dependence to the given circumstances, they are capable to predict what happens if the given system is changed. Thereby, the major application of transport models is to predict the effects of introducing measures. Of course, such an investigation starts with a representation of the current state and extends it by the measure to evaluate. The size of the modelled area should match the size of the area that is affected by the measure to evaluate. In case of optimizing a traffic light, it may be reduced to the regarded intersection only. But usually, traffic measures have side effects – improving a certain mode of transport will attract persons from more distant regions. For including these effects in the evaluation of a measure, a bigger area should be modelled.

Nowadays, the most common application for traffic models is the design of new traffic light signals or their schedules. In such cases, the effects on the respectively investigated junctions' throughput are evaluated. But proper transport models are capable to investigate the effects of a large variety of measures, including infrastructure (changes in the road network, infrastructure at stations), regulative (vehicle bans and toll zones, speed limits, guidance for heavy duty vehicles, …), political (emission regulations, …), or technological (automation, V2X-communication, new adaptive traffic light controls, …) changes. And, modelling as well allows to take a look into the future by using models that predict how the population or how the urban structure will change. Yet, one should admit that predicting the future always holds big uncertainties. To avoid guessing how the regarded system will behave into the blue, the dependencies between socio-demographic and infrastructure attributes of a heterogeneous population and the area(s) it lives within is mapped to its behaviour, first. From this, models that describe the behaviour of an individual in dependence to these attributes can be derived that can be used to predict the behaviour under changing conditions afterwards.

2.3 Transport Models

Models are a simplified replication of a selected part of the real world with a specific aim. Transport models reproduce the users and their behaviour by using abstract descriptions and mathematical functions. Due to the large variety of actions and decisions mobility behaviour consists of – ranging from controlling a vehicle through the road network up to the decision about moving to a different place of inhabitancy – a large number of different model classes, each reproducing a certain aspect of mobility, exists. Often, models of different kinds are combined for answering more complex questions, like in the case of the four-step model where different steps are performed for finally obtaining the state on the regarded road network.

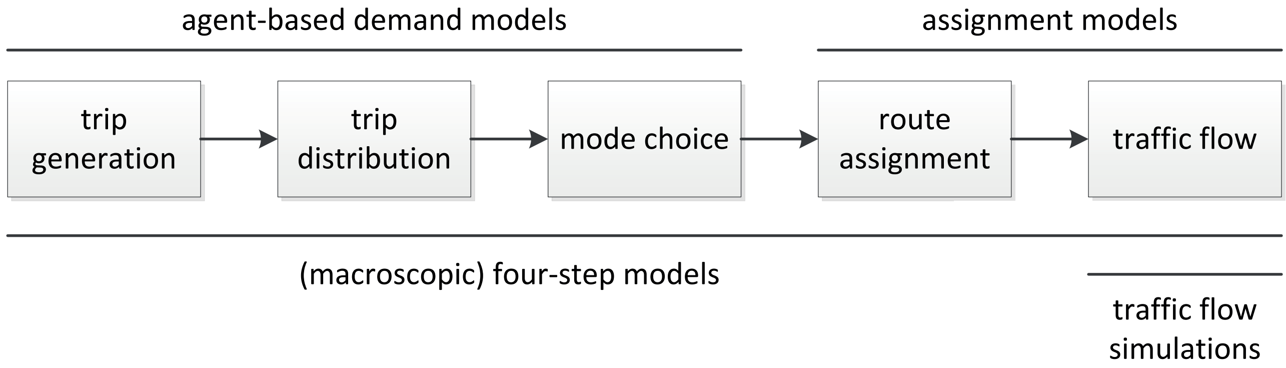

Figure 7: The process of modelling mobility and traffic and the coverage of subtopics by different simulation types.

In the following, different approaches for modelling the mobility demand and the resulting traffic are presented. We start with the classic, most accepted approach, called the four-step model. Subsequently, more modern attempts, including microscopic traffic flow simulations and agent-based demand models are described. Finally, other views on mobility and traffic, namely methods for modelling land use and transport interaction as well as accessibility computation are given. One may find as well a set of further tools and models that compute or describe certain aspects of mobility or traffic, including freight transport scheduling or public transport optimisation, traffic lights algorithms, computation of noise and pollutant emissions, dispersal and immissions, computation of safety measures, etc. They are not covered in here due to being too heterogeneous and too specific.

2.3.1 The Four-Step Model

One of the oldest and still widely used models for replicating the mobility patterns within a city including the resulting traffic state of the transportation network is the so-called four-step model (see, e.g. [8] or [9]). The model uses a representation of the modelled region divided into areas called “traffic analysis zones” (TAZ). There are no standard rules for defining the TAZ. Rather, experience and the needs resolution of the final model determine their choice. [8] lists the following criteria for defining zones: a) reduce aggregation error, b) compatibility with administrative divisions, c) most homogeneous as possible in terms of land-use and population characteristics, d) compatibility with cordons and lines, e) choice of a shape that allows for easy determination of the zone’s centroid. Each TAZ is mainly described by the number of its inhabitants, including their socio-demographic attributes, mainly the income level, car ownership, and household size and structure.

Figure 8: Examples for sub-dividing a city into TAZs, here: the city of Berlin.

Within the first step, the number of trips performed by the population during a day is computed for each TAZ, usually by using statistics about the mobility behaviour found in the region. Within the second step, the destination places for the generated trips are determined. For this purpose, the information about activity locations available in the modelled region, including schools, universities, work places, shops, etc., is needed. In the third step, the given trips are divided on the available transport modes. Again, data from surveys is used to determine the modes' respective shares. Within the last step, routes through the transportation network are computed using a so-called route assignment method. While the first three steps deliver the mobility needs within the modelled region, meaning the number of trips between the combinations of sources and destinations for the modelled modes of transport, the fourth step is responsible for predicting the resulting situation on the region's roads. The overall process is depicted in Figure 9. Different methods for each of the steps have been developed in the past. They differ in the used methodology, the amount and type of needed data, their integration – e.g. can the steps of choosing a destination and choosing the mode of transport be computed in one step or subsequently – and the needed computational effort. Within the following more detailed descriptions of the computation steps, the most often used approaches are presented. For further details and possibilities, the interested user is referred to [8].

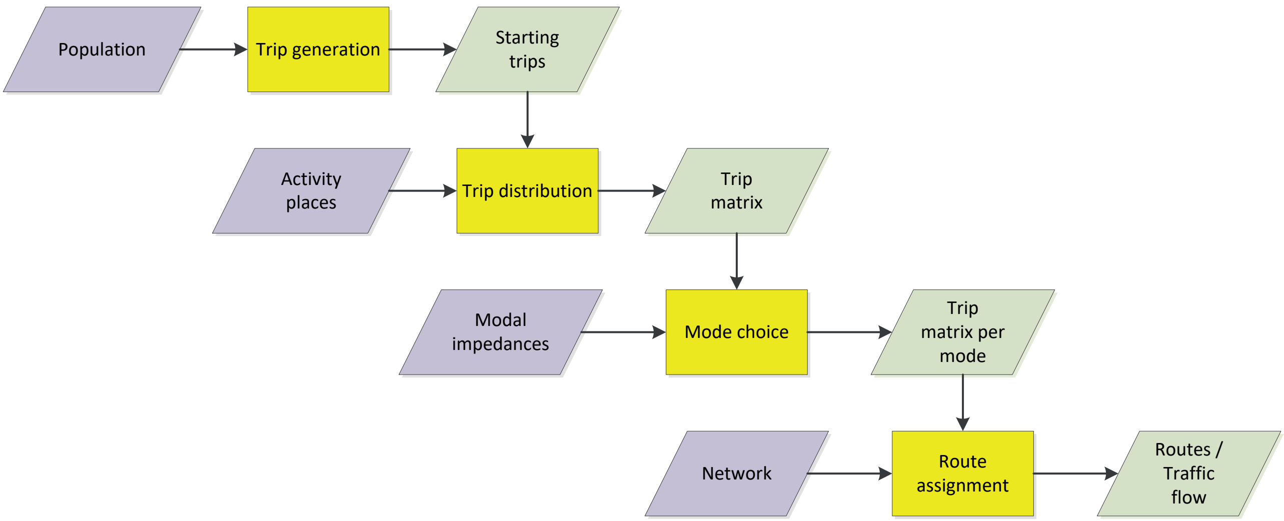

Figure 9: The four steps of the four-step model and their main inputs and outputs.

When computing the number of trips starting within a TAZ, one can coarsely assume that each person performs about 2,5 trips per day in average, with the purposes shown in Figure 2. Of course, this only counts for persons that perform activities by themselves, children who do not visit a school yet are usually not treated explicitly. A more exact used method for building a model for trip generation is to use travel surveys. In such cases, the numbers of trips distinguished by purpose as reported within the survey are often mapped to variables that describe the area’s inhabitants as given before and the availability of mobility offers, mainly the availability of a car. The result of this computation is the number of trips per purpose for each of the modelled TAZs.

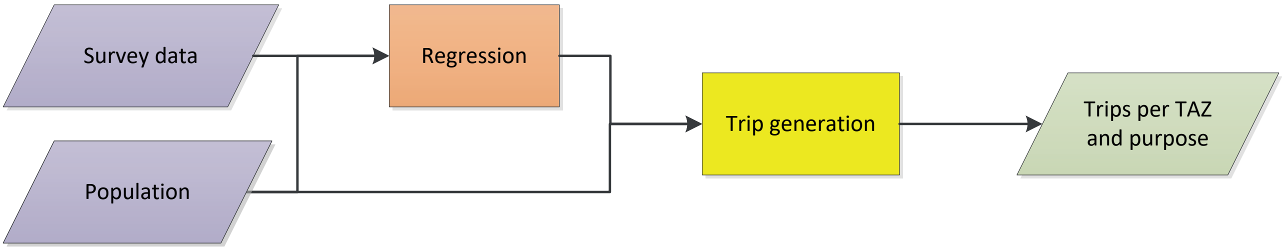

Figure 10: Step 1: trip generation – input and output data.

The computation of destinations of the trips done within the second step usually uses the information about the locations of places where the different activities can be performed at. When using the so-called gravity approach, these locations are weighted by their capacity and their distance to the respective source a journey starts at. The nearer and the bigger an activity location is the more persons are attracted to it.

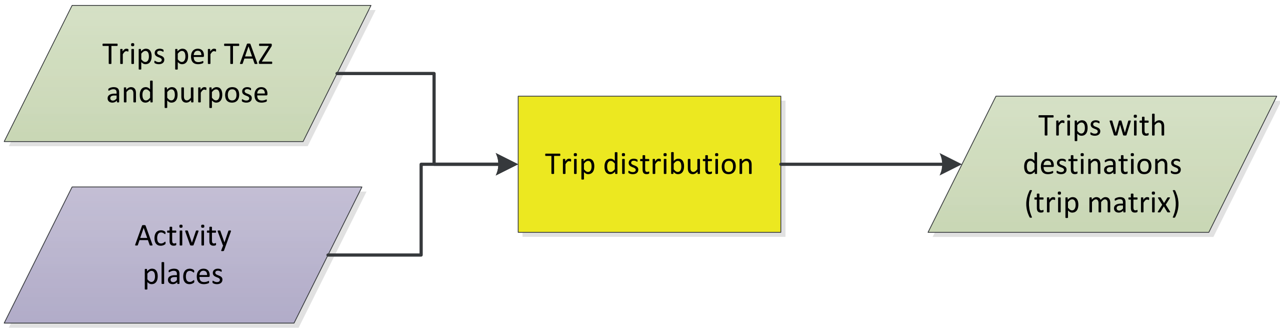

Figure 11: Step 2: trip distribution – input and output data.

The mode choice within a region or area depends on the infrastructure, the socio-demographics, the mobility options available by the population, and the respective utility for a person to visit the respective location regarding the monetary costs and the time needed to access the location. Again, a regression model based on given survey data is usually used to determine the utility of the available and modelled modes of transport in dependence to the trip purpose and the properties of the trip like. The most often used variables are the travel time in the respective carrier, the access and egress times, the waiting time, costs of the ride and the number of necessary interchanges. As well, one may find personal attributes, such as the age, the income, and the availability of mobility options, such as a car (and a driving licence), a public transport ticket, or a bike.

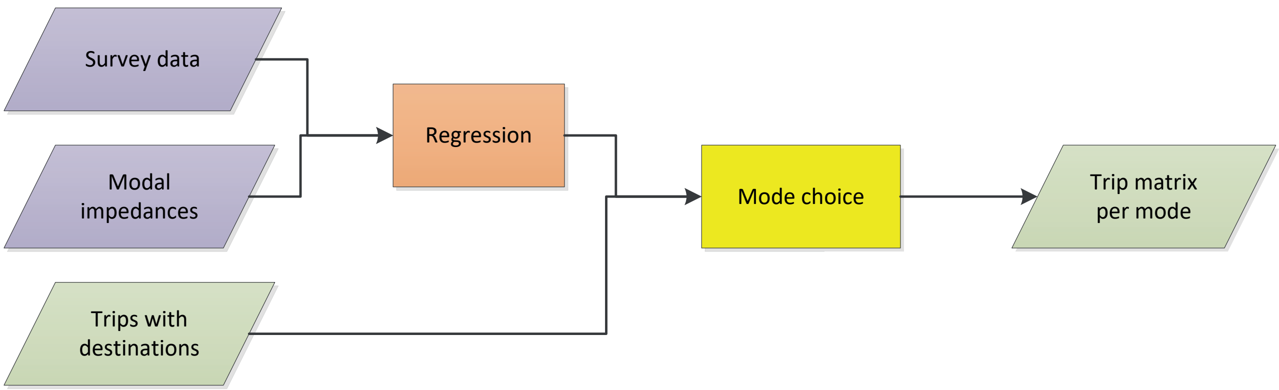

Figure 12: Step 3: trip distribution – input and output data.

The average travel time needed to pass a road increases with an increasing number of vehicles that use this road. Consequently, traffic spreads across available roads when a major road, being the fastest connection when being free of vehicles, gets jammed. Due to this, computing the shortest paths through the empty road network is not sufficient when modelling traffic. Instead, a so-called "assignment" has to be performed that computes which routes through the road network are chosen taking into regard the changes in the roads' travel times. Besides the routes, one major output of this computation step is "traffic flow" – the number of vehicles passing a road segment in a given time span – as well as the average velocities.

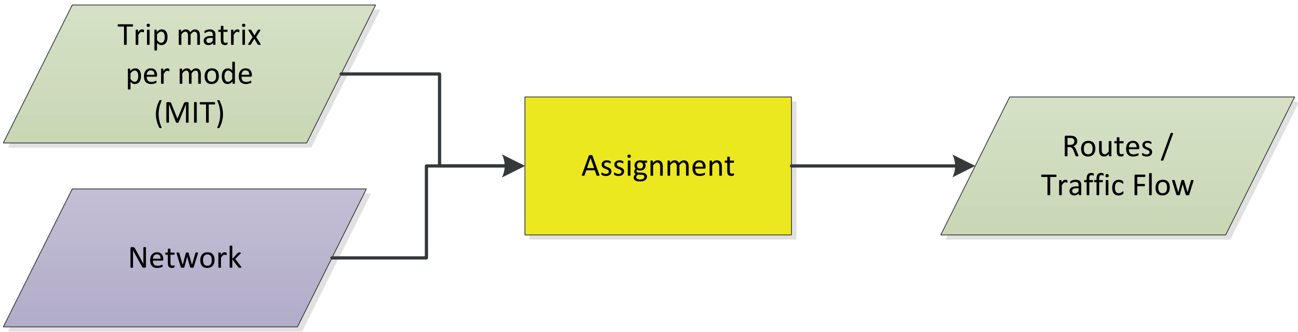

Figure 13: Step 4: assignment – input and output data.

2.3.2 Macro- vs. Microsimulation of Traffic Flow

Four-step models are usually "macroscopic" in their nature. "Macroscopic" means that a compound measure is directly modelled. In case of the four-step model the compound measure simulated in within the last step of traffic assignment is the "traffic flow", which in reality is composed of the behaviour of single vehicles. Being macroscopic in its nature, the four-step model does not replicate single vehicles. But for some purposes, for example for designing single traffic light schedules, a greater detail is needed. Such a detail is delivered by so-called "microscopic" models. Microscopic models simulate each entity a compound measure consists of explicitly. Thereby, microscopic traffic flow models simulate the behaviour of single vehicles for obtaining the compound measure traffic flow. Frankly, the term "macroscopic" is used for aggregated, the term "microscopic" for disaggregated views on a topic.

Of course, simulating single entities needs more computation time than simulating the compound measure directly. Yet, with an increasing computation power, microscopic traffic flow simulations can be used to simulate even complete big cities in real-time or faster. Nonetheless, one may find additionally so-called "mesoscopic" traffic flow models, which regard single vehicles as microscopic models do, but model their progress through the road network in a simpler way, e.g. using queues [10].

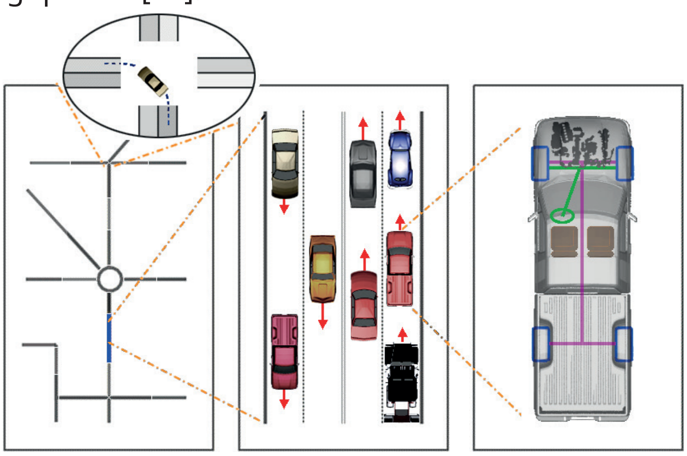

Figure 14: From left to right: macroscopic, microscopic, and sub-microscopic simulation; within the circle: mesoscopic simulation.

Microscopic simulations have many benefits in comparison to macroscopic ones. This is best explained when looking at the progress of vehicles through a network. When assuming a mixed flow of slow vehicles, e.g. trucks or busses, and faster ones, e.g. passenger cars, an aggregated, macroscopic view disallows to distinguish their progress. Instead, an average value for the velocity has to be chosen. A microscopic simulation but models the dynamics of both types of vehicles explicitly and computes their individual progress through the network. Besides, it is capable to regard different regulations for the vehicle types, e.g. disallow to use certain road types for trucks.

As a consequence, microscopic simulations promise to be capable of simulating a larger variety of additional investigations than macroscopic ones do. One reason is the greater detail of road layout and infrastructure representations. Traffic lights can be modelled including their real-world timings and/or the traffic adaptation algorithms they use. Other infrastructure units, such as variable message signs, can be replicated as well. This goes beyond the features of macroscopic simulations, which do not model individual vehicles and thereby lack measures used by present-day traffic light algorithms, such as the time headway of vehicles or the number of waiting vehicles. It should be mentioned, though, that these highly detailed representations come at the price of increased duration of a simulation and costs for building up the necessary data base for an according simulation scenario.

A further advantage of microscopic simulations is the possibility of distinguishing between different types of vehicles. This allows reproducing regulations such as closing roads or restricting turns for heavy duty vehicles or prioritizing certain vehicle types at intersections. In conjunction with lane usage restrictions, the addition of dedicated public transport or HOV lanes can be modelled. In addition, modern ITS (intelligent transport systems) applications that use on-board vehicle devices that are not included in all vehicles can be evaluated. This is hardly possible using macroscopic simulations, because a) the macroscopically simulated traffic flow usually does not support different behaviours for individual vehicles it consists of, and b) an individual vehicle's distinct position as given in the real world via GPS and often used by on-board applications is not given in macroscopic simulations either.

A third profit is the availability of acceleration and speed profiles of all simulated vehicles for all simulation steps within microscopic simulations. These measures are the major input to so-called instantaneous emission models and are thereby crucial for a valid computation of pollutants emitted within a region.

When looking at microscopic traffic flow simulation packages (see Section 3.2) one may notice that demand modelling is not an integral part as it is the case for four-step models. The major reason is the fact that microscopic models need higher computational effort and due to this, microscopic traffic flow simulations were initially used to simulate and optimise single intersections or corridors only. Meanwhile, due to improved models and increased computational power of modern computers, microscopic models can be applied to city-wide questions. Still, most traffic flow simulations usually require the information about the routes of vehicles from an external source.

When simulating vehicle routes, one must distinct between a plain driving along pre-defined routes and the assignment of traffic to the road network. Because the average speed along a road section goes down with an increasing number of vehicles passing this section, the fastest path across a road network may be different for different traffic amounts. The replication of the route choice of a population of drivers is named traffic assignment. On the one hand, not all microscopic traffic flow simulations come with methods for traffic assignment. On the other hand, one may still find macroscopic traffic assignment models.

2.3.3 Agent-Based Demand Models

What counts for representing the traffic flow is as well true for computing the demand. As described, conventionally, the demand is computed at macroscopic level within the first three steps of the four-step model. A relatively new approach for computing the demand uses so-called agent-based demand models (ABM) [11] that regard each person individually. The demand within a modelled region is the sum of all rides of the single persons.

The four-step approach results in road use measurements that can be set against available traffic counts for validation or calibration. McNally states that "[a]lthough this approach has been moderately successful in the aggregate, it has failed to perform in most relevant policy tests, whether on the demand or supply side" [11]. Indeed, the coarse aggregation level seems to obstruct the view of possibilities to model a single road user's individual decisions. Flow-oriented, macroscopic demand modelling has other limits, such as hardly achievable consistencies of trip chains or of shared resources as cars in the same household, because of operating with user groups instead of households with their inter-personal dependencies. Microscopic ABM approaches regard personal attributes as driving licenses and manage shared household resources such as the availability and usage of cars for computing consistent daily activity patterns. Current ABMs generate the travel behaviour for every person in a synthetic population with respect to the person's household context and are thereby capable to determine the population's reactions of changes in costs, travel time and infrastructure at an individual level, taking each individual's or household's possibilities and restraints into account.

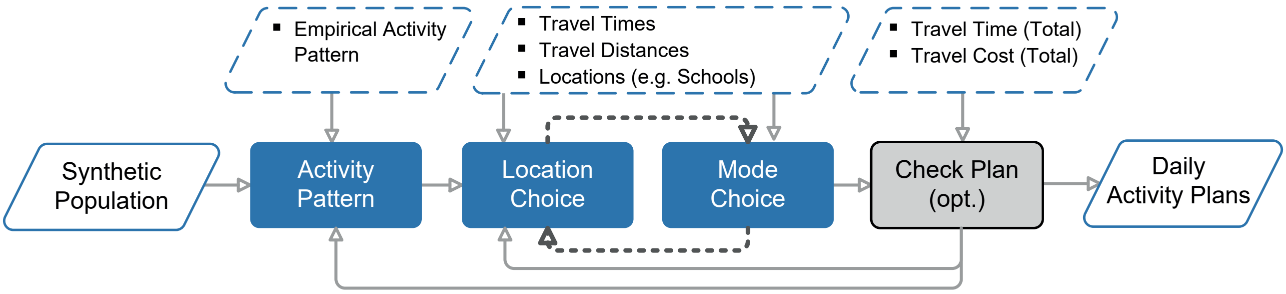

Figure 15: Modules of agent-based demand models

The figure above shows the flow chart of the functionality of many ABMs which consists of three major parts: activity generation, location choice and mode choice. One of the most important prerequisites is a synthetic population of the regarded city. The result of a simulation run is a list of daily activity plans, one for each person contained in the simulated population. Such a day plan consists of activities, locations, used modes, as well as travel-times. Some ABMs check the final plan for feasibility with respect to the simulated person's time and budget constraints. If the plan gets rejected, plan generation is usually repeated until an acceptable plan is found. The activity plans are often fed into a traffic flow model to map the demand onto the supply network and to feedback travel times and distances to the location and mode choice.

Each person and household of the synthetic population includes socio-demographic characteristics such as the number of persons, car ownership, age, gender and employment status. Further attributes like the availability public transport ticket, a driver license or bike ownership are needed in many models.

All ABMs compute the daily activity plan for each person by generating trips for all activities out of home. For performing a respective activity, the simulation has to determine a proper location for each activity and to determine the mode to get there. The activities are usually derived from national household travel surveys (NHTS) or similar. There are many methods to map appropriate activities to the simulated persons. ABMs either use statistical approaches, such as discrete choice models, to fit observed behaviours or use activity patterns obtained from surveys directly.

For each activity, possible destinations are selected based on available transport modes, mode specific accessibility, remaining capacity of the activity location, as well as the locations of previous and subsequent activities. The mode specific accessibility takes the individual restrictions into account, e.g. no available driving license or city tolls. Next, a mode of transport is chosen, based on the availability of bikes and cars, costs, travel times and the distance to the destination. Additionally, parking fees for the duration of the stay and restrictions of the destination area are usually taken into account. In principle, the methods employed in ABMs are similar to those of traditional four-step models. Yet, as being applied to single persons, no aggregation is done reducing the effects of averaging characteristics and/or results.

The trips chains obtained from an ABM are often fed into a traffic flow model to check for changes in times and costs. These updated travel times are usually fed back into the ABM until some kind of equilibrium is reached.

2.3.4 Land Use and Transport Integration

Transport demand depends to a large extent on longer term decisions. The places demand is generated at are to a large extent determined by land use patterns that result from the location decisions of firms and households. So-called land use models have a long tradition, see [12] or [13]. Alonso [14] and Lowry [15] laid the foundation by describing how a city's structure could be explained and how it will develop. While Alonso's framework is based on microeconomic theory where the land market determines rents and thereby which land use is located in what distance from the city centre, Lowry employs spatial interaction theory explaining how two objects in space interact with each other depending on their attraction (gravity model) and how that determines land use allocation.

The random utility theory developed and applied to residential location choice by McFadden [16] helped in explaining the choice of the agents in such models and thereby allowed for a much more disaggregate approach to distributing locations. From that time on, several land use models have been developed, such as TRANUS (see 3.4.3), UrbanSim (see 3.4.4), MUSSA/Cube Land (see 3.4.2), SILO (see 3.4.6) to mention but a few. With increasing computational power and data availability, the latest advance in the field is the development of microsimulation and agent-based models which simulate choices at a very disaggregate level (such as households) and in a dynamic way. I.e. they integrate processes such as marriage, birth of a child, and death in the case of individual demographics, or the auction of single properties, etc. Thereby they do not consider only one point in time but rather a period in which the city develops what has enabled answering many new research questions.

Since land use and transport always interact with each other, the common approach is to combine both in so-called land use and transport interaction models (LUTI). LUTI include different components, such as: population (households and firms), real estate and land use and their prices, accessibility, employment, economy, and of course all components of the transport model, as shown in Figure 16. These components must be described by characteristics according to the scenarios the model is intended to analyse.

Typical applications of such models involve the investigation of the effects of new transport infrastructure on the distribution of households and firms or the impact of transport measures such as road pricing. On the other hand, LUTI models also enable the user to analyse the impact of new real estate development on transport, the environment and the overall urban pattern. Furthermore, it is possible to analyse measures such as different land use plans and zoning, subsidies, taxation, affordable housing etc., see, e.g., [17].

One of the most important components in these models is the accessibility (see 2.3.5) of locations, which connects the models for land use and transport. On the one hand, a good accessibility is a key factor for deploying new infrastructure to perform activities at and is thereby needed for computing the land use development. On the other hand, accessible locations attract more people and are thereby the major sources of transport and are thereby regarded in the transport model. Figure 16 illustrates the basic interactions most models consider. Accessibility can be measured in many different ways, such as by the number of activities that can be reached in a certain time or by the travel time to certain locations, etc., see [13], [18].

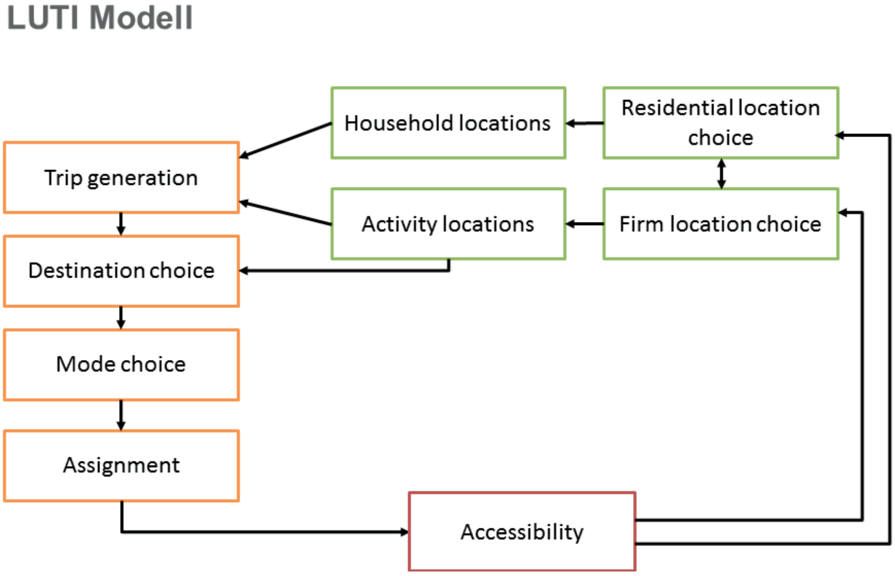

Figure 16: Main components of a land use and transport interaction model.

Here, the population consists of the agents that should be distributed in such models, i.e. households and firms. The agents are characterized by attributes such as household structure (presence of children and number of persons), income, car ownership levels, employment etc. in the case of households. Firms and companies are usually described by assigning them to an industry type and by their size in terms of number of workers. In dynamic models, households can grow and shrink and households and firms can be established or closed according to different sub models while in static models either the number of households or the number of real estates or both must be given.

Real estate, or land, is the component households and firms are allocated to. For modelling, they should be characterized according to the specific needs of the scenario. Real estate can be constructed and demolished. Some models are also able to convert between different types of real estate markets such as housing and commerce. In most models, the population decides where to locate based on the prices of the real estate which often is a result of supply and demand.

In several models, employment plays an important role as it is the connection between households and work places. Employment can be included in the real estate characteristics and in the attributes of the households it is not only important to know where a work place is available but also who is actually likely to work there. Here, many models miss the link between a household and the workplace which requires a workplace choice model. However, this component can also be treated in an aggregate way: how much employment of which type is available in a region? Here, the problem is often a lack of data.

This brings us to another component that some recent models consider and which depends on the spatial extent of the area of interest. In many cases, not a single city is the focus but a whole region. Accordingly, some models consider the regional economy and other interactions within the region including commuting as the result of the mismatch between employment demand and supply.

Finally, an important feature to consider in the choice of a model is the time scale – the difference in time between single simulation steps. Wegener and Fürst [19] describe that the processes involved in these interactions are characterized by different speeds. Many questions thus require a dynamic model rather than a static one.

Yet, one should mention that LUTI models have not yet found their way to be a common tool. One and probably the main reason is the fact that building new infrastructure often depends on decisions from local governments or authorities. Thereby, land use development is often hardly predictable.

2.3.5 Accessibility Computation Tools

As mentioned (see 2.3.4), accessibility measures are a major data used within LUTI models. Yet, they deliver very valuable information about the currently available mobility offers by their own. While the usage of the simulation types described before mainly concentrates on motorized individual transport (MIT), accessibility measures are often applied to all available modes of transport. Therefore, the advocates of accessibility measures speak about a “shift of paradigm”, away from car-oriented to mobility-oriented city planning that emphasizes short ways and active modes of transport.

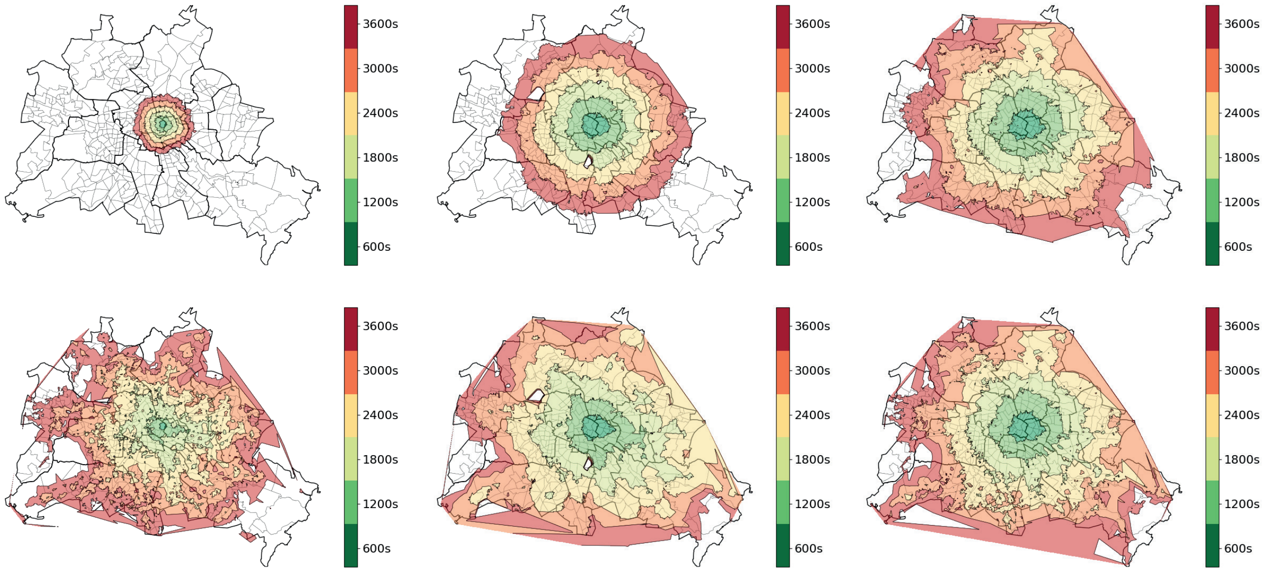

Figure 17: Distances covered using different modes of transport when starting in Berlin, Mitte (city center) at 8am; left to right: walking, bicycling, driving a car; top: monomodal, bottom: in combination with public transport.

The most basic definition of accessibility is the amount of locations of a certain type, e.g. work places accessible within a given time scale, e.g. half an hour. But different extensions have been proposed with the aim to properly describe the available locations and their capacities as well as the persons’ possibilities to travel during a day, see Figure 18. Yet, these extensions usually come at the price of being not supported by empirical data. E.g., a person’s location during the day or the utility for a certain person to visit a specific place can be only determined using a model. Basic contour measures, which rely on physical data only, namely the locations of facilities and the travel times through the transportation network, can be computed without any additional models. As well, they are easy to understand. Therefore, they belong to the most used type of accessibility measures [20], together with gravity measures [21].

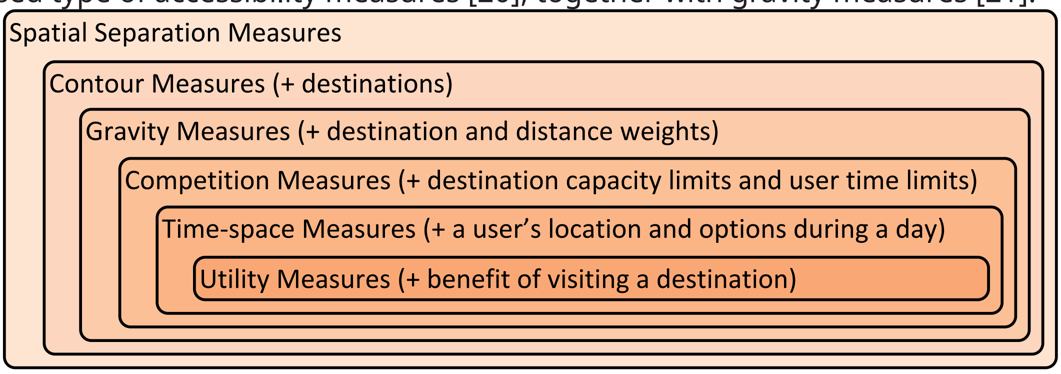

Figure 18: Classes of accessibility measures.

3. TRANSPORT MODELLING: SOFTWARE PACKAGES

Transport modelling applications are mature, well established tools used by transport planners and consultancies. For modelling the users, their mobility, and the resulting traffic within a regarded region, these software packages implement one or a set of the models presented in Section 2. Many commercial transport modelling applications have been continuously developed for a long time period. Besides being extended to meet new planning questions, e.g. by including new modes of transport, much effort is put in making them comfortable to be used. This is a major benefit of commercial applications. Besides, many commercial applications have been approved to be valid and following this approval, one may be sure that they are capable to be used for developing new measures with an honest degree of reliability. In addition, most commercial applications come along with a good user support offered by the respective supplier.

Besides mature commercial solutions, one can find as well some open source developments that cover almost all of the reported model classes. Yet, one should be aware that most of these open source applications have been developed in the scope of an academic work. One of the consequences is that their development is often not continued after the limited period of the academic work, may it be a doctoral thesis or a research project. As well, the number of the software's users is usually smaller, yielding in a lower rate of experience in using the tool and a lower number of found and solved issues. As well, mainly due to concentrating on the design and implementation of the underlying models, open source tools often lack a valuable user interface. Data and simulation settings have often to be prepared manually, without any additional support by standard tools or graphical user interfaces. Thereby, open source transport models are often "expert tools": Even though one can obtain valuable results comparable to those of commercial applications, the learning curve is steep and the time needed for preparing a simulation may be long. On the other hand, open source tools incorporate new methods or address new research questions, such as modelling new modes of transport that are not yet included in commercial applications. Above all, one can hardly find commercial tools that apply modern simulation approaches. Thereby, agent-based demand modelling or integrated land use and transport modelling are mainly covered by open source tools.

The following overview on software packages follows the structure of Section 2.3 where different types of models for modelling mobility and traffic have been presented. It should be mentioned that only a small portion of known models and simulation packages is described. The basics of microscopic modelling of traffic reach back to 1950ies [23], other approaches exist for long as well. Consequently, several generations of transport models got on the market and disappeared again. The authors tried to include descriptions for the major simulation packages, where "major" denotes their visibility in the community. As well, the availability of the simulation packages for third-party users was regarded, as some applications are used by the developing organisations for internal purposes only. Finally, an assumed potential of the applications to be available for a longer time span was considered. These selection criteria count for both, commercial and open source packages.

One may notice that with a growing maturity of the used modelling paradigm, the set of expected features is homogenised – applications that implement variants of the well-known four-step model or microscopic traffic flow models respectively share similar features. This is not the case for applications that use new, modern models. Instead, the applications of a class are very heterogeneous. Thereby, one may find more in-depth descriptions for land use and for agent-based models in the following than given for established models, such as the four-step model or traffic flow simulations.

3.1 Classical Macroscopic Four-Step Models

Being the most mature way of transport planning, four-step model applications have developed a very professional status. As discussed in 2.3.1, four-step models compute the demand in an area, first, and compute the resulting distribution of routes and traffic. They are designed for computing mobility and transport within a large area, yet at the price of aggregation and simplified models for the on-road behaviour. Thereby, they are mainly used for strategic planning within large areas, e.g. big cities. Their input consists mainly of the socio-demographics, the road network and public transport offers as well as activity locations in an area. After computing the demand and subsequently the traffic on the roads, these models deliver information about the use of the road network and public transport, including capacities, average velocities, etc. In-between steps of demand generation deliver the modal split or the number of performed trips.

Modern four-step traffic planning software packages support the user in setting up the simulation scenario, including a graphical representation of the area of interest or the definition/ import of traffic assignment zones using well-established formats for spatial data. They support the import of other data from well-known formats, including the road network, the infrastructure, public transport offers in the region or data on the socio-demographics. Usually, a broad range of different models/methods for computing the demand are included and the applications offer graphical editors for interacting with the models, data, and the investigated network. Most of the tools support built-in management of simulation scenarios, allowing to compare the initial representation of traffic as-is against the outcomes of different measures.

As said, not all existing applications that implement the four-step model are named in the following. One may several others, among them OmniTRANS[5], PSV[6], CORFLO[7], METROPOLIS [22] or INTEGRATION[8]. Please notice that so-called traffic assignment tools, which perform only the last step of the four-step model are not included. A list of such applications can be found in Section 3.6.2.

3.1.1 VISUM

PTV Visum is commercial software for traffic analysis, traffic forecasting and GIS-oriented data management. It is capable of depicting all transport users and their interaction in a macroscopic transport model. The transport demand can be modelled using a large variety of methods. Visum allows running feedback loops between the demand generation and the traffic assignment, hereby covering the whole four-step transport modelling process. Transport planners use PTV Visum to model transport networks and traffic demand, to analyse expected traffic flows, to plan public transport services and to develop sophisticated transport strategies and solutions.

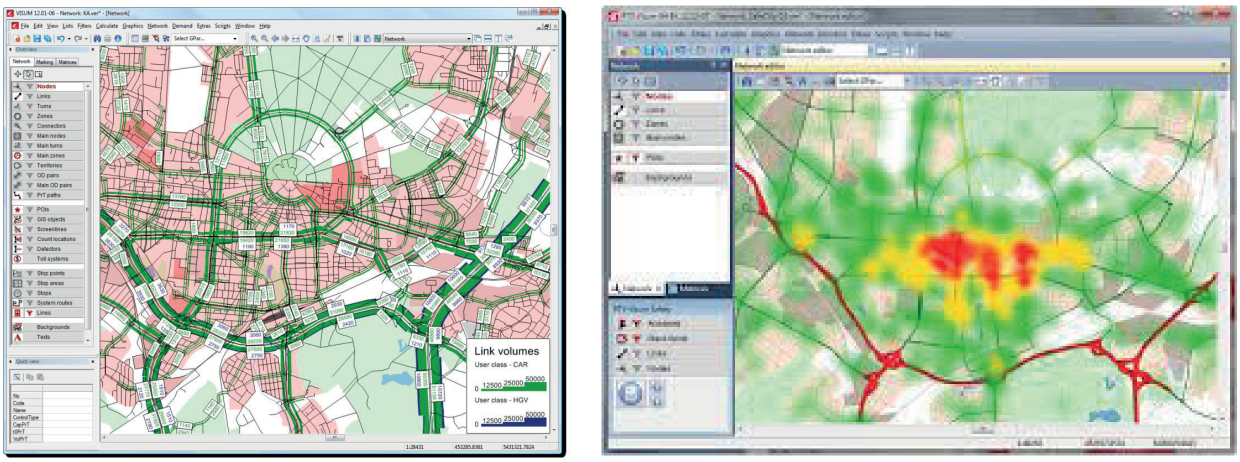

Figure 19: VISUM screenshots (source: PTV).

5 https://www.dat.nl/en/solutions/transport-modelling-omnitrans/
6 https://software-kontor.de/psv.html
7 https://mctrans.ce.ufl.edu/mct/index.php/products/demonstrations/
8 https://sites.google.com/a/vt.edu/hrakha/software

PTV Visum contains powerful models capable to simulate large areas up to complete countries. It covers all modes of transport, including combinations of transport modes (e.g. park and ride) as well as car, bike, and ride sharing. Visum supports a large variety of models for computing the demand and for traffic assignment and is continuously extended. While using macroscopic traffic assignment models, Visum is capable to replicate public transport schedules based on a per-ride base. The definition and optimisation of public transport is supported by integrated models and tools, including GTFS-import (see 5.3), timetables, fare model, and the calculation of business relevant key performance indicators. The most recent extension to Visum is a module for modelling demand responsive transport[9], which is usually not covered by macroscopic simulations due to the need to simulate single vehicles.

PTV Visum offers a very comprehensive graphical user interface that helps in preparing the scenario, including very powerful editors for matrices and the transport network. It is capable to import networks from sources as shapefiles, DIVA, or OpenStreetMap. As well, Visum supports a large variety of output processing and visualisation and can be scripted using the programming language Python.

VISUM	
Type	Four-Step Model (macroscopic)
Vendor	PTV
Licence	commercial (demo available)
Website	https://www.ptvgroup.com/en/solutions/products/ptv-visum/

3.1.2 Emme

Emme is a scenario-based tool for strategic and public transport planning. A log book lists the steps performed during the computation of a model with respective outputs. EMME supports multimodal networks distinguishing between different public transport carriers and supporting all common modes of transport. Emme puts emphasis on a user friendly modelling, including a large number of evaluation and explanation reports, a large set of visual evaluation possibilities, and on multimodal traffic. Emme supports the development and management of scenarios that describe different settings.

A transport model is composed in Emme using modules from the supported library. The complete chain from demand generation to assignment can be performed. Emme supports the classical four-step approach as well as trip chains, coming close to agent-based demand modelling.

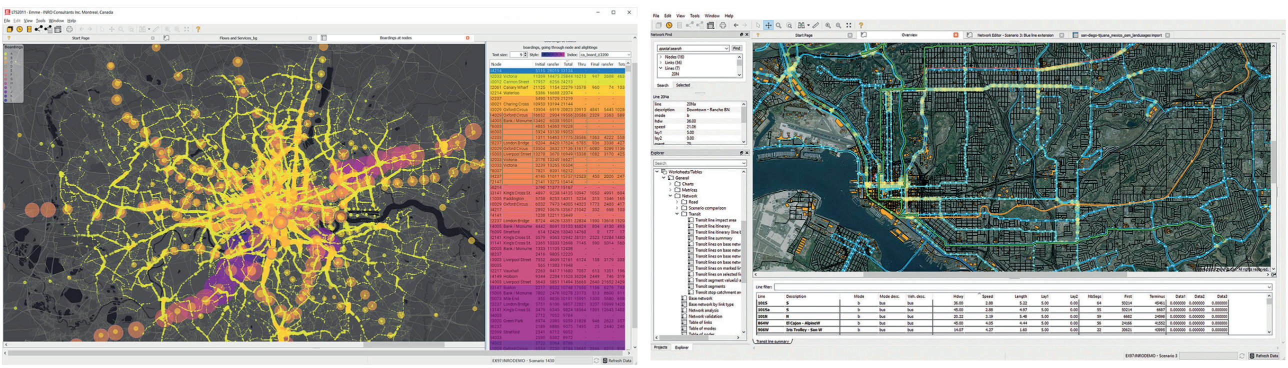

Figure 20: EMME screenshots (source: INRO).

9 *https://www.ptvgroup.com/en/mobilitynext/accelerator-program/?utm_source=Blog*

Emme	
Type	Four-Step Model (macroscopic)
Vendor	INRO
Licence	commercial (demo available)
Website	https://www.inrosoftware.com/en/products/emme/

3.1.3 Cube

Cube is a suite of transport modelling tools covering the complete range from four-step traffic assignment for strategic planning of transport networks on city level down to microscopic simulation of single intersections. This is achieved by a set of tools: Cube Voyager is a macroscopic strategic transport planning application that supports generating a demand as done in the first three steps of the four-step model including the selection of activities and mode choice. Cube Avenue allows simulating big areas using a mesoscopic model, while Cube Dynasim offers microscopic simulation models. These tools are accompanied by the land use model Cube Land (see also Section 3.4.2), a freight traffic model Cube Cargo, and a tool for processing real-world counts and survey named Cube Analyst.

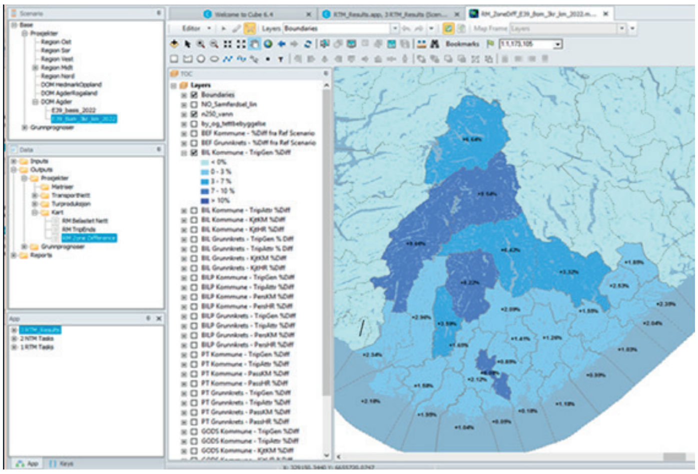

Figure 21: CUBE Voyager screenshots (source: Citilabs).

Like the other presented simulation packages, Cube supports the work with scenarios. Remarkable here is a split-screen visualisation of the same area for comparing two different scenarios. Cube offers graphical user interfaces for generating the model chain that can be composed from existing models as well as the definition of the road network. Further specific features include the simulation of parking management, pedestrian crowds simulation, e.g. for stations planning or freight transport modelling using Cube Cargo.

Cube	
Type	Cube Voyager: Four-Step Model (macroscopic) Cube Avenue: Mesoscopic assignment model Cube Dynasim: Microscopic traffic flow simulation Cube Land: land use model (see Section 3.4.2) Cube Cargo: freight traffic model Cube Analyst: data processing
Vendor	Citilabs
Licence	commercial (demo available)
Website	http://www.citilabs.com/software/cube/

3.1.4 TransCAD

The authors of TransCAD define it as "[...] the first and only Geographic Information System (GIS) designed specifically for use by transportation professionals to store, display, manage, and analyze transportation data"[10]. TransCAD support methods for computing the demand of a given area and for assigning it to the road network. Albeit not following the four-step approach strictly, the same set of results can be obtained as if using the applications named before. TransCAD integrates with different applications, such as Esri Personal Geodatabases, Access, Excel, and Google Earth and data from GIS, CAD, and planning software packages can be imported. TransCAD is mainly targeting the US market, bringing ready-to-use data for demand generation based on the US census.

Figure 22: Example TransCAD visualisations (source: Caliper Corporation).

TransCAD is a feature-rich application that supports the user by offering GIS-like interfaces. It supports all modes of transport, supports public transport planning as well as the replication of freight transport. TransCAD is being applied to complete cities as well as for modelling country-wide traffic.

TransCAD	
Type	Macroscopic Demand Generation and Assignment Model
Vendor	Caliper Corporation
Licence	commercial (demo available)
Website	https://www.caliper.com/tcovu.htm

3.1.5 Summary

Being in development for decades, the presented commercial four-step model applications have reached a mature state and usually offer a very comprehensive set of features that allows tangling all real-world tasks and problems. They usually come with well-designed user interfaces that support the user in all tasks. The available open source packages usually lack such functionalities, concentrating on the theories and models.

3.2 Traffic Flow Simulations

The most common application of traffic flow simulations is the design of single intersections or corridors, mostly regarding the schedule and synchronisation of traffic lights. Modern traffic flow simulations are capable to replicate the behaviour of all common modes of transport, including pedestrians, bicyclists, road- and rail-based public transport as well as motorised individual transport, including passenger and heavy duty vehicles. Microscopic traffic flow simulations use a very exact representation of both, the underlying road network as well as of

10 *https://www.caliper.com/tcovu.htm*

the simulated traffic participants. Regarding motorised traffic, different vehicle types with different sizes, maximum velocities, or accelerations can be defined. All these features enable a very exact representation of traffic at a single intersection or a corridor. Yet, this comes at the price of a high effort that has to be spent on defining a simulation.

Regarding traffic lights, most microscopic traffic simulations are capable to simulate complex, adaptive logics and/or public transport prioritisation. They support the user in defining traffic lights by according user interfaces. E.g., intersection clearing time matrices can be extracted from the simulation or be defined by the user. When simulating multiple intersections, modern simulations support setting up green waves regarding the vehicle's progress through the road network. Additional APIs allow attaching commercial real-world traffic light controllers or at least their algorithmic representatives.

One currently often found extension is the capability of simulating mixed-mode traffic that uses sub-lanes as found in Asian cities. Sub-lane models are as well used for simulating bicycle flows. As well, some traffic flow simulation packages have been extended by pedestrian simulation in the recent past. Besides, one may find the inclusion of mesoscopic traffic flow models for simulating larger areas, possibilities to simulate modern technologies, such as V2X communication, or other traffic management artefacts, such as variable message signs or route guidance signs. A further modern topic is the design and operation of parking places.

Microscopic traffic flow simulations usually come with facilities for importing road networks from GIS or CAD applications. Routes and types of traffic participants are usually defined in a proprietary, yet well supported way. Finally, many traffic flow simulations have at least one emission model included for computing the effects of introducing a measure or a technical solution on the environment. Most commercial traffic flow simulations come with a three-dimensional view and interfaces for being extended by own methods and models.

Again, only few of the existing simulation packages are presented in the following. The SMARTEST project[11] evaluated more than 30 different microscopic traffic flow models. Yet, being performed in 1999, many of the collected applications do not exist anymore or are no longer supported.

3.2.1 PTV Vissim

PTV Vissim is a mature and world-wide used microscopic traffic flow simulation developed by the German company PTV. PTV Vissim is capable to simulate all modes of transport and is probably one of the leading simulation packages when coming to including new modes of transport. Individual motorised transport including passenger and heavy duty vehicles with freely definable dynamics and other attributes are supported as well as different kinds of road- and rail-based public transport. Vissim allows the simulation of bicyclists and pedestrians as well as mixed-mode traffic with a large set of vehicles including rickshaws. One of Vissim's main characteristics is the high spatial resolution used, which enable an exact dimensioning of lanes, intersections, halts, etc.

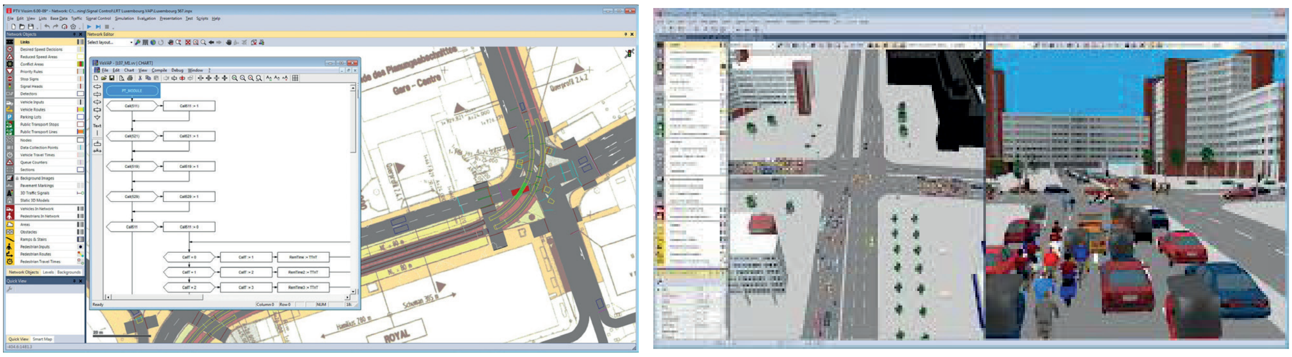

Figure 23: PTV Vissim screenshots (Source: PTV).

11 *http://www.its.leeds.ac.uk/projects/smartest/*

Not only the vehicle fleet that is simulated has a high variability, but as well the infrastructure, including different kinds of traffic lights, variable speed signs, etc. Here, Vissim breaks the usually used view on the road network as a graph of nodes (intersections) and edges (roads). Instead, vehicle paths are defined. This view on the road network enables a skilled modeller to represent the road network with a high degree of geometrical detail. Vissim offers APIs for programming own behaviour models, but comes as well with interfaces to common traffic light controllers, such as APIs for interaction with real-world traffic controllers, including Sitraffic Office, VS-Plus or LISA+.

While the simulation models and the respectively replicated vehicle types are frequently extended, a further strength of Vissim is the graphical representation of the simulated area using a 3D visualisation as well as a large set of possibilities for graphical evaluation of the simulation results.

The great feature set comes at the price of the need of skilled users that can unleash the simulation's full capabilities. Additionally, setting up simulations in Vissim is – despite the given possibilities to import external data and the very good editor – a complex task. On the other hand, much effort has been put into a seamless cooperation between Vissim and VISUM in the recent past what eases the import of a part of a previously defined area.

Vissim	
Type	Microscopic Traffic Flow Simulation
Vendor	PTV
Licence	commercial (demo available)
Website	http://vision-traffic.ptvgroup.com/de/produkte/ptv-vissim/

3.2.2 AIMSUN

AIMSUN is a further well-known and established microscopic traffic flow simulation. It is capable to simulate all modes of transport, including motorized individual traffic, public transport, pedestrians and bicyclists, yet the last only with a reduced representation of lateral movements. AIMSUN is targeted at fast simulations of large areas. For this purpose, AIMSUN includes not only a microscopic, but additionally a mesoscopic traffic flow model. Both models can be used within a single simulation setting, mainly used for simulating a certain part of the area with a greater, microscopic detail, while the rest of the area is simulated using the mesoscopic model.

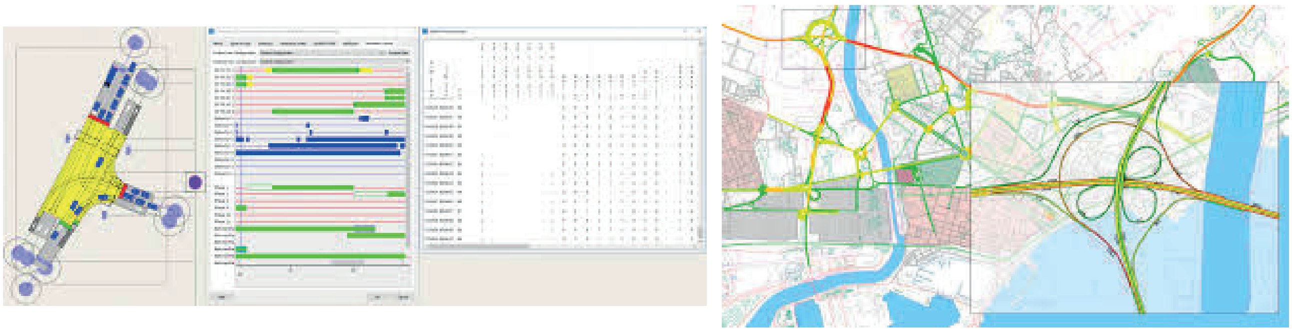

Figure 24: AIMSUN screenshots (Source: AIMSUN).

A further major focus is put on O/D matrix estimation, traffic assignment, and route choice. AIMSUN is capable to import simulation settings from a large of simulation packages, such as CONTRAM, EMME, VISUM, CUBE, TransCAD, SATURN, Quadstone Paramics, VISSIM, GIS and CAD. It offers interfaces to traffic light controlling applications, including SCOOT, TRANSYT 15, SCATS, UTOPIA, LISA+ and VS-PLUS. AIMSUN is portable – versions for Mac OS, Linux, and Windows exist. It offers additional extension possibilities and interfaces and comes with a built-in revision control for traffic scenarios.

AIMSUN	
Type	Micro-/Mesoscopic Traffic Flow Simulation
Vendor	Aimsun
Licence	commercial (demo available)
Website	https://www.aimsun.com/

3.2.3 Quadstone Paramics

Paramics belongs as well to the group of mature and very often used commercial traffic flow simulation packages. As the ones named previously, Paramics is capable to simulate different vehicle types as well as different types of public transport. While Paramics has a well-established model for pedestrian movements that is capable to simulate shared spaces, it lacks a dedicated representation of bicyclists. Bicycle traffic has to be represented by defining an own vehicle model, which runs on own roads. Paramics' strength is the representation of many different infrastructure artefacts found in the USA, such as HOV and HOT lanes or specific intersection types like the diamond intersection.

Paramics comes with a large set of import functions and emission computation modules. In addition, Paramics offers a sophisticated 3D representation of the simulated scene, including different weather settings and capable of being extended by own modules.

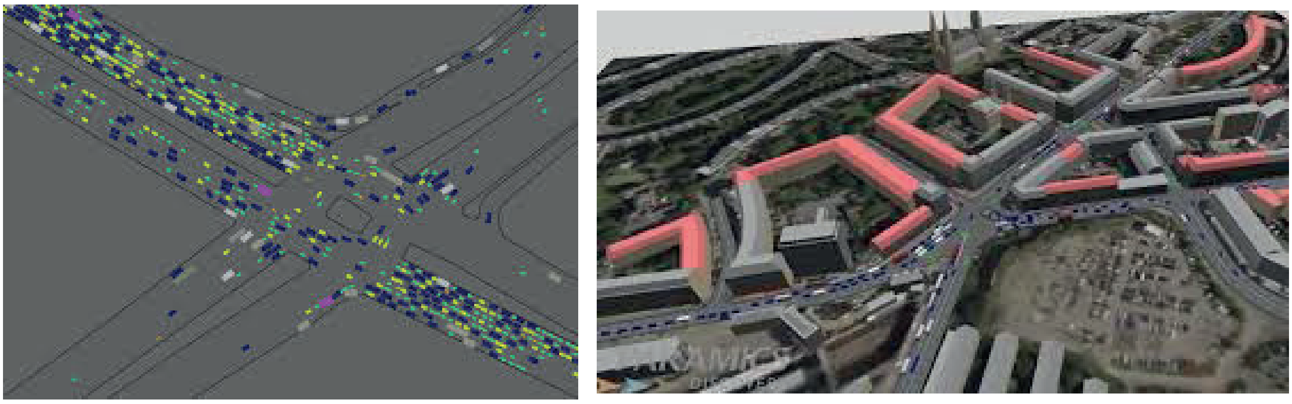

Figure 25: Paramics screenshots (Source: Quadstone)

Paramics	
Type	Microscopic Traffic Flow Simulation
Vendor	Quadstone
Licence	commercial (demo available)
Website	http://www.paramics-online.com/

3.2.4 Dynameq

Dynameq is a traffic flow simulation and assignment model from INRO, designed to be applied to areas starting at single corridors up to complete cities. Dynameq is applied for evaluating static and variable tolling schemes, public transport optimisation, or the evaluation of variable speed limits, ramp metering, or the effects of constructions sites on traffic flow. A strong focus is put on the availability of robust assignment methods for identifying bottlenecks in the given road network.

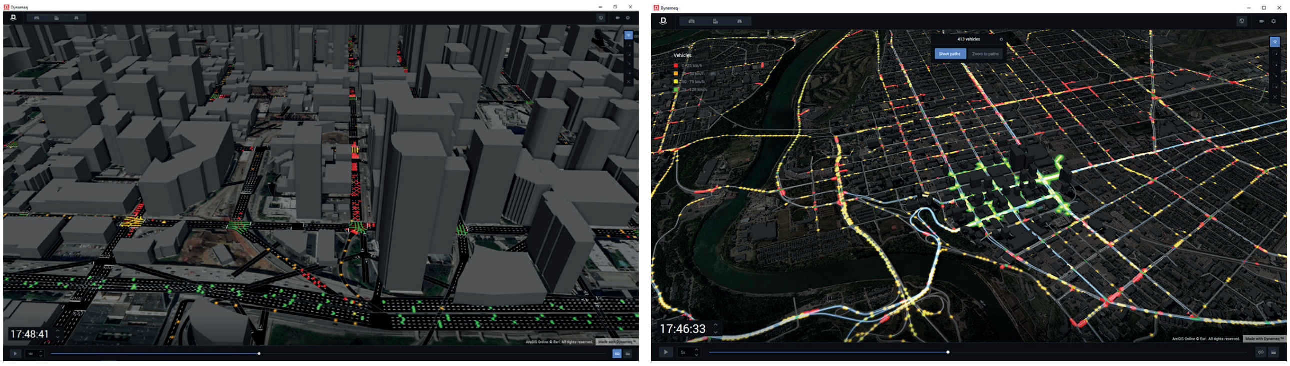

Figure 26: Dynameq screenshots (Source: INRO).

Dynameq integrates with Emme (see 3.1.2), a four-step model from the same company.

Paramics	
Type	Meso-/Microscopic Traffic Flow Simulation
Vendor	INRO
Licence	commercial (demo available)
Website	https://www.inrosoftware.com/en/products/dynameq

3.2.5 CORSIM

CORSIM is a compound of two traffic flow simulators, NETSIM (for surface street simulation) and FRESIM (for freeway simulation) and is under development since 1998. CORSIM is capable to simulate complex intersections, freeway acceleration lanes, deceleration lanes, ramp meters, HOT lanes, toll plazas as well as two-lane rural highways with passing and no-passing zones. One specific usage scenario is the simulation of pre-emption mechanisms for emergency vehicles. Yet, CORSIM is limited to cars only, though including both, passenger cars and heavy duty vehicles.

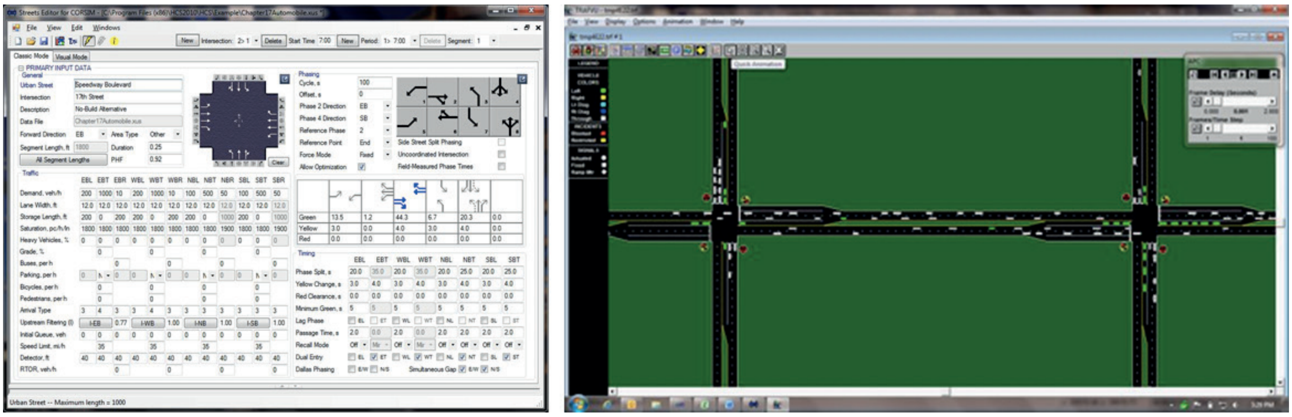

Figure 27: CORSIM screenshots (source: McTrans).

CORSIM	
Type	Microscopic Traffic Flow Simulation
Vendor	McTrans
Licence	commercial
Website	https://mctrans.ce.ufl.edu/mct/

3.2.6 MITSIM Lab

MITSIM Lab is a microscopic traffic flow simulation developed by a scientific team from MIT and VOLPE and released under an open source licence. The simulation consists of three different modules: Microscopic Traffic Simulator (MITSIM), Traffic Management Simulator (TMS), Graphical User Interface (GUI). MITSIM Lab mainly targets at the simulation of traffic management measures including ramp control, freeway mainline control, lane controls signs, variable speed limits, portal signals at tunnel entrances, intersection control, variable message signs, and in-vehicle route guidance. MITSIM Lab simulates passenger vehicles only.

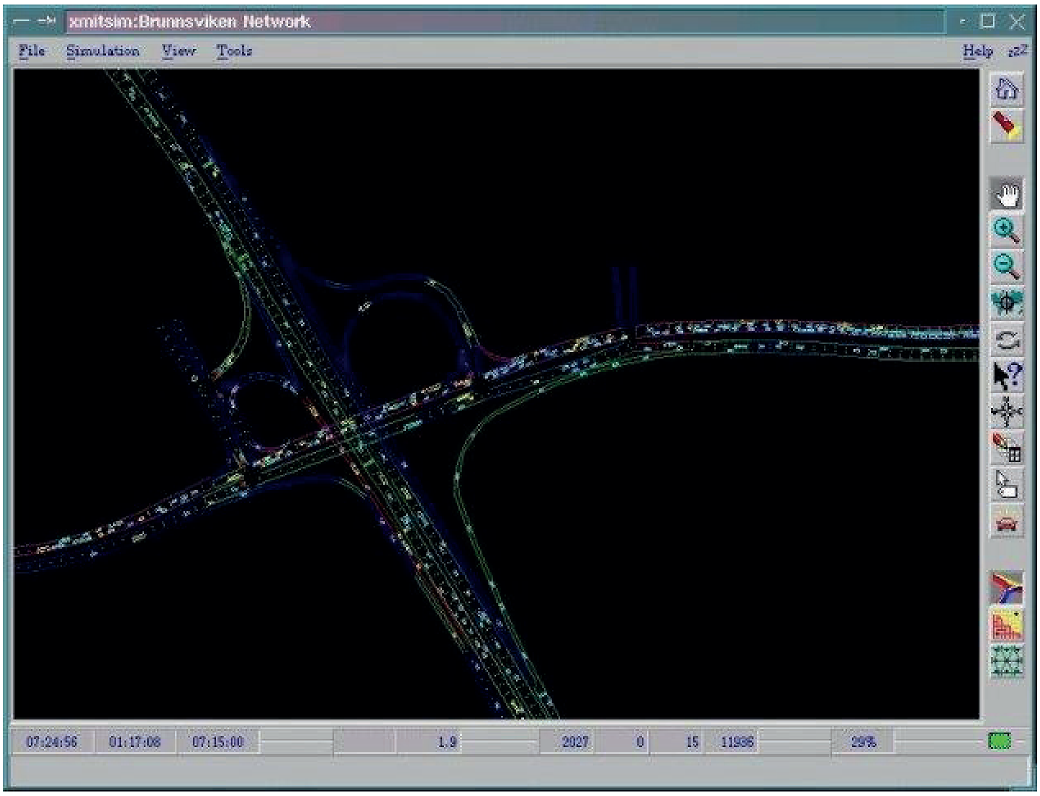

Figure 28: MITSIM Lab screenshots (source: MIT).

The last known version of the application is from 2015.

MITSIM Lab	
Type	Microscopic Traffic Flow Simulation
Vendor	MIT / Volpe
Licence	open source (MITSIMLab Open Source License)
Website	https://mctrans.ce.ufl.edu/mct/

3.2.7 SUMO

SUMO is a development of the Institute of Transportation Systems at the German Aerospace Center (DLR). The first version was released in 2002 and mainly due to its continuous development, SUMO is a well-known tool, used mainly by the academic traffic research community. The simulation is capable to replicate the movement of different modes of transport, including MIT, public transport (both road- as well as rail-based), bicyclists, and pedestrians. SUMO supports different intersection types, including right-before-left or priority intersections, as well as ones controlled by traffic lights and roundabouts. The simulation package comes with a set of additional tools for importing / generating road networks or for importing / generating a demand. Since December 2015, a graphical network editor is available.

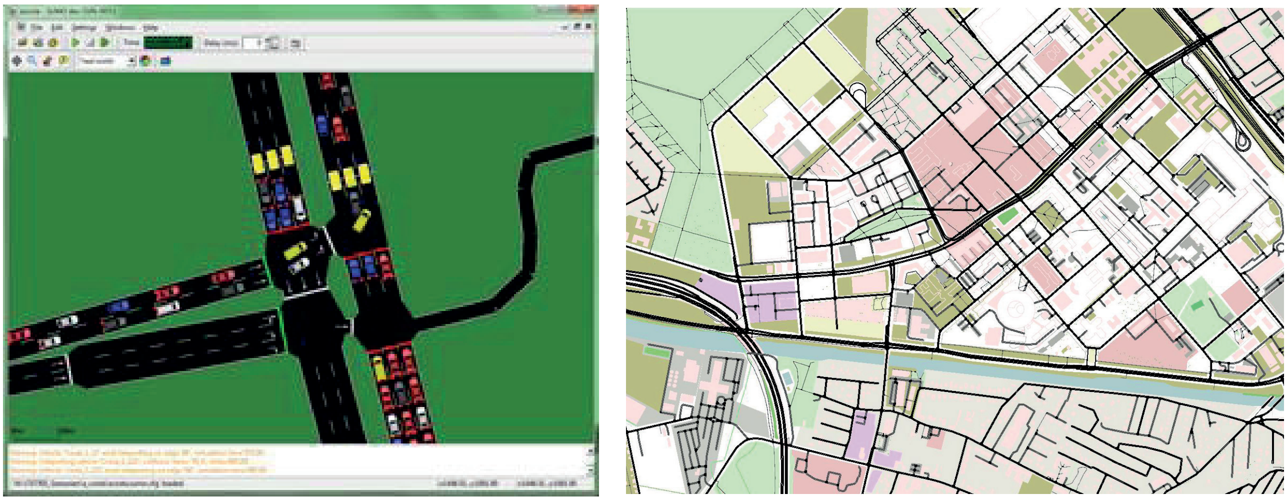

Figure 29: SUMO screenshots.

SUMO was designed to be fast for simulating whole cities in real-time or faster. SUMO's basic models are thereby kept simple and the default simulation time step duration is 1s while commercial applications usually use a simulation time step of 0.1s. Over the time, the simulation was extended by models for sub-lane occupation, smooth lane-changing and variable time steps as well as by a mesoscopic traffic flow model, making SUMO competitive to commercial applications.

SUMO's strength is the possibility to be extended by own mechanisms and / or models. This can be either done by changing SUMO's source code directly or by scripting the simulation via a socket-based interface. Different programming languages are supported, including Python or Matlab. SUMO uses XML-based files for describing the simulation, including the infrastructure as well as the demand, making the tool being easy to extend.

SUMO's weakness is the need to define different kinds of input data manually. While basic simulations can be set up very fast by importing OpenStreetMap or other network data and building a random demand, they usually do not have much in common with real world traffic. Usually, the road network has to be edited and different data source must be used for setting up a valid demand.

SUMO – Simulation of Urban MObility	
Type	SUMO – Simulation of Urban MObility
Vendor	DLR
Licence	open source (Eclipse licence)
Website	http://sumo.dlr.de/

3.2.8 MATSim

MATSim is a mature open source transport simulation package developed by the Technical University of Berlin. It has a big international user community, which applies the tool for a large variety of research questions, including the simulation of the effects of air pollution, autonomous vehicles, public transport or computing traffic for the land use interaction model UrbanSim (see also Section 3.4.4).

In contrary to commercial applications, MATSim is rather a set of methods and modules that may be re-ordered for answering a certain question. The supported graphical user interface is very basic, showing the simulated situation on the roads, but with no support for defining the road network or the transport offers. It should be thereby treated as an expert tool. Although recent extensions for simulating other traffic participants as well, MATSim originally regards MIT and PT only using a very fast mesoscopic simulation model.

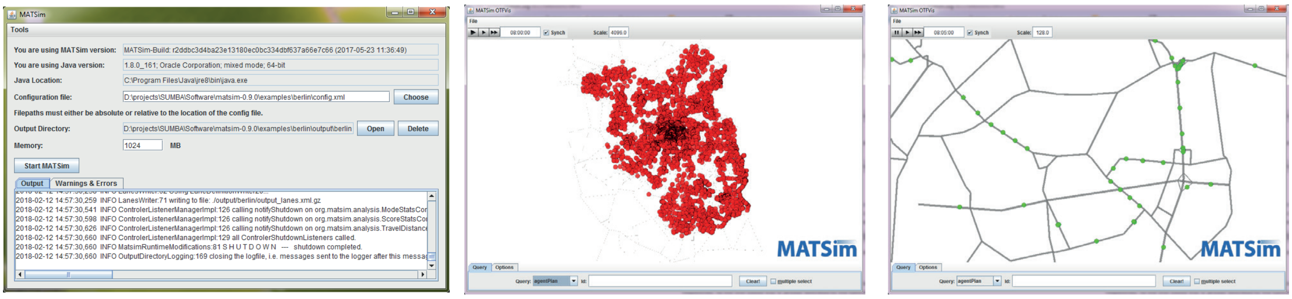

Figure 30: left: MATSim interface; middle / right: OTFVis MATSim visualiser.

Some of these shortcomings, especially the visualisation and a custom development of a demand are solved by additional tools supported by the commercial company “Senozon”[12].

MATSim	
Type	Assignment model
Vendor	Technical University Berlin
Licence	open source (GPL v2)
Website	https://matsim.org/

3.2.9 OpenTrafficSim

A relatively new open source traffic flow simulation stems from the TU Delft. OpenTrafficSim is rather a set of modules and libraries for composing a traffic flow simulation than a software program. As the development started recently, only few applications and descriptions exist, yet.

OpenTrafficSim	
Type	Microscopic Traffic Flow Simulation
Vendor	TU Delft
Licence	open source (MIT licence)
Website	http://opentrafficsim.org/index.php

3.2.10 Summary

Most modern traffic flow simulations share a similar set of features. While being originally designed to simulate passenger vehicles, almost all are capable to represent different vehicle types including heavy duty vehicles and public transport and most have additional models for bicyclists and pedestrians. One found trade-off is the one between a very exact representation of the infrastructure and the time needed to set up a simulation. Usually, as well the execution speed of the simulation is reduced with an increase in the level of detail as well. For this reason, some traffic flow simulations support hybrid simulations where a coarse mesoscopic model is used to simulate traffic in the surrounding area while the focused area is simulated using a microscopic model.

12 *https://senozon.com/*

3.3 Agent-Based Demand Models

One can hardly find commercial agent-based demand models. One could assume different reasons. The first is that the origins of these models go back to about 1980ies only so that the models are still in the progress of being academically evaluated. The second is that the data requirements are huge, making an application of these models to other areas than the ones targeted during the development difficult. As a consequence, ABMs differ strongly in their features what was discussed to be not the case for applications that use mature transport models, such as the four-step model or microscopic traffic flow simulation.

Besides the agent-based demand models described in the following, one may as well find further ones, such as TASHA [24], ALBATROSS [25], or TAPAS [26], which are well-described in literature but lack an online presence where further information or the software itself could be obtained.

3.3.1 DaySim

DaySim is software that simulates activities and according trips performed within a day for each person in each household of a synthetic population distributed throughout a given geographical area. It does this using an integrated set of econometric discrete choice models. DaySim uses up to nine activity purposes, represents activity locations as land parcels or microzones, and schedules activity and travel to the minute. DaySim works iteratively with any standard or custom software that is able to route the trips that DaySim generates between origins and destinations and to provide back to DaySim matrices of travel times and costs.

The software is free of charge, as long as you employ one of the copyright holders for the initial setup. Part of this consulting scheme is the evaluation for needed data-sources and guarantees a proper simulation set-up as well as the ability for custom modifications.

The software is used in many cities across the USA: Sacramento/California (SacSIM), Tampa/Florida, Nashville/Tennessee, and Seattle/Washington. Beside its US activity DaySim has been applied for the city of Copenhagen/Denmark.

DaySIM	
Type	Agent-based Travel Demand Model
Vendor	Massachusetts Institute of Technology (MIT), USA
Licence	Open source / consulting business model
Website	http://jbowman.net/#DaySim

3.3.2 TRANSIMS

TRANSIMS was created as a planning tool that simulates traveller behaviour and was originally designed for vehicle emissions simulation. Its main focus is on mode choice with respect to net-performance, toll rates and parking restrictions. TRANSIMS consists of a series of modules that produce populations, activities for the populations including locations and modes of transport, routes for travellers, and simulate traffic dynamics using a microscopic model. The travel demand is calculated by matching every household in a given synthetic population to a provided trip-survey. Within this model locations are selected by accessibility and occupancy, which is updated during the simulation process. The mode choice covers walking, bicycling, car, transit and park&ride but only in fixed combinations. The choice is based on provided survey data and tries to fit the shares with respect to activity, costs and time. The network routing of the trips is done in an integrated routing program called TRANSIMS Router.

The open-source model is publicly accessible and comes with a good documentation and example data of Portland for a quick evaluation. Its example for travel behaviour data is US-based and needs adaptation to fit European behaviour.

The car-trips are routed over a user-provided street network in either a macroscopic way using a classic flow model or a mesoscopic/microscopic routing simulation. The latter allows detailed analysis of lane occupancy and intersection performance but needs good knowledge of the infrastructure, like turning possibilities and traffic light control data.

TranSIMS	
Type	Agent-based Travel Demand Model
Vendor	Los Alamos National Laboratory (LANL), USA
Licence	Apache License 2.0
Website	https://code.google.com/archive/p/transims/ https://sourceforge.net/projects/transims/

3.3.3 SimTRAVEL / OpenAMOS

Another framework for agent-based travel demand modelling is called OpenAMOS. It is part of the greater research project called SimTRAVEL, which addresses the whole range of modelling urban systems including land development, human activities, travel demand, traffic flow and freight movement. For each year, OpenAMOS simulates the travel demand for one day of a synthetic population. It's divided in four parts: The first part is run only once for a simulation year and covers the modelling of the long term choices: synthetic population, vehicle ownership, work- and school-locations. As a result, the following steps have a synthetic population with all necessary information about its mobility options. The second part simulates the activities of each person for one whole day with respect to its status and household context and provides an activity skeleton for the last two steps. The third step divides one day into different time slices and models for each slice the location, mode and vehicle choice. The time slices enable the program to simulate accompaniment for activities (solo vs. joint) and rides. The output of this step is an optimized activity-travel pattern. This pattern is fed into the last step, where the utility of the simulated time-use is computed. This utility and convergence regarding to origin-destination relations and travel times is checked. Finally, feasible activity-travel patterns for all persons are saved for upcoming analyzation steps.

To run the program, the transportation network, a household travel survey comparable to the US NHTS-data, land use and census data for the population synthesizer are necessary. The program is successfully applied for Phoenix Arizona with a whole example dataset.

SimTRAVEL/OpenAMOS	
Type	Agent-based Travel Demand Model
Vendor	Arizona State University (ASU), USA
Licence	Open source
Website	http://simtravel.wikispaces.asu.edu/

3.3.4 Summary

Agent-based demand models support a high variety of investigations. However, the setup of these models is very time consuming and has a high demand on data. Therefore, custom made adaptations to the model to fit the region like done for TranSIMS or tailor made setups like in DaySim are very common. If an authority raises questions to the travel demand model, which cannot be answered by four-step models, ABMs are an option, yet special knowledge must be obtained to maintain the model.

3.4 Land Use and Transport Interaction Models

LUTI models provide the opportunity to analyse the interaction between land use and transport. In the simplest case, they enable the user to distribute agents across land uses based on their location characteristics and preferences of the agents or other rules defined by the user. These models either include a transport component or can be linked to an existing transport model. A very recommendable aspect is the consideration of prices as part of the decision mechanism which most but not all models do. This is important since many measures include them as the main trigger.

While most models in the past have been commercial ones due to the high amount of resources required to develop them, nowadays there is a clear trend towards open source solutions. However, most models are complex and institutions developing these tools offer consulting services in order to implement their models, independent of being open source or not.

A recent report by Rolf Moeckel [17] investigated the application and usefulness of several models in planning organizations in the United States. The complexity of these models ranges from simple sketch planning models to aggregate spatial-input output models and highly complex microsimulation models. According to [17], the most often applied models in the U.S. were Cube Land, CommunityVIZ and UrbanSim, included in the following list. This is complemented by the classical and widely applied TRANUS, as well as by SimMobility and SILO, which are two very new and promising models. While SimMobility is rather complex but has tremendous opportunities for functionality, SILO focuses on the main processes in urban modelling, thereby promising less rigorous data requirements and less effort for model development.

3.4.1 CommunityViz

CommunityViz [27] is proprietary ArcGIS-extension with an annual licensing fee. It belongs to the class of sketch planning models that are often used in planning organisations, because of being rule-based and therefore easy to implement, allowing for an ad-hoc application within meetings of planners and even public discussions of land use plans. Due to their simplicity, they neglect some heterogeneity e.g. in preferences. Sketch planning tools are rarely integrated with transport models. However, resulting land use can be considered in travel demand models and accessibility might be used to reassess scenarios.

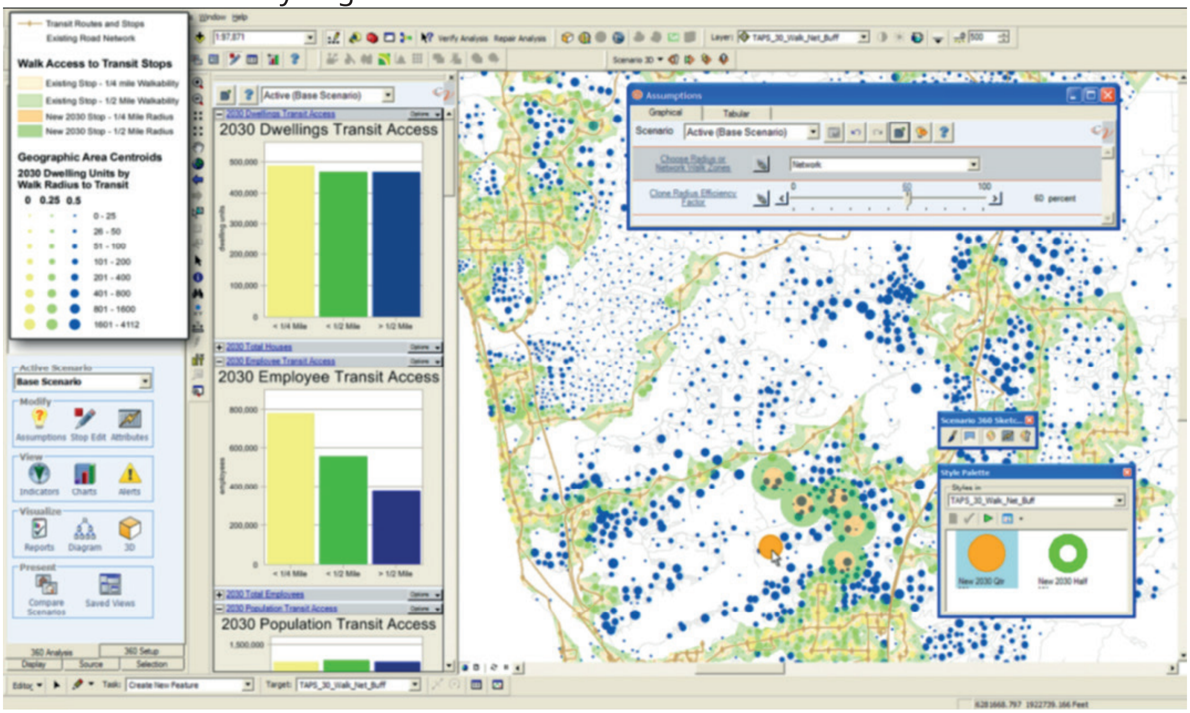

Figure 31: CommunityViz user interface in ArcGIS shows possibilities to alter input data and assumptions and instantaneously visualise results (source: CommunityViz, n.d.)

The tool has low data requirements using spatial entities such as zones or parcels as units of analysis. Input data on this level comprises development status of these zones as well as zoning plans and parcel data. The toolkit allows performing formula-based calculations on geographic data and on-the fly visualisation of results supporting planning decisions. As one possibility, previously defined suitability indices are used to assess whether and to what extent a zone will be developed, in other words what will be the growth rates of different land uses under varying scenario assumptions. The weight such indices represent can be developed in stakeholder focus groups, e.g. CommunityViz provides further alternatives to represent the mechanisms by which the growth of land use is determined.

CommunityViz	
Type	Sketch Planning Land Use Development Model
Vendor	City Explained, Inc.
Licence	commercial
Website	https://communityviz.city-explained.com/

3.4.2 Cube Land / MUSSA

Cube Land is part of the software package Cube distributed by Citilabs (see 3.1.3). Here, it considers the land use part, to be exact the location choice of households or firms. Cube Land is based on the land use model MUSSA that has first been developed by Francisco Martinez at the University of Chile for the Chilean government [28].

Cube Land follows microeconomic theory and simulates the urban real estate market, where agents (households and firms) maximize their utility and developers their profit. Agents issue bids for locations, i.e. real estate property types in zones (demand model). The more the characteristics of their locations meet the agents' preferences and the more resources they have available, the higher will be their bid. Cube Land assumes that one developer offers these locations. An auction determines the highest bid for a location, which is the rent (rent model). Depending on the highest bid the rent and the cost of the real estate they decide on whether to offer a location or not (supply model). Then agents' re-evaluate their bids until everything is in equilibrium, i.e. all agents are assigned to a location.

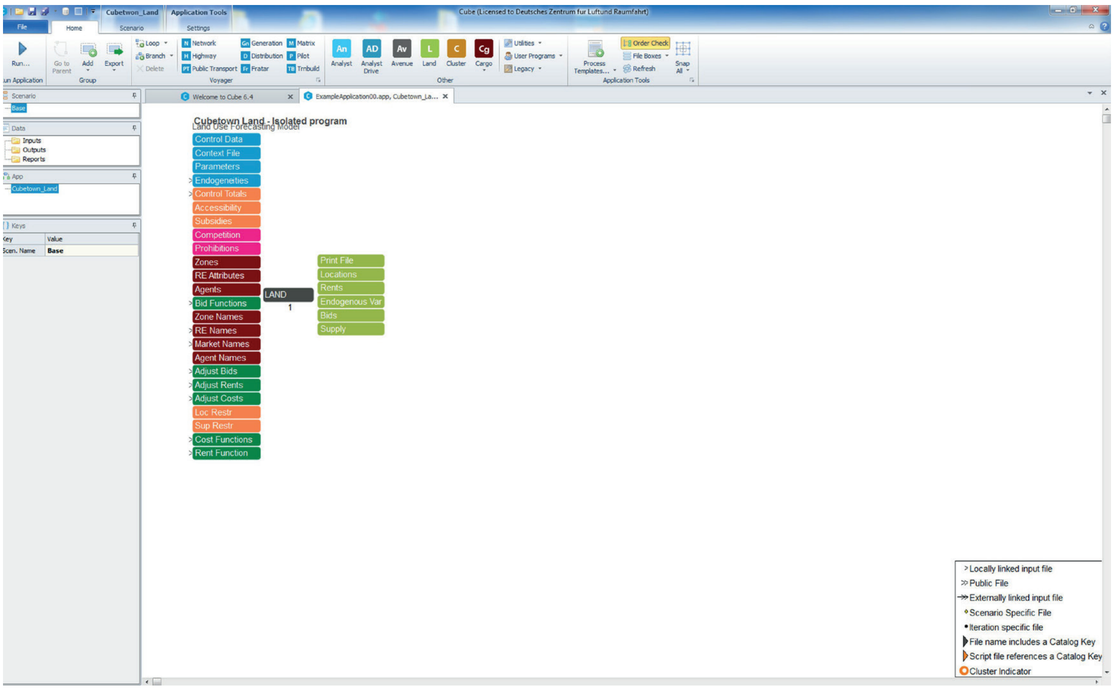

Figure 32: Cube Land simulation environment (source: Demo Model by Citilabs).

Cube Land is thus a static equilibrium model. All agents must be located in the end. So far, it does not include functionalities to depict the dynamics of the real estate market during a period of time (households grow or shrink, real estate is demolished, etc.). Rather the model covers one point in time and assigns agents to locations. In general, two scenarios can be simulated: (1) Fixed supply, where locations are fixed and (2) a variable supply, where the city gets 'rebuilt', i.e. the number of locations and the number of agents adjust to each other. These two specifications can also pertain to a part of the study area.

Cube Land needs the population, the real estate supply, regulations, zones and parameters for bid, rent, and cost functions and input. Parameters for the functions must be estimated from observed location data externally. The outputs of Cube Land are the number of locations, number of occupied real estates, bids by location and agent and rents by location. Cube Land also considers so-called endogenous variables. Using an internal feedback loop, it is possible to update variables during the simulation process, such as zonal income or the number of households of a certain type or the amount of retail floor space. Linking Cube Land to a transport model by using accessibilities which influence location demand and rent can turn it into a land use and transport interaction model.

Cube Land	
Type	Location Choice Model for Households or Firms
Vendor	Citilabs
Licence	commercial (demo available)
Website	http://www.citilabs.com/software/cube/

3.4.3 TRANUS

TRANUS is one of the very first LUTI-models and is still applied in many cities and regions. It is an integrated land use and transport model but also works as stand-alone transport model. The framework is often categorized as a spatial input/output model, i.e. it simulates flows between origins and destinations of production, consumption and transport. The system represents the whole economic system including the supply and demand of real estate and transport connected via accessibility and transport demand. Its applications range from urban areas to regions consisting of several nations and it is used to predict the outcomes of urban development plans, land use regulation, specific development projects, reorganization of public transport system, road pricing or restrictions to car-use.

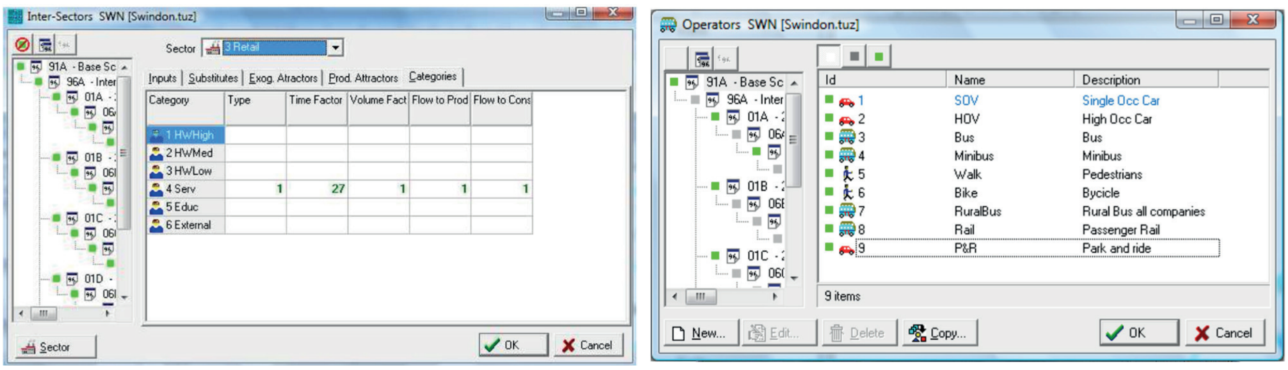

Figure 33: TRANUS; left: interface for generating transport categories from economic sectors, right interface defining transport operators.

The instrument follows a traditional approach and thus is constrained in its possibilities to simulate projects and policy instruments. However, due to its long tradition and many applications this tool is very well documented with explicit examples of applications on its webpage. Furthermore, it features the possibility to include freight transport and public transport.

The tool works as following: The modeller specifies whether he or she wants to use TRANUS as integrated LUTI or as a stand-alone transport model. Then, the zoning system must be defined as well as the socioeconomic sectors to regard. Further specifications include the transformation from production to transport (see Figure 33, left) and detailed information on the transport sector, e.g. transport operators (see Figure 33, right). After having defined exogenous production for the first time period, the land use model generates locations and functional flows which are transformed to transport flows between corresponding locations in the transport model. The model adjusts real estate supply and demand by prices until equilibrium is reached. Transport costs are in turn calculated in the transport model and fed back to utility functions in the location model for the next time period.

The instrument uses as input: the segmentation of zones, economic sectors, and transport, land use production data including households, jobs, floor space per zone and demand functions that describe how much land use consumes activities and how different activities interrelate, as well as a transport network.

For evaluating scenarios, TRANUS generates location indicators (production and demand for each land use in each zone), travel times, as well as general environmental, economic and financial impacts such as costs and benefits, fuel prices, land consumption, emissions.

TRANUS	
Type	LUTI Model
Vendor	Modelistica
Licence	Open source (Creative Commons)
Website	http://www.tranus.com/tranus-english

3.4.4 UrbanSim

UrbanSim is an open source simulation platform intended to analyse urban development scenarios including land use, transport, economy and the environment. Paul Waddell started its development in 1998. Alike many other LUTI-models, agents and real estate are grouped into types. UrbanSim simulates the generation and changes of agents (households and firms/jobs), location choices of individual agents as well as the development of real estate (construction or demolition) depending on the state of the regional economy and regulation by the government and other constraints.

Figure 34: UrbanCanvas user interface[13].

13 *source: http://cloud.urbansim.com/docs/parcel-model/documentation/interface.html#user-interface-and-menus*

In a simulation period, a transition model generates new households and firms while a relocation model determines which agents are likely to move. Then utility-based location choice models assign agents to those locations which are vacant and for which agents have the highest utility which depends on location characteristics and prices. In the development model, real estate is either constructed or demolished depending on whether rent deducted by cost still generates a profit [29]. Further models predict prices and rent values of real estate. Similar to Cube Land these values are used to adjust demand and supply to each other. Unlike the former, UrbanSim also accepts disequilibrium in the market, i.e. houses can be unoccupied and agents can be looking for a location for a certain time without being actually assigned. This reflects reality conditions in tense real estate markets.

The model operates at the building, parcel or zone level. The modelling suite also provides tools to estimate parameters required as input to the choice models. Simulations run annually. Results are provided as indicators at user-specified summary geographies.

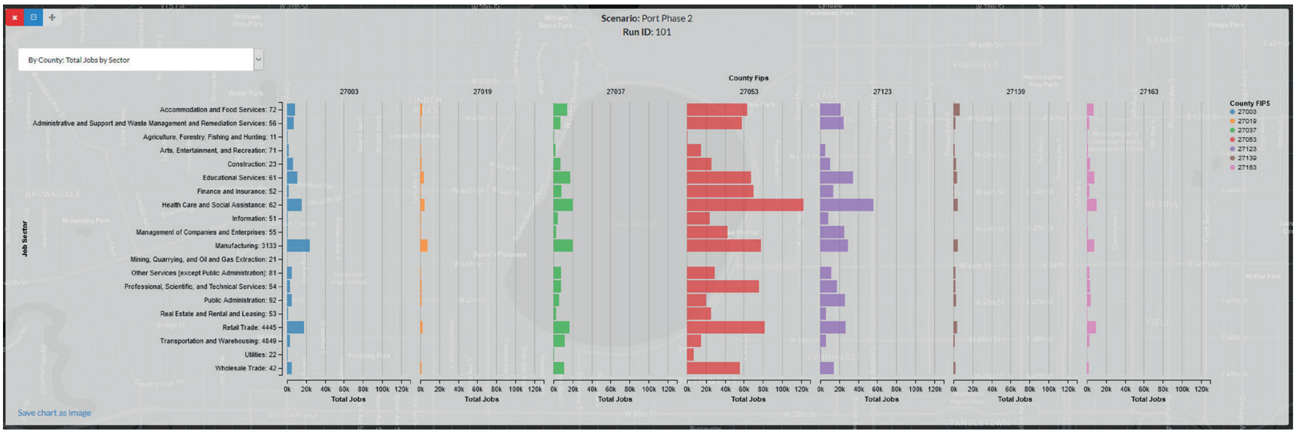

Figure 35: UrbanCanvas indicators from simulation results[14].

UrbanSim requires as input: geometries and attributes of the chosen spatial model level (blocks, parcels, zones) including their land use and land prices, buildings by spatial level and type and with number of residential and non-residential units, construction year, real estate data to estimate real estate price models, information about the area per job and building type; synthetic households with attributes such as number of persons, income, tenure, cars, race and age of the head, number of workers and children, and if the household is a recent mover; jobs and establishments including sector, number of employees and occupation category, control totals for population and jobs (regional economy), travel data (generalized cost, travel time, utility) commonly coming from a transport model, and zoning (development constraints) provided by the user[15].

The integration between transport and land use in UrbanSim is achieved in the following way: UrbanSim simulates each year until the year for which the transport model was set up is reached. Then it provides zonal indicators that are used by the transport model to update travel times/accessibilities which then feed back to UrbanSim and so on. Using UrbanSim the effects of different measures, such as cordon-pricing, densification, transit network transformation, environmental policies or demographic change on land use patterns were investigated.

UrbanSim Inc. develops the platform which is available on github[16] but also provides commercial services such as a Cloud to compute simulations via a user interface on the web (UrbanCanvas Modeler) saving computing resources of own computers, and consulting contracts e.g. to couple the local transport model and UrbanSim.

14 source: http://cloud.urbansim.com/docs/parcel-model/documentation/simulation-runs.html#simulation-status-log-download-results
15 http://cloud.urbansim.com/docs/general/documentation/urbansim%20parcel%20model%20data.html#parcels-attr-table
16 https://udst.github.io/urbansim/index.html

UrbanSim	
Type	LUTI Model
Vendor	UrbanSim
Licence	Open source (unknown/proprietary licence)
Website	http://www.urbansim.com/

3.4.5 SimMobility

SimMobility is an activity-based and integrated model of urban transport, spatial, and demographic development. It is separated into three layers that resemble different time scales the respectively modelled processes take place at. The long-term model describes the land use and economic activity. The basic time step is one day, but can be adapted. The simulator computes how land use changes, including the development and use of properties, the demographic changes of the population, and it calculates further long-term decisions of agents as well as the interaction between the population and firms. The mid-term module performs the computation of the agents' daily activity plans as well as the choice of the used modes, where different modes along a day are supported. The short-term module is responsible for simulating the within-day activity and thereby replicates the movement of individual agents across the road network. It is based on the MITSIM Lab microscopic traffic flow simulator (see chapter 4.2.5). Long-term and mid-term modules exchange activity-based accessibility measures and new locations of households and firms as well as information about vehicle ownership (see Figure 36).

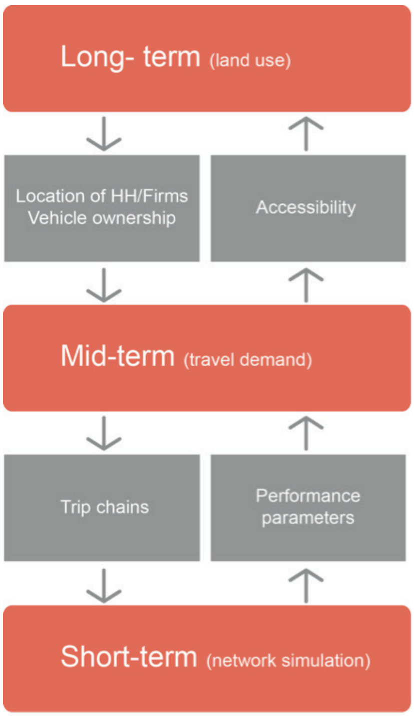

Figure 36: SimMobility - interactions between short-term, mid-term and long-term modules

The long-term module simulates day-based bidding procedures of households subject to searching for new housing. Buyers consider that they want to maximize their utility surplus (in comparison to their recent dwelling) when choosing a house from all available options. After having determined the new location households reassess their work location and where children go to school and whether they need to own a car or not. All these models include activity-based accessibility measures (cf. section 3.5). On the supply side, developers produce housing if their expected return on investment is higher than a threshold. Sellers offer such new and other dwellings on the market.

The framework has been developed since 2011 by the Future Urban Mobility Research Group at the Singapore-MIT Alliance for Research and Technology (SMART) and is still under development. Many modules are already functional, others are still missing. However, we could not find actual applications of the model framework other than in Singapore. The model is currently prepared for including autonomous mobility on demand.

SimMobility	
Type	LUTI Model
Vendor	MIT
Licence	Open source (SIMMOBILITY Version Control License)
Website	http://its.mit.edu/software/simmobility

3.4.6 SILO

The 'simple integrated land use orchestrator' SILO is a framework consisting of several models that represent events, i.e. processes and decisions. It is intended as a lean framework with limited data requirements using national averages and heuristic derivations of parameters from similar applications. Like other microsimulation models, SILO uses a synthetic population and the information about work locations. Decisions with spatial implications (housing relocation and development of new real estate) are modelled using discrete choice logit models. Persons, households and dwellings are agents in the system. Non-spatial processes are represented as Markov models with transition probabilities.

SILO includes a model for housing demand and supply. Based on vacancy rates, developers mimic household location choices to decide where to construct new housing. Hedonic price models are used to adjust housing prices. Housing location choice distinguishes between essential (e.g. price within budget constraint) and desirable factors (such as dwelling size).

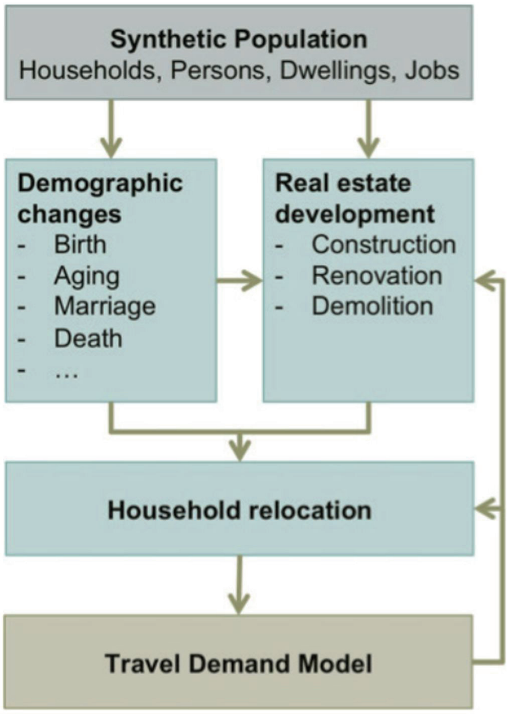

Figure 37: SILO flowchart

SILO is an open source software and available through github[17]. It is strong with regards to keeping model development and implementation simple, and it can be integrated with transport models. Furthermore, SILO employs several constraints, not only budget but other as well, such

17 *https://github.com/msmobility/silo/*

as constraints for the commute travel time or housing cost. This makes it more realistic than other models. Developers checked sensitivity and reasonability for several U.S. counties finding a high goodness of fit. However, SILO so far does not capture the life cycle of work locations or commercial floor space, in other words it focuses on the residential market. In the latest development phase, SILO is equipped with functionalities to consider autonomous mobility.

For input data, the framework requires a synthetic population, the locations of dwellings and jobs, as well as further land use data. According to the authors, such data is often publicly available. Results comprise updated synthetic population, housing prices, as well as population, dwellings and other indicators by zone.

SILO	
Type	LUTI Model
Vendor	Technical University Munich
Licence	Open source (GPL v2)
Website	https://silo.zone/

3.5 Accessibility Computation

As outlined in Section 2.3.5, accessibility measures are based on routing from a set of sources to possible destinations, usually assuming constant travel times for the regarded road network. The lack of dynamics allows for computing such measures using tools that deal with geospatial data, as done by geographic information systems (GIS). One of the most prominent GIS is ArcGIS and in the following, two extensions for this application that compute accessibility measures are outlined. As well, two open source approaches are presented, yet one being limited in the number of calculations.

3.5.1 ArcGIS Network Analyst

The ArcGIS Network Analyst by ESRI is an extension to ArcGIS Desktop, ArcGIS Engine or ArcGIS Server that has to be additionally licensed. It considers user-defined networks such as street or electricity networks or oil pipelines in order to perform different analysis tasks. A network in the simplest case consists of edges with directions and nodes that connect the edges. Furthermore, attributes such as different types of costs, constraints or hierarchies can be assigned to the network elements. This enables the user to calculate routes with the highest utility, be it the route with the lowest cost in terms of distance, travel time or monetary units or any other user-defined measure. Such routes may even consider mode changes on intermodal trips.

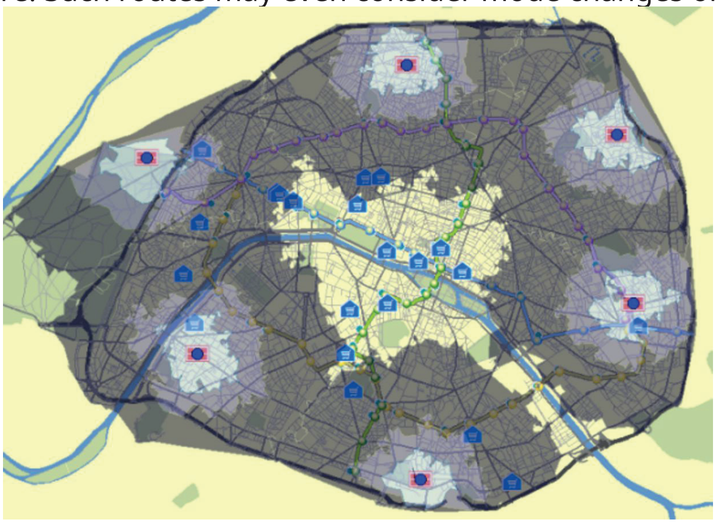

Figure 38: Service Area tool in ArcGIS Network Analyst

Besides this most basic task, ArcGIS Network Analyst is able to calculate origin-destination cost matrices, service areas, closest facilities, the vehicle routing problem (tour planning) and location-allocation, i.e. the assignment of facilities to points of demand e.g. in order to find out which of these facilities is not needed for satisfying the demand.

ArcGIS Network Analyst	
Type	Accessibility Measures Computation Tool
Vendor	ESRI
Licence	commercial
Website	https://www.esri.com/en-us/arcgis/products/arcgis-network-analyst/overview

3.5.2 Sugar Access

Sugar Access[18] was developed by Citilabs and is another extension to ArcGIS. It is designed to calculate accessibility, such as multi-modal accessibility scores to different types of activity locations. It is a closed-source commercial software requiring the basic ArcView version of ArcGIS for Desktop. Thus, the tool can be used without the Network Analyst license. However, the latter enables analysts to calculate a wider range of metrics while the former is focused on specific types of accessibility. Sugar Access comes along with globally available ready-to-use data from the provider “Here”. Considering that it is tailored to such network data and includes calculations and representations, it is more convenient for planners but with lower functionality than ArcGIS Network Analyst. Metropolitan Planning Organisations in the U.S. use Sugar Access to calculate different kinds of accessibility scores under varying scenario conditions, i.e. the tool also enables users to easily edit the network and assess the effects of such a change, e.g. to see how many destinations are accessible and how that changes with the introduction of a new transit line. Another example is the computation of accessibility by bike (Bike Score), which may also include other attributes than just travel time such as elevation.

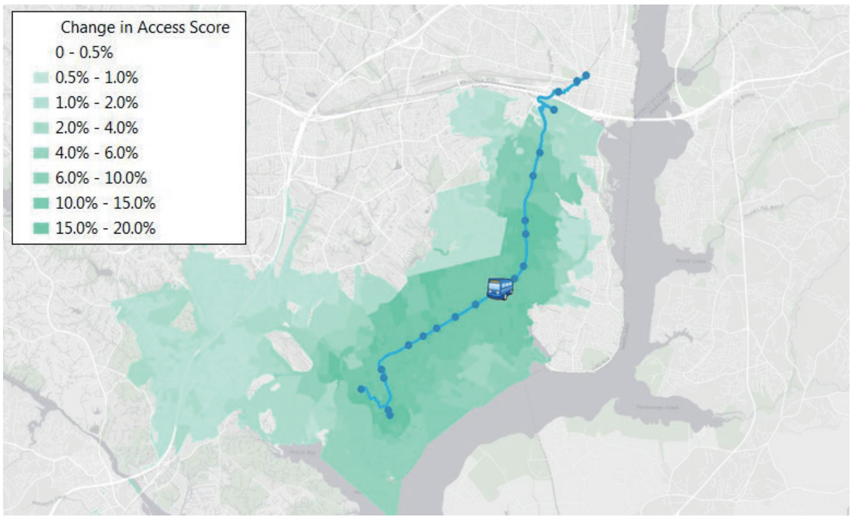

Figure 39: Sugar Access - example for Walk Score (souce: Citilabs)

Sugar Access	
Type	Accessibility Measures Computation Tool
Vendor	Citilabs
Licence	commercial
Website	http://www.citilabs.com/software/sugar/sugar-access/

18 *http://www.citilabs.com/software/sugar/sugar-access/*

3.5.3 QGIS and ORSTools/openrouteservice.org

The OSRTools offer the possibility to compute different accessibility measures, among them isochrones or matrices containing the travel times between a set of sources and a set of destinations. The tool is an extension to the open source GIS QGIS[19]. OSRTools use the openrouteservice.org APIs. They are free to use, yet only a limited number of requests can be sent and the covered area is limited as well[20].

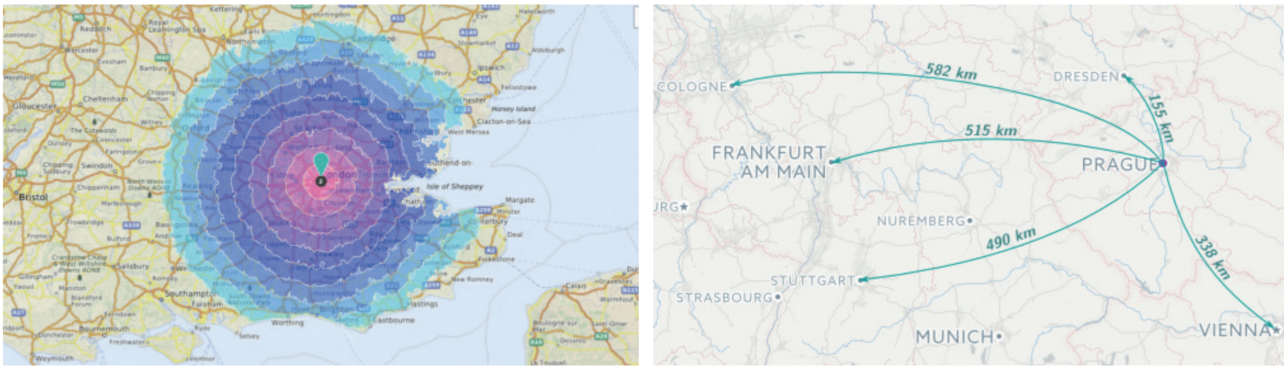

Figure 40: Accessibilities computed using the openrouteservice.org – the used visualisation technique is unknown (source: openrouteservice.org).

Sugar Access	
Type	Accessibility Measures Computation Tool
Vendor	University of Heidelberg
Licence	open source (MIT License)
Website	https://github.com/GIScience/orstools-qgis-plugin

3.5.4 UrMoAC

The “Urban Mobility Accessibility Computer” (UrMoAC) is an open source tool for computing contour accessibility measures. It is a standalone tool, not needing a hosting GIS application. The tool is targeted at computing accessibility measures at a very fine-grained level of detail. This counts for both, the data – sources and destination are represented as points in an area, e.g. by using addresses – as well as for the process of routing that computes the access to the road network and uses only roads accessible by the regarded mode of transport.

If necessary, the obtained accessibility measures can be aggregated using variable areas. The tool supports different types of limits for accessibility computation, including a maximum travel time, a maximum travelling distance, a maximum of places to access, a maximum weight of places to collect or the accessibility to the closest (in terms of travel time) place of a certain type. UrMoAC supports the modes walking, riding a bicycle, using a private car and public transport as well as intermodal combinations of using the public transport with access/egress by a bicycle or with access by car. Besides, it is not only capable to compute the basic accessibility measures as travel times and distances, but as well emissions, the price, and personal energy consumption.

Tools for importing freely available OpenStreetMap network data and public transport information in GTFS format are supported. Still, UrMoAC is an expert tool, run on the command line and having no native visualisation features. It is thereby necessary, for employing own post-processing methods for statistical evaluation or visualisation.

19 https://www.qgis.org/
20 https://openrouteservice.org/restrictions/

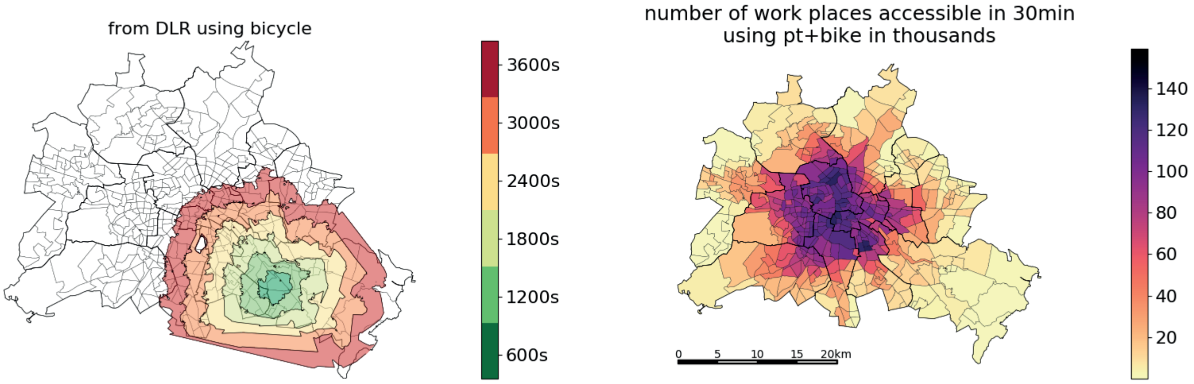

Figure 41: Examples of visualization of UrMoAC results; left: accessible area when starting at the DLR location in Berlin, Adlershof at 8:00 am using a bike, right: the number of accessible places using the combination of a bike and public transport.

UrMoAC	
Type	Accessibility Measures Computation Tool
Vendor	German Aerospace Center
Licence	Open source (GPL v3)
Website	https://github.com/DLR-VF/UrMoAC

3.6 Other Models and Applications

Besides the listed main model classes, one may find some new approaches for modelling traffic or certain parts of it. The number of these applications and their use cases is high and only some selected ones are presented in the following.

3.6.1 Real-World Demand Data

There are a number of commercial providers of transport demand models for planning purposes (e.g. Telefonica Next[21], TomTom[22], TERALYTICS[23], Streetlight Data[24], CityCast[25]) which are mostly based on smartphone data analyses. Moreover, sidewalklabs[26], an Alphabet company, created a planning tool for public agencies and land developers.

3.6.2 Assignment Models

Assignment models perform only the last step of the four-step model, relying on an existing demand. Being mostly macro- or mesoscopic in their nature, they are usually not applied for the design of single intersections or corridors as the case for microscopic traffic flow simulations. Instead, they compute the distribution of routes in a large road network and subsequently the resulting key performance indicators, such as traffic flow, density or average speeds. One may find different applications of this class. Commercial ones to name would be DynusT[27], Vista[28] or DYNASMART. One may as well find open source solutions, such as DTALite[29].

21 *https://next.telefonica.de/en/solutions/transport-analytics*
22 *https://www.tomtommaps.com/odanalysis/*
23 *https://www.teralytics.net/*
24 *https://www.streetlightdata.com/transportation-planning-product*
25 *https://citycast.io/*
26 *https://replica.sidewalklabs.com/*
27 *https://www.dynust.com/*
28 *https://nmc-compute1.ctr.utexas.edu/vista/*
29 *https://github.com/xzhou99/dtalite_software_release*

3.6.3 Public Transport Systems Planning

The public transport planning process is usually divided into five steps: (1) the design of the routes, (2) the setting of frequencies, (3) the timetabling, (4) the vehicle scheduling and (5) the crew scheduling and rostering. Especially the first (also called strategic planning), second and third (also called tactical planning) steps are covered in a high number of commercial software products. They mostly deal with parts of the known Transit Network Design and Scheduling Problem (TNDSP). A non-exhaustive selection of software focussing on mainly operational planning steps is: Hastus[30], IVU[31], Heures[32] and Trapeze[33].

Public transport design and optimisation is as well supported by "Transit" from Remix[34]. Transit uses GTFS, population and other GIS data to analyse changes in routing of PT lines, stops, timetables, costs or travel times. Another approach of assessing enhancements of public transport systems is the simulation of entire transportation systems considering individual passengers behaviour. This can, for example, be realised using the transportation planning software VISUM.

4. NEEDED DATA

In the following, a brief summary of the data needed to model certain aspects of mobility, transport, and traffic is given.

4.1 Transport Modelling

In analogy to the four-step model, the data needed for transport modelling can be separated in four groups, which are more or less independent. Hence, the following sections are distinguished between trip generation, distribution, mode choice and assignment. The basic spatial structure used within a transport models is a "traffic analysis zone" (TAZ). Most of the data relate to this spatial resolution or – especially in the case of agent-based demand models where individuals are regarded – to distinct places, e.g. buildings, in space.

4.1.1 Data for Trip Generation

Trips are generated due to the necessity for an individual to change her or his location for performing a specific activity (see 2.1), where the individual may be a person or a service-provider, e.g. a truck driver. To predict the mobility of persons that live in a zone, usually information about the number and the attributes of the population within the zone is needed, about their mobility behaviour, and about the built infrastructure within the zone.

The number of persons and their attributes determine the number of performed trips. Yet, besides the number itself, further attributes of the population are need, e.g. the household structure, the employment rate, or the availability of cars. These data are usually available at census offices, or official statistics like car registration offices or the local administration. The behavioural data describe what kind of actions people living in the regarded area perform over a day. Here, activity patterns from a household mobility survey may be used as well as statistics of time use or generalized generation rates like statistics how many times employed people go to their workplace during a whole year. Information about the built environment in the area describes on the one hand locations persons live at, on the other possible activity places that attract persons.

At present, an alternative source for trip generation emerges, which is based on cell-phone data or tracking apps. These data sources usually lack purpose and individual information due to anonymization requirements but can be useful if only movement patters are required for the desired application.

30 *http://www.giro.ca/en/products/hastus/index.htm*
31 *https://www.ivu.de/*
32 *https://www.lumiplan.com/*
33 *https://www.trapezegroup.com.au/*
34 *https://www.remix.com/*

4.1.2 Data for Trip Distribution

The trips for specific activities often start at home and need an appropriate destination. These destinations act as sources for further activities, e.g. driving home or shopping after work. Usually, the locations of destination can be derived from disaggregated land use data. OpenStreetMap may be a valuable source, yet only for well-covered areas, see 5.5. As well, some information, especially about public services, can be found on national data portals. One may as well find commercial suppliers of such information, e.g. NEXIGA[35].

Besides the locations and their types or lists of activities that can be performed at these locations, usually the information about their size – the number of employees at a working location or the capacity of a school – is needed for determining the location's attraction. If not given, methods for deriving the capacity from the building's respective size can be used.

4.1.3 Data for Mode Choice

The mode choice depends heavily on the quality of the input data, e.g. car and bike availability, seasonal tickets, accessibility via different modes and the structure of the population. This information is usually provided by census data and car registration offices, as well as national household travel surveys.

Additionally, mode-specific information about distances, travel times or prices of rides between different locations within the region is needed. This information can be collected via in-field measurements. A further source may be accessibility tools. Yet, especially when computing these measures for MIT using accessibility tools, a source for the average velocity is needed for each road of the road network. Here, coarse assumption could be used and improved by iteratively running the transport model and the tool that computes accessibility measures. As well, this information can be obtained from previously built transport models.

Furthermore, appropriate behavioural information is necessary to take regional attributes like pricing, price sensitivity, value of time savings and other mode specific preferences into account. Usually, such a "mode choice" model is derived from local surveys.

4.1.4 Data for Trip Assignment

The result of a successful travel demand model after the mode choice-phase is either a) a list of trips with origin and destination, b) a trip chain consisting of single rides along a day, or c) a matrix with trip volumes for each origin/destination-pair. To assign these trips onto a given infrastructure a proper representation of the infrastructure, mainly the road network, including its capacities, speed restrictions and usually the time settings of traffic lights is needed.

Networks obtained from free data sources, mainly the OpenStreetMap project (see 5.4) usually need manual verification and adaptation for supporting correct capacities. Traffic light programs can be usually obtained from the administrations.

4.2 Land Use Modelling

Depending on the specific model applied, data for land use modelling is required at different spatial scales and thus in varying level of detail. Frankly speaking, microsimulation models require quite detailed data while more aggregate models use more aggregate data.

All land use models require data describing the spatial configuration such as the number and allocation of inhabitants or buildings or the proportion of the area that is covered by green space. Models which represent the urban real estate market require more detailed information on demand and supply of housing including again (synthetic) population information (number of persons, car-ownership, age of households members, income levels etc.) and real estate data (buildings, building types, number of dwellings etc.). When being applied to a new

35 *https://www.nexiga.com/*

region, some of these models also presuppose land prices or rent values for being initially calibrated. Surveys on the residential location or very detailed location data (at a very detailed spatial level) is required for estimating weights for variables in location choice functions which compute the probability of an agent to choose this property. Crucial are accessibilities which influence the attractiveness and thus prices of a location. They are usually derived from travel times generated by transport models, distinguished by different types of activity locations. Finally, regulation data from governmental institutions is very relevant for operationalising status-quo interventions by planning departments and evaluating different types of scenarios, e.g. limiting growth in certain urban areas.

For calibration and validation purposes, additional data sources for the spatial distribution of population (preferably by household size, income or car-ownership), dwellings, and housing prices are necessary. Here, a more aggregate level such as city districts may be sufficient.

4.3 Validation

The obtained results of a simulation of the traffic system under regard as-is should be validated against real-world data. Here, one could think about the following options:

- Putting the mode share and individually travelled distances against surveys from the regarded area;
- Putting the simulated traffic volumes and speeds against measures obtained from traffic counts;
- Putting travel times between certain places against measured ones.

4.4 Data Requirements and Sources

In the following, a summary of data needed to set up transport and land use models is given. Table 1 shows the data needed for these model types.

Table 1: Data used for different tasks within transport and land use models.

	Travel demand			Land use					
Task	Trip generation	Trip distribution	Mode choice	Synthetic population	Housing location choice	Work location choice	Firm location choice	Real estate supply	Rent model
Population data	X		X	X	X				
Synthetic population					X	X			
Data on mobility behaviour	x		X						
Travel surveys	X		X			X			
Residential location surveys					X				
Smartphone Data	X								
Land use Data (activity locations)		X			X		X		
Jobs						X			
Parcels and buildings									
Real estate properties (including their number)								X	
Real estate prices								X	
Road networks		X	X						

	Travel demand			Land use					
Task	Trip generation	Trip distribution	Mode choice	Synthetic population	Housing location choice	Work location choice	Firm location choice	Real estate supply	Rent model
Data on public transport supply		X	X						
Accessibility					X	X	X		
Zoning					X	X	X	X	
Regulation							X	X	X

Possible source for the named data types are given in Table 2.

Table 2: Possible sources for such data.

	Administration	OSM	Phone companies	Public transport provider	Data companies	Map services	NGOs	own survey	own calculation
Population Data	X		X		X				
Synthetic population									X
Data on mobility behaviour	X						X		
Travel surveys	X						X	X	
Residential location surveys								X	
Smartphone Data			X		X				
Land use Data (activity locations)	X	X			X	X	X		
Jobs	X				X				
Parcels and buildings	X	X			X				
Real estate properties (including number of units)	X				X				
Real estate prices					X				
Road networks	X	X			X	X			
Data on public transport supply	X	X		X	X	X			
Accessibility									X
Zoning	X					X			
Regulation	X								

5. TRANSPORT DATA: SOURCES

Different data that may be used for modelling transport or land use can be found on the internet for free. The selection presented below concentrates on data sets available on an international scale, or at least on European level. When looking for further data, national statistical services[36] should be taken into account.

5.1 INSPIRE and Transportation Data

The Infrastructure for Spatial Information in the European Community (INSPIRE) is an initiative of the European Commission [30]. The goal of this initiative is to create a European Spatial Data Infrastructure (SDI) for the purposes of European Community environmental policies and policies or activities which may affect the environment. Based on the Directive 2007/2/EC, every member state is obliged to gradually provide geo data of the 34 annex themes using interoperable web services based on fixed data standards including standardised metadata. This obligation counts only for data which already exist, therefore the directive does not require the acquisition of new data. An overview on the 34 themes in the three annexes can be found on the INSPIRE website[37]. It also shows detailed information about the technical specification, the content and the expected metadata of each theme. Information about national INSPIRE geo data portals, the responsible institution and the implementation status of the directive can be found at the INSPIRE web pages[38],[39]. A summary on the implementation status has been developed by the Joint Research Centre (JRC)[40];[41].

5.1.1 INSPIRE Data Relevant for Transportation Models

Out of the broad range of INSPIRE themes, only certain topics are relevant for transport models. This section gives an overview on themes and subsequent data, which can be used for transport modelling and shows how these data can be included into the models.

5.1.1.1 Addresses

In the INSPIRE data specification, 'Addresses'[42] are identifications of the fixed location of a property. The full address is a hierarchy consisting of components such as geographic names, with an increasing level of detail, e.g. town, then street name, then house number or name. It may also include a post code or other postal descriptors. The address may include a path of access but this depends on the function of the address.

Addresses are important input parameters for allocating a synthetic population within the regarded area (see 6.2). Within microscopic transport demand models, addresses of buildings are activity locations (e.g. home, working, school, shopping) of single agents.

5.1.1.2 Transport Networks

The specification for INSPIRE 'Transport Networks'[43] define application schemas of common transport elements, road transport networks, cable transport networks, water transport networks and air transport networks. Elements in these networks are handled as nodes, links, aggregated links, areas and points. Connections between networks across national and regional border have to be included. Based on the geometric properties, the described elements should have temporal aspects (validity, date of creation, modification or removal) as well as thema-

36 https://en.wikipedia.org/wiki/List_of_national_and_international_statistical_services
37 https://inspire.ec.europa.eu/Themes/Data-Specifications/2892
38 https://inspire.ec.europa.eu/inspire-your-country-table-view/51764
39 http://cdr.eionet.europa.eu/
40 http://publications.jrc.ec.europa.eu/repository/bitstream/JRC109035/jrc109035_jrc109035_jrc_inspire_eu_summaryreport_online.pdf
41 https://inspire-dashboard.eea.europa.eu/#/
42 https://inspire.ec.europa.eu/id/document/tg/ad
43 https://inspire.ec.europa.eu/id/document/tg/tn

tic characterization through types of subtheme-specific property types. Road networks are needed in all kinds of transport models. They are not only relevant for the traffic assignment but are also essential for computing travel times, distances and other measures needed by demand models. As well, they may be used for different kinds of routing tasks conducted for lightweight analyses like accessibility measures.

5.1.1.3 Cadastral Parcels

The application schema of 'Cadastral Parcels'[44] focuses on the geographical part of cadastral data. Thereby, cadastral parcels should be considered as a single area of Earth surface (land and/or water), national law under homogeneous property rights and unique ownership, property rights and ownership being defined by national law. They may be required for mapping information that lacks an own spatial geometry but rather refers to the parcels.

5.1.1.4 Land Cover

The data specification for 'Land Cover'[45] information splits up in two core models (one for vector data and one for raster data). The models are designed to enable the representation of well-known international nomenclatures (like CORINE land cover or the GMES High resolution layers) as well as most regional and national land cover data sets. Therefore, all national land cover information can be transformed into a standardized, INSPIRE compliant data model. Thematic focus of this specification is the earth's surface including artificial surfaces, agricultural areas, forests, (semi-)-natural areas, wetlands and water bodies. Possible application of land cover data sets in transport/land use modelling are: The calculation of accessibilities to parks, lakes or other places for recreational activities or to calculate density indicators of soil sealing or urban green for the estimation of travel decisions. Such data may be used, e.g., for determining the attraction potentials of areas, such as the probability of a green field to be a place for performing leisure activities.

5.1.1.5 Buildings

The application schema of the INSPIRE scheme 'Buildings'[46] includes geometric and semantic representation of single buildings. Considered as under scope of the theme 'Buildings' are constructions above and/or underground which are intended or used for the shelter of humans, animals, things, the production of economic goods or the delivery of services and that refer to any structure permanently constructed or erected on its site. Thereby, the Buildings2D profile includes various geometrical representations of buildings as 2D or 2,5D data whereas the Buildings3D profile has the same semantic content as the buildings2D profile and allows in addition the geometric representation of buildings in any of the four levels of detail of the OGC compliant CityGML standard[47]. Furthermore, there are two BuildingsExtended profiles which allow additional thematic attributes (e.g. doors, windows, roof, rooms or internal installations) and links to other data sources.

At national level, there may be several databases related to the theme 'Buildings'. For instance, it frequently coexist a topographic view (2D or 2,5D) at scales around 1:10000 and a cadastral view (mostly 2D) at scales generally larger or equal to 1:2000. In some countries there is also a statistical view on buildings. A reliable overview about the databases available at the local level cannot be provided due to the lack of reference material. However, some local administrations have volumetric views (3D data) on buildings.

Building information can be used in transport models to distribute a synthetic population in space (see 6.2), to create activity locations (see 2.3.1 and 2.3.3) for the destination choice module or as a basis for a land use or LUTI model (see 2.3.4).

44 https://inspire.ec.europa.eu/id/document/tg/cp
45 https://inspire.ec.europa.eu/id/document/tg/lc
46 https://inspire.ec.europa.eu/id/document/tg/bu
47 https://www.citygml.org/

5.1.1.6 Land Use

The INSPIRE application scheme 'Land Use'[48] includes territory characterised according to its current and future planned functional dimension or socio-economic purpose (e.g. residential, industrial, commercial, agricultural, forestry, recreational) [Directive 2007/2/EC]. The 'Land Use' scheme splits up into 'Existing Land Use' (with existing land use as polygons – ELU, sampled land use – SLU and the gridded land use - GLU) and 'Planned Land Use' - PLU. To reflect the variety of spatial information that is already available on land use, the application schemas can be applied for ELU, SLU, GLU and PLU and support two different classification systems: the hierarchical INSPIRE Land Use Classification Scheme (HILUCS) or the respective local classification system of the member state. In general, it should be possible to transfer the local schemes into the HILUCS. Therefore, in terms of comparability, this conversion is desirable.

Land use data are very important for transport demand and land use models. They report where people possibly perform their activities throughout the day (e.g. living, working, recreation) and can therefore be valuable input for the distribution of a synthetic population in space and the identification of activity places.

5.1.1.7 Population Distribution and Demography

The theme 'Population Distribution'[49] includes the geographical distribution of people, including population characteristics and activity levels using the economic activity classification NACE Version 2 [31]. The data is aggregated by grid, region, administrative unit or other analytical unit. The theme may be thematically divided into several components. The directive points at broad groups of sub-themes:

- Human population by individual characteristics (sex, age, marital status, nationality);
- Human population activity levels (education, profession);
- Human beings living together in groups for different reasons (households, institutions such as retirement homes).

The theme 'Population Distribution/Demography' contains attributes related to statistical units. This means that this theme has no direct spatial features like many other INSPIRE Annex III themes. Instead, it needs to be linked to these features by the use of statistical units for example NUTS-codes or grid identifier.

Information where and how people live is crucial for transport models as well as for land use models. They are required as inputs for the synthetic population generation (e.g. for having the number of inhabitants of an area), or as part of the models itself, e.g. for trip generation or for distributing the population.

5.1.1.8 Statistical Units

As part of the INSPIRE theme, 'Statistical Units'[50] describe spatial features (polygons, lines, points or grid cells) that can be used to attach statistical information. Thereby, statistical information can be defined as "any numerical representation of a phenomenon" (from the data specification) like for example human population.

Important characteristics of statistical units are:

- They may have a hierarchical structure (like NUTS1, 2, 3) or a standardised grid structure[51];
- Their spatial extent can go from sub-local (smaller than municipalities/communities) level to country level;
- Their temporal extent differs per country. They can change in time, what makes comparisons of different points in time difficult;
- In many cases they are derived from administrative units, but other sources are possible.

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48 *https://inspire.ec.europa.eu/id/document/tg/lu*
49 *https://inspire.ec.europa.eu/id/document/tg/pd*
50 *https://inspire.ec.europa.eu/id/document/tg/su*
51 *https://inspire.ec.europa.eu/Themes/131/2892*

Statistical units are the geospatial reference of other INSPIRE data and are thereby needed as the connection between statistical information and the respective area.

5.2 Data from the European Commission and corresponding institutions

European institutions offer a range of publicly available and mostly comprehensive data bases.

One of them is the Urban Atlas[52]. It provides high-resolution land cover/ land use information for over 300 'Large Urban Zones' and their surroundings for the reference year 2006 and for over 800 Functional Urban Areas (FUA) for the reference year 2012. The data includes information on urban land use differentiated in around 30 classes. This data is freely available and can be downloaded in ESRI – shapefile format.

In addition, Eurostat provides a number of statistics on different themes (including transport, trade, economics, regional statistics, agriculture etc.) in different resolutions[53]. Additionally they provide the census 2011 dataset on the spatial resolution of municipalities, which may be a valuable input for building synthetic populations.

5.3 Google Transit Format Specification (GTFS)

GTFS[54] is a format developed by Google for describing a public transport offer within a specific region. It consists of six to 13 files, where each contains the information about a specific part of the offer, e.g. the halting places of public transport, definitions of the public transport routes, time schedules, etc. The files use the "comma separated value" (CSV) file format and are usually encoded in UTF-8.

Due to the simplicity of parsing these files, the format is supported by a large variety of tools and free GTFS descriptions are available for different cities around the world. One possible source for GTFS files is the "OpenMobilityData" web page[55]. GTFS is a very valuable source for information about the public transport offers within a specific region.

5.4 OpenStreetMap (OSM)

OpenStreetMap (OSM) is a free, editable map of the whole world that is being built by volunteers largely from scratch and was released with an open-content license. The OSM License allows free access to the map images and all of the underlying map data. It includes various kinds of information about land cover, infrastructure, land use and is constantly getting more comprehensive. Information about OSM can be found on the OSM wiki[56].

OSM data can be obtained from different sources in several file formats. A weekly updated OSM database dump-file[57] containing a temporal snapshot of the entire world with a current compressed size of approximately 28 GB is available. Smaller extracts of specific regions are also offered by other sources[58]. Several tools can be used to process OSM data. The most important ones within the OSM software environment are the open source command-line Java tool "osmosis"[59] and the flexible C++/JavaScript framework "osmium"[60].

In addition to the abovementioned snapshot of the most recent OSM database, the OSM-Full-History-Dump[61] contains the entire history of the OSM data. A new version of an OSM object is created whenever a feature's geometry is changed.

52 *https://land.copernicus.eu/local/urban-atlas*
53 *https://ec.europa.eu/eurostat/en/data/database*
54 *https://developers.google.com/transit/gtfs/*
55 *https://transitfeeds.com/*
56 *https://wiki.openstreetmap.org/wiki/Main_Page*
57 *http://planet.openstreetmap.org/*
58 *E.g. http://download.geofabrik.de/*
59 *http://wiki.openstreetmap.org/wiki/Osmosis*
60 *https://osmcode.org/osmium-tool/*
61 *http://planet.openstreetmap.org/planet/full-history/*

OSM data is a valuable source for a large set of different geospatial information. The major application is to extract the road or rail network for a specific region. Here, OSM supports the information about the restrictions of different modes of transport, the allowed velocity, and a large number of other information that allow in-depth evaluations of the available road/rail infrastructure. In addition, OpenStreetMap includes many other types of information[62], e.g. buildings, green areas, shops, other activity locations, etc. Thereby, OSM may be used for different purposes for both transport, as well as land use modelling. Nonetheless, it should be pointed out that a) the quality of data differs between different regions of the world, see next section, and b) especially the road network often needs additional rework for being usable within a transport model, because of lacking some fine-grained information, see, e.g., [32].

5.5 Quality of Crowd-Sourced Data

Based on the International Organization for Standardization (ISO) geographic information data quality standard (ISO 19114), the quality of geo-information is divided into the categories completeness, logical consistency, positional accuracy, temporal accuracy and thematic accuracy.

In regard to OpenStreetMap, data quality can be usually assessed using the following criteria:

1. The evolution of OSM features over a specific period of time provides a first insight into the development and quality of a chosen area within OSM. Histograms allow the visualization of these quantitative developments.
2. One general indicator is the overall number of (active) contributors within an area. Several investigations demonstrate that a high number of active contributors leads to a stable and good quality OSM dataset which is more probably kept up-to-date.
3. Beside the overall number of contributors, the mappers' actual amount of created data can provide more in-depth information. The more mappers with a high number of contributed nodes can be identified, the more active contributors are present in an area.
4. An important point in OSM is the currentness of data. After the initial collection process, the further maintenance of OSM data is essential for a high quality and up-to-date dataset. Ideally, the process of updating the OSM features' geometries and attributes is carried out continuously, homogeneously, throughout and is not limited to specific features. However, this is not the usual case within OSM. A possible way to analyze and represent the currentness is the visualization of the data's latest modification.
5. The positional accuracy of the OSM data depends very much on the way the data was collected. Several factors such as GPS signal preciseness displaced aerial images or bulk movements have an impact on data quality. A way to identify these possible positional inaccuracies without a reference dataset is the enhancement and modification of the method proposed in [33]. Instead of comparing OSM with a ground truth reference dataset, the location of currently valid road junctions is compared with its previous location.

Generally, most studies on the quality of OSM data show one commonality: a high positional accuracy and a huge amount of details are found around urban areas with a high number of contributors. In contrast, more rural areas often show a lower level of OSM data quality.

62 *https://wiki.openstreetmap.org/wiki/Map_Features*

6. TRANSPORT DATA: DERIVING MISSING DATA

Data requirements of some of the mentioned models are quite high and although availability of data increases, rarely all necessary data is available. Depending on the type of missing information, different methodologies exist that help to impute data, i.e., to fill the missing information based on existing data. They will be discussed in the following section.

In addition, available software tools for generating synthetic populations are discussed in the second half of this section. The motivation is the need for a synthetic population within different of the models discussed before.

6.1 Imputation

Different kinds of patterns of missing data can be categorised ([34], [35]): if data is missing completely at random (MCAR), the information gap does not depend on what is already inside the database used. An example for that is a person just overlooked a question in the survey because he or she was distracted. MAR (missing at random) describes a pattern where missing information can be explained by the values of the observations rather than the variable where entries are missing. Finally, MNAR (missing not at random) corresponds to a situation in which the missing information depends on the observed variable – a typical example here is if a person with high income does not want to state this.

Missing information can be imputed by applying data fusion techniques to fill the gaps. Existing information from the same or from other datasets serves as input to derive missing values. The simplest example of such imputation techniques is filling empty records with the average value of this variable, e.g. taking the average household income of all persons in the survey. This is called single imputation and is used if data is MAR. In Figure 42, a case with missing information in one dataset (Dataset X) is represented. Here, single imputation would correspond to averaging all values in Variable 1 and apply this value to empty data points (i.e. Record No. 3, 5, and 11 through 14). More advanced techniques use regression analysis in order to derive values based on one or several other variables in the same dataset. Applying such a methodology would mean to impute income values not only from other income values but also from related variables such as age, employment etc. In Dataset X in Figure 42, the association between observations in Variable 1 and explanatory values in Variables 2 and 3 could be used to fill the gaps in Variable 1. Based on the result, the process can be repeated several times to reduce the error. This so-called multiple imputation applies another methodology to combine all resulting values into one.

	Dataset X														
Record No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Variable 1															
Variabe 2															
Variable 3															

Figure 42: Dataset with missing values in two variables (blank white cells represent missing data)

A case different from the above one is if important variables are missing completely in a dataset (cp. Figure 43). Here, data fusion techniques can help to combine different datasets into one requiring, however, variables common to both databases. If the analyst can identify individuals in both datasets, he or she can apply so-called record linkage. An example for that would be using the address and other person-related information common to both datasets to relate a record in one file to a similar one in the other. Again, regression techniques can be applied for imputing whole variables as well. The association between the variable in question and other common explanatory variables can be transferred to construct this variable in another dataset. This method is called statistical matching.

In Figure 43 Variable 1 is missing in Dataset Y. Here, results of a regression analysis of Variable 1 as observed in Dataset X and common explaining Variables 3, 6, and 10 can be applied to Dataset Y in order to impute Variable 1 there. In consequence, missing variables can be added by combining two different data sets.

	Dataset X	Dataset Y	Pattern
Variable 1			specific to X
Variable 2			specific to X
Variable 3			common
Variable 4			specific to X
Variable 5			specific to Y
Variable 6			common
Variable 7			specific to Y
Variable 8			specific to Y
Variable 9			specific to Y
Variable 10			common

Figure 43: Datasets with missing variables (blank white cells represent missing variables)

6.2 Population Synthesizer

One of the most important input data sets for transport modelling is the population information as it directly correlates with the volume and the spatial distribution of the generated transport demand. Spatial accuracy and the number of person/household attributes needed thereby strongly depend on the chosen modelling technique. Since microscopic, agent-based transport demand models focus on the behaviour of single persons, they normally need high-resolution population information on the level of single addresses. This means that this information must include detailed description of single individuals (e.g. age, sex, status) and their corresponding households (e.g. household size, number of children, income) and the exact address the person/household is located at. Especially household information plays an important role in the generation of daily activity plans and the mode and destination choice of single persons.

Normally, this kind of high resolution population data does not exist and has to be generated using appropriate statistical methods and heterogeneous data sources including travel surveys, lower resolution population data, land use characteristics, building heights/floors and address data. The result of this synthesizing process is therefore called “synthetic population” of the respective region of interest. To generate model inputs for future scenarios, this synthetic population can then be extrapolated to a certain time in the future.

Usually, different sources of data have to be merged for obtaining a complete description of the population. Often, not all of the needed data is available at the same spatial level. E.g. the employment rate may be given for a complete city only, while the number of persons is given at the level of the city’s districts. For aligning data, especially disaggregated one, the Iterative Proportional Fitting (IPF, [36]) and the Iterative Proportional Updating (IPU, [37]) algorithms have proved to be a reliable method. Both align a given sample to given margins iteratively, where the IPU algorithm supports multiple optimization targets, e.g. best match of both, person and household attributes.

Since the majority of tools used for population synthesis were developed within research activities and are not freely accessible, only two current solutions, which are freely available and well maintained will be outlined. Other known applications include SYNTHESIZER [38], ARC [39], ILUTE [40], PopGen [41], PopSynWin [42], TRANSIMS [43], SynthPop [37], FSUTMS [44], CEMDAP [45], ALBATROSS, SimBRITAIN [46], MORPC [47], TRESIS [48], OREGON2 [49], SFCTA [50], METRO [51] or BNY [52], an overview can be found in [53].

The first one to describe is SynthPop[63], an open source software available under BSD 3-Clause license. This means non-commercial as well as commercial usage is permitted, but with a 3rd clause that prohibits others from using the name of the project or its contributors to promote derived products without written consent. SynthPop is written in the Python programming language and has no visual user interface. Execution and adaptions have to be performed in the code. In this tool, an Iterative Proportional Updating (IPU) algorithm is used to generate synthetic populations whereby both household-level and person-level characteristics of interest can be matched in a computationally efficient manner. This involves iteratively adjusting and reallocating weights among households of a certain type until both household and person-level attributes are matched against known marginal distributions. The software requires five input tables: Household marginal (the number of households in the area), household sample, person marginal, person sample and geographic correspondence.

The second one, Doppelganger[64], is a Python package of tools to support population synthesizers. It is open source software under Apache-2.0 license. It is developed by ©sidewalk labs, an organization of ©Alphabet Inc. Doppelganger uses Bayesian networks to generate synthetic populations from a small sample of observations and allocates this population to geographical units using a procedure called convex optimization. Like SynthPop, this package has no visual interface and has to be executed in the code.

Working at the aggregated level of traffic analysis zones, macroscopic four-step models do not need such a fine-grained and detailed information. To some degree the needs to describe the population in means of their age, economic status, and the availability of mobility options holds nonetheless. While the step of distributing the population on dwellings is not necessary, the process of aligning margins may be nonetheless interesting when using them.

63 *https://github.com/UDST/synthpop*
64 *https://github.com/sidewalklabs/doppelganger*

7. SUMMARY

The choice of a proper tool depends on different factors. First, the questions to answer should be regarded. When trying to find bottlenecks in one's network, a short view on GoogleMaps could be sufficient and they may be solved by improving the respective traffic light schedules with the help of a microscopic traffic flow simulation. But when coming to the estimation of effects of big traffic management measures or changes in the infrastructure, the whole transport system may change, including the choice of the used modes. In such cases, a comprehensive tool that supports the evaluation of changes in the demand and the resulting traffic is needed. The factors for choosing a model could be:

- The size of the regarded area; frankly, macroscopic models are more appropriate for bigger areas while smaller areas can be well represented in microscopic simulations. One should notice that the affected area may get bigger when secondary effects, such as changes in the modal split or changes in land use shall be regarded;
- The type of measure to simulate – when concentrating on changes in traffic flow only, like the case for traffic lights optimisation, no demand model is needed. Hence, only a traffic flow simulation would be needed;

Besides choosing the right model and deciding about the simulation package to purchase, setting up a transport model is not a trivial task that usually requires a skilled person. Yet, there are different options for obtaining a transport model of an area: a) a consultant builds and maintains the model, b) a consultant builds the model, the city maintains it, c) a city decides to build and maintain the model itself.

Commercial transport models are professional tools with an according price that can easily reach 15,000 to 50,000 Euros. Additionally, some data may have to be bought, prepared, and validated. And building a model requires skilled personnel. But in hands of a skilful team transport models are capable to save millions of Euros put in building inappropriate infrastructure.

8. REFERENCES

[1] D. Bongardt, F. Creutzig, H. Hanna, K. Sakamoto, S. Bakker, S. Gota, S. Böhler-Baedeker (2013) Low-Carbon Land Transport - Policy Handbook, Routledge, Abingdon, 2013, ISBN 978-1-84971-377-1.

[2] W. B. Jones, C. R. Cassady, R. O. Bowden (2000) Developing a Standard Definition of Intermodal Transportation. In: Transportation Law Journal, 27 (3), pp. 345-352.

[3] BMVI (2018) Mobilität in Deutschland 2017 – Ergebnisbericht, obtained from http://www.mobilitaet-in-deutschland.de/publikationen2017.html on 15th September 2019.

[4] B. S. Kerner (1998) Experimental Features of Self-Organization in Traffic Flow; In: Physical Review Letters, 81 (17), pp. 3797–3800; The American Physical Society.

[5] Y. Kim, H. Keller (2001) Zur Dynamik zwischen Verkehrszuständen im Fundamentaldiagramm; In: Straßenverkehrstechnik 9/2001; pp. 433-442.

[6] S. Beige, K. W. Axhausen (2008) Long-term and mid-term mobility decision during the life course: Experiences with a Retrospective Survey, In: IATSS Research, Volume 32, Issue 2, 2008, Pages 16-33

[7] T. Litman (2015) Analysis of public policies that unintentionally encourage and subsidize urban sprawl; Victoria Transport Policy Institute, LSE Cities, for the Global Commission on the Economy and Climate.

[8] J. Ortúzar, L. G. Willumsen (2011) Modelling Transport, 4th Edition, ISBN: 978-0-470-76039-0.

[9] D. A. Hensher, K. J. Button (eds.) (2007) Handbook of Transport Modelling, ISBN: 978-0-08-045376-7, eISBN: 978-0-857-24567-0.

[10] T. van Woensel, N. Vandaele (2007) Modeling traffic flows with queueing models: A review, In: Asia Pacific Journal of Operational Research 24(04), pp. 435-461, DOI: 10.1142/S0217595907001383.

[11] M. G. McNally, C. Rindt (2012) The activity-based approach. In: Handbook of Transport Modelling, D. A. Henscher, K. J. Button, editors, Elsevier, pp. 53-69.

[12] R. A. Acheampong, E. Silva (2015) Land use–transport interaction modeling: A review of the literature and future research directions. In: Journal of Transport and Land Use, 8(3), pp. 11-38.

[13] R. Cordera, Á. Ibeas, L. dell'Olio, B. Alonso (2017) Land Use–Transport Interaction Models, CRC Press, ISBN 9781138032460.

[14] W. Alonso (1964) Location and land use. Toward a general theory of land rent. Cambridge, United Kingdom: Harvard University Press

[15] I. S. Lowry, (1964) A Model of Metropolis, RAND Corp., Santa Monica, Calif.

[16] D. McFadden (1978). Modelling the choice of residential location. In: A. Karlqvist, L. Lundqvist, F. Snickars, J. Weibull (Eds.), Spatial interaction theory and planning models (pp. 75 - 96). Amsterdam: North Holland.

[17] R. Moeckel (2018) Integrated Transportation and Land Use Models (R. Moeckel Ed. Vol. 520): Transportation Research Board.

[18] A. M. El-Geneidy, D. M. Levinson (2006) Access to destinations: Development of accessibility measures. Retrieved from http://hdl.handle.net/11299/638

[19] M. Wegener, F. Fürst, (1999) Land-Use Transport Interaction: State of the Art. Berichte aus dem Institut für Raumplanung 46. Dortmund: Institute of Spatial Planning, University of Dortmund.

[20] G. Boisjoly, A. M. El-Geneidy (2017) How to get there? A critical assessment of accessibility objectives and indicators in metropolitan transportation plans, In: Transport Policy, Volume 55, Pages 38-50, ISSN 0967-070X, https://doi.org/10.1016/j.tranpol.2016.12.011.

[21] A. El-Geneidy, D. Levinson (2006) Access to Destinations: Development of Accessibility

Measures, retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/638.

[22] M. Saifuzzaman, A. de Palma, K. Motamedi (2012) Calibration of METROPOLIS forIle-de-France. hal-00683464

[23] D.C. Gazis, R. Herman, R.B. Potts (1959) Car-following theory of steady state flow. In: Operation Research 7 (4), 499-505.

[24] M. J. Roorda, E. J. Miller, K. M. N. Habib (2008) Validation of TASHA: A 24-h activity scheduling microsimulation model, In: Transportation Research Part A: Policy and Practice, Elsevier, vol. 42(2), pages 360-375.

[25] T. Arentze, H. J. P. Timmermans (2004). Albatross: A Learning Based Transportation Oriented Simulation System. In: Transportation Research Part B: Methodological. 38. 613-633. 10.1016/j.trb.2002.10.001.

[26] M. Heinrichs, D. Krajzewicz, R. Cyganski, A. von Schmidt (2016) Disaggregated car fleets in microscopic travel demand modelling. In: The 7th International Conference on Ambient Systems, Networks and Technologies (ANT 2016). DOI: 10.1016/j.procs.2016.04.111

[27] D. Walker (2017). The planners guide to CommunityViz: The essential tool for a new generation of planning, Routledge, ISBN 9781932364934.

[28] F. Martinez (1996) MUSSA: Land Use Model for Santiago City. In: Transportation Research Record, 1552(1), 126–134. https://doi.org/10.1177/0361198196155200118

[29] R. Hurtubia, M. Bierlaire (2015) Microsimulation for land use modeling: implementation challenges, In: Integrated Transport and Land Use Modeling for Sustainable Cities, M. Bierlaire, A. de Palma, R. Hurtubia and P. Waddell (Eds.), EPFL Press / Routledge

[30] Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). OJ L 108, 25.4.2007, p. 1–14, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32007L0002.

[31] Regulation (EC) No 1893/2006 of the European Parliament and of the Council of 20 December 2006 establishing the statistical classification of economic activities NACE Revision 2 and amending Council Regulation (EEC) No 3037/90 as well as certain EC Regulations on specific statistical domains. OJ L 393, 30.12.2006, p. 1–39, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006R1893.

[32] D. Krajzewicz (2010) Traffic Simulation with SUMO – Simulation of Urban Mobility. In: Barceló J. (eds) Fundamentals of Traffic Simulation. International Series in Operations Research & Management Science, vol 145. Springer, New York, NY.

[33] C. Barron, P. Neis, A. Zipf (2014) A Comprehensive Framework for Intrinsic OpenStreetMap Quality Analysis. In: Transactions in GIS, 18: 877-895. doi:10.1111/tgis.12073.

[34] S. Rässler (2016) Data fusion: identification problems, validity, and multiple imputation, In: Austrian Journal of Statistics, 33(1&2), 153-171. doi: https://doi.org/10.17713/ajs.v33i1&2.436

[35] D. B. Rubin (2004). Multiple imputation for nonresponse in surveys, Wiley, ISBN: 978-0-471-65574-9.

[36] W. E. Deming, F. F. Stephan (1940) On a Least Squares Adjustment of a Sampled Frequency Table When the Expected Marginal Totals Are Known. In: Annals of Mathematical Statistics, 11, 1940, pp. 427-444.

[37] X. Ye, K. Konduri, R. M. Pendyala, B. Sana P. Waddell (2009) A methodology to match distributions of both household and person attributes in the generation of synthetic populations. Presented at 88th Annual Meeting of the Transportation Research Board, 1 Washington, D.C.

[38] A. von Schmidt, R. Cyganski, D. Krajzewicz (2017) Generierung synthetischer Bevölkerungen für Verkehrsnachfragemodelle - Ein Methodenvergleich am Beispiel von Berlin. In: HEUREKA‘17 - Optimierung in Verkehr und Transport, Seiten 193-210. FGSV-Verlag, ISBN 978-

3-86446-177-4.

[39] Atlanta Regional Commission, 2012. Activity-Based travel model specifications: Coordinated travel – Regional activitybased modeling platform (CT-RAMP) for the Atlanta Region.

[40] D. R. Pritchard, E. Miller (2012) Advances in population synthesis: fitting many attributes per agent and fitting to household and person margins simultaneously. In: Transportation 39, 685-704.

[41] R. M. Pendyala, C. R. Bhat, K. G. Goulias, R. Paleti, K. Konduri, R. Sidharthan, K. P. Christian (2013) SimAGENT Population Synthesis. Southern California Association of Governments (SCAG).

[42] J. Auld, A. Mohammadian (2010) Efficient methodology for generating synthetic populations with multiple control levels. In: Transportation Research Record 2175, 138-147.

[43] Los Alamos National Laboratories (LANL) (2010) Population synthesizer: TRANSIMS 4.0.08 user Manual.

[44] L. Ma, S. Srinivasan (2014) Synthetic Population Generation with Multilevel Controls: A Fitness-Based Synthesis Approach and Validations. In: Computer-Aided Civil and Infrastructure Engineering, published online ahead of print

[45] J. Y. Guo, C. R. Bhat (2007) Population Synthesis for Microsimulating Travel Behavior, In: Transportation Research Record, 2014(1), 92–101. https://doi.org/10.3141/2014-12.

[46] D. Ballas, G. Clarke, D. Dorling, H. Eyre, B. Thomas, D. Rossiter (2005) SimBritain: A spatial micro-simulation approach to population dynamics. In: Population, Space and Place 11, 13-34, https://doi.org/10.1002/psp.351.

[47] Parsons Brinckerhoff Consult (2005) The MORPC travel demand model: Validation and final report. Mid-Ohio Regional Planning Commission (MORPC).

[48] D. A. Hensher, T. Ton (2002) TRESIS: A transportation, land use and environmental strategy impact simulator for urban areas. In: Transportation 29, 439-457, DOI: 10.1023/A:1016335814417.

[49] Parsons Brinckerhoff Consult, HBA Specto Inc., EcoNorthwest (2003) Oregon2 model development, HA module description at finalization. Oregon Department of Transportation.

[50] Cambridge Systematic Inc. (2002) Population synthesis. South Florida County Transit Authority (SFCTA).

[51] M. Bradley, J. Bowman, K. Lawton (1999) A comparison of sample enumeration and stochastic micro-simulation for application of tour-based and activity-based travel demand models, In: Proceedings of the European Transport Conference, Cambridge, UK

[52] D. W. Wong (1992) The Reliability of using the iterative proportional fitting procedure. In: The Professional Geographer 44, 340-348, https://doi.org/10.1111/j.0033-0124.1992.00340.x.

[53] A.-A. Choupani, A. Reza Mamdoohi (2016) Population Synthesis Using Iterative Proportional Fitting (IPF): A Review and Future Research, In: Transportation Research Procedia, Volume 17, Pages 223-233, ISSN 2352-1465, https://doi.org/10.1016/j.trpro.2016.11.078.

[54] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, OJ L 152, 11.6.2008, p. 1–44.

[55] C. Vahlsing, K. R. Smith (2012) Global review of national ambient air quality standards for PM10 and SO2 (24 h). In: Air Quality, Atmosphere, & Health, 5(4), pp. 393–399, doi:10.1007/s11869-010-0131-2.

ABOUT SUBMA

WHY DO WE NEED SUMBA?

More and more people chose to live in suburbs while they continue to work in cities, resulting in high number of daily commuters. Commuter traffic is still dominated by private cars, resulting in problems such as

• congestion
• air pollution
• high demand of parking spaces
• higher costs of public transport.

SUMBA will address commuter transport and help to mitigate these problems!

OUR ACTIVITIES

The urban transport system can be reshaped to an intermodal network that off ers a combination of various transport modes, including bike and car-sharing. This helps cities to achieve a more attractive and environmentally friendly commuting system. SUMBA will develop and test tools that help urban and transport planners to assess, plan, and integrate intermodal mobility solutions into transport plans and policies of their cities and municipalities.

OUR PARTNERS CITIES

Hamburg (Germany)
Tallinn city, Union of Harju municipalities (Estonia)
Tartu (Estonia)
Riga (Latvia)
Växjö (Sweden)
Šiauliai (Lithuania)
Olsztyn (Poland)
Associated cites Gdynia, Warsaw suburban region, Słupsk municipality (Poland), and Helsinki (Finland)

EXPERT PARTNERS

German Aerospace Center, Institute of Transport Research
Baltic Environmental Forum Latvia, Estonia and Germany
Earth and People Foundation

SUPPORT

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