LEVITATE: applying mesoscopic activity chain simulation

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Abstract

The present article focusses on the application of an agent-based mobility simulation model for the city of Vienna which utilizes activity chain descriptions of the simulated agent's daily objectives. This is done in the context of the goals of project LEVITATE. It entails a brief description of the model method, the specific features of the model, the expectable and intended output of the model, its general assumptions as well as details on two specific areas of interest within the project objectives, namely automated urban transport and road use pricing.

LEVITATE project scope

With the advent of automated vehicles, there arises the need for an assessment framework, which enables policymakers to manage the introduction of connected and automated transport systems. A **policy support tool** (PST) will provide an impact assessment framework to aid local authorities in evaluating the consequences of introducing **connected automated transport systems** (CATS). An accompanying back-casting tool is intended to provide help on decisions which measures to take to achieve desired goals of regional development and mitigate effects of possible drawbacks due to the foreseeable fundamental changes in mobility behavior. Three use cases which are defined as **automated urban transport** (WP5), **passenger cars** (WP6) and **automated freight transport** (WP7) allow to consider the impacts of oncoming changes. Using a variety of methods, several scenarios and applied tools within each use case provide more specific details to enable sound conclusions on the most likely developments.

A MATSim model for Vienna

MATSim: agent-based activity chain simulation

As an agent-based modeling (ABM) framework, MATSim (Horni et al., 2016) allows to simulate mobile agents that strive to fulfill their daily plans of activities (the "activity chain") and the trips in between their locations. Activity locations are reachable by using the transport network consisting of roads and public transport lines. Activity types, among others, include "home", "work" and "leisure". ABMs have found wider applications with the increase of computing capabiities and MATSim has been applied in many different research contexts and locations (see Examples of MATSim for impact assessments).
Based on predefined plans and according to a scoring function, a simulation yields the ability of each agent to complete the planned trips and activities throughout its whole day journey in a timely manner. Subsequently, this score is used to make randomized adaptions of these plans in the fashion of a genetic algorithm, allowing the agent

behavior to “evolve”, consequently. Repeated simulation lets agents “relive” their whole day of activities with slightly altered plans, which will ultimately yield optimized plans for all the agents (in the sense of a Nash-equilibrium) and capture the multitude of interdependencies concerning transport capacities, times and the various individual plans.

MATSim model Vienna

The MATSim model Vienna (shown in Figure 1) that is being developed at AIT (Müller et al., 2021) covers the wider area of 4170 km² around the city of Vienna at a total radius of about 30 km. Simulating roughly 200000 agents equivalent to 12.5% of the total population within the area results in about 680000 trips over one whole working day.

To receive feedback and a wider scope of review the model (excluding our own extensions) was made available openly on Github (Straub, M. et al. 2021). These extensions involve the use of AIT’s in-house intermodal routing solution “Ariadne” (Prandtstetter et al. 2013), that enables flexible trip-assignment, utilizing different modes of transportation.

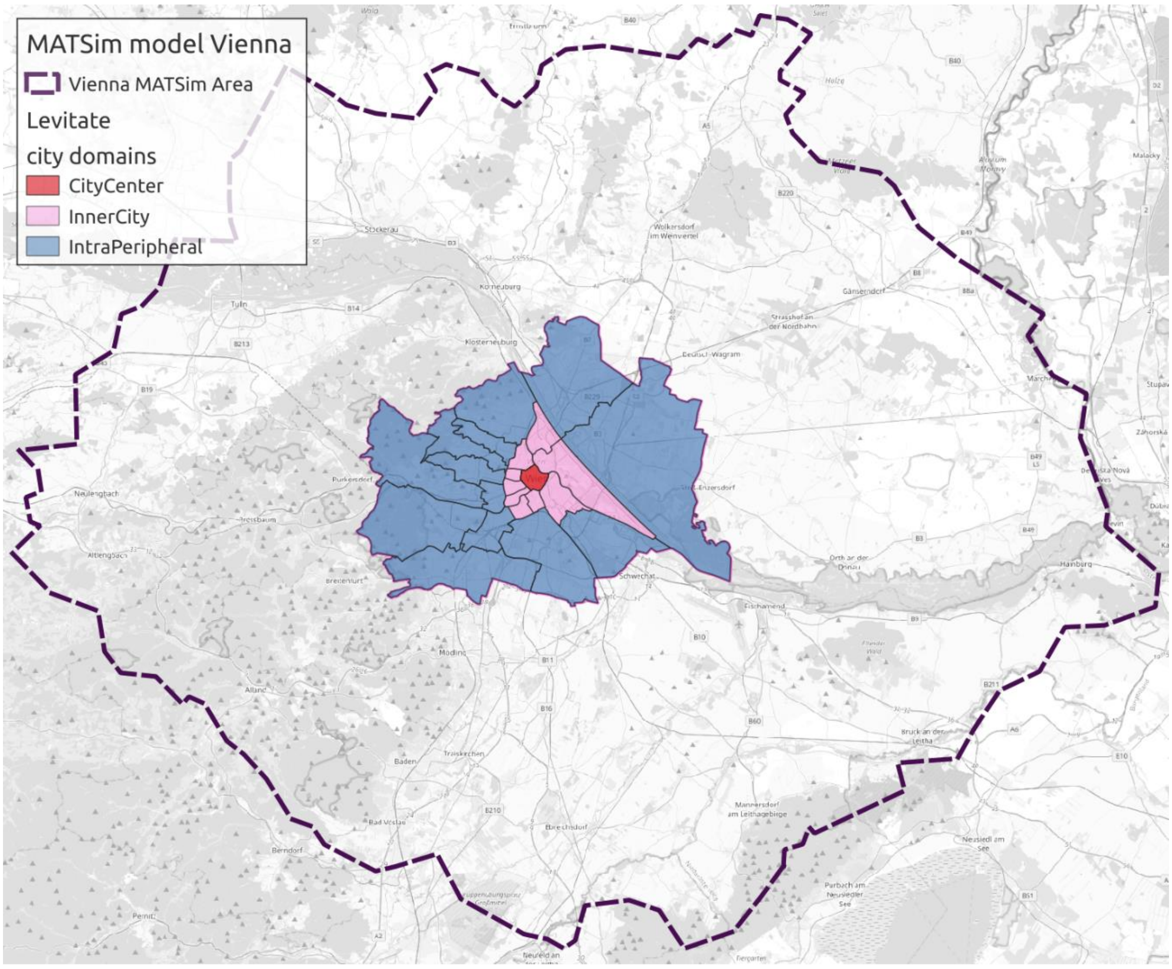

Figure 1: MATSim model Vienna total area overview. The color-shaded domains within the model area cover the actual extent of the city of Vienna.

Base data

The following major data sets were utilized to generate the overall calibrated traffic model of the greater Vienna area.

- "Österreich unterwegs (2013/2014)" (Tomschy et al. 2016): A representative mobility survey onthe population of Austria which provides the sample of mobility behaviour to generate agent plans, as well as socioeconomic profiles.
- OpenStreetMap (OSM) data: To provide the graph of the road network.
- Statistical data on population and workplace densities from different national and european open government data sources.
- Traffic counts and floating car data: Provide information on the traffic load on the road network over the simulation time span and are used to realistically calibrate the traffic patterns.
- Public transport time tables: Describe the transport capabilities of the public transport facilities.

- Choice model (Hössinger et al. 2020): Connecting the behavior of simulated agents to circumstantial parameters.

Mode choice behavior

The integration of a choice model into the simulations is facilitated by socioeconomic characteristics of the agents that are obtained from mobility survey data. On the basis of surveyed travel preferences in relation to such socioeconomic characteristics, realistic predictions can be derived about the agents and their decisions with respect to the mode of transport (e.g.: "public transport", "car", "walk", "bike" or an automated transport vehicle – if available), all depending on varying circumstances of transport costs and availabilities.

This choice model is the very basis for a central descriptive factor of mobility behavior, the "**modal split**". It describes the frequency of choices that a population of agents (or people) will make regarding their mode of transport, under given circumstances. The modal split in the MATSim model is calibrated in accordance with the mobility survey to resemble real-world behavior patterns. In the larger context it is is of great importance for matters of transport planning, infrastructure investments and -most importantly- issues of climate change mitigation. Any implemented policy measure will therefore consider impacts on changing modal splits, whenever available.

Impact assessment

To derive impact assessments for defined implementation measures, the mesoscopic simulation model is applied to two different use cases within the project, which are the **"automated urban transport"** of work package 5, and the **"passenger car"** use case of work package 6. Within each of these use cases there are several sub use cases ("SUC" - in the sense of application measures) to more precisely specify impacts of implemented measures.
The overall model area shown in Figure 1 was defined as four distinct domains to allow for generalization of the derivable impacts. An abstract depiction of these domains is shown in Figure 2: Schematic view of the four city domains used for mobility investigations. The domains are city center (CC), inner city (IC), intra peripheral (IP) and extra peripheral(XP)., where the actual area of investigation includes all but the extra peripheral domain XP.

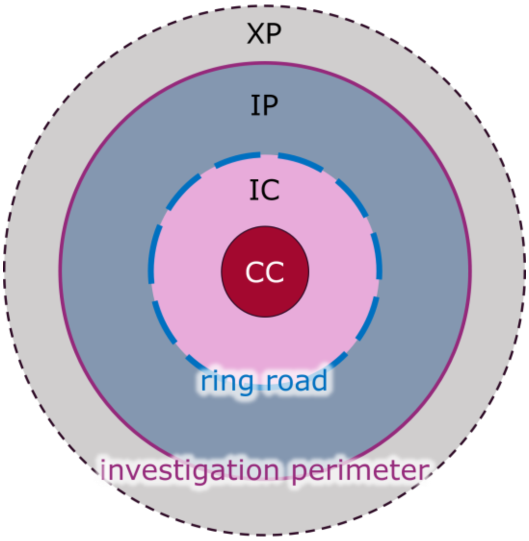

Figure 2: Schematic view of the four city domains used for mobility investigations. The domains are city center (CC), inner city (IC), intra peripheral (IP) and extra peripheral(XP).

Use case: Automated urban transport

The **automated urban shuttle service** (AUSS) is a transport mode that is not limited to be used by only one agent. The vehicles have capacity for up to four people and are comparable to a cab service. It is common that detours are done to pick up other agents. A relocation of vehicles according to the estimated demand is done every three hours. The performance and impacts of such a system can thus be measured by the following indicators:

- modal Split and modal shifts
- travel time of an average 5km trip within the inner city
- emissions according to the vehicle kilometers traveled
- empty vehicle kilometers of the AUSS
- revenue vehicle kilometers of the AUSS
- average occupancy rate of the AUSS

Use case: Passenger car

To investigate the implementation measure of **road use pricing** (RUP), deployment of automated passenger cars considers each vehicle as a privately owned car. They are not capable to relocate or carry out rides by themselves, thus providing autonomy and driving capabilities only when the owner is aboard.
The indicators derivable from the developed scenarios as specified within the project are:

- travel time of an average 5km trip within the inner city
- modal splits and modal shifts (i.e. changes in modal split) of active and passive modes of travel
- total distances traveled within the inner city
- emissions according to the vehicle kilometers traveled

General scenario definitions

To better represent the development of technological maturity of vehicle automation, a distinction is made in the form of **two principal levels of automated car behavior**, namely "**cautious AVs**", being more conservative or careful in clearing- and anticipationdistances and "**aggressive AVs**", tending towards the full utilization of technological capabilities and exceeding those of a human driver. The resulting dynamism of driving behavior and shorter reaction time of connected automated vehicles ("CAV"s) was shown in microscopic traffic simulations within the project. On average it leads to reduced inter-car distance on the road. This, in turn affects the occupied road-length equivalent of a passenger car unit - "PCU", which ultimately increases the transport capacity of the streets by packing more vehicles on a given stretch of the road. Such an effect, depending on the total fleet share of CAVs was incorporated into the mesoscopic simulation model.

Considering the pace of adoption of CAVs, it is the chosen approach in the project of Levitate to investigate the impacts of several likely timelines. Therefore, several levels of car automation progressing over time are represented in the mesoscopic simulation scenarios, which are shown in Table 1. Here, each column describes a certain car fleet partitioning scheme ("CFPs") with a defined share of cars having been replaced by automated vehicles at some point in the future. These CAV deployment scenarios – without any additional measure or intervention – are considered as baseline (as mentioned above).

Table 1: Investigated automation progression scenarios with percentages of the total vehicle share for human driven vehicles and two different automation levels. Each column represents a certain pivotal point in the future, when human driven vehicles have been replaced by automated vehicles to a certain degree.

CAV Deployment Scenarios								
CFPs	**h100**	**h80**	**h60**	**hc40**	**ca40**	**a60**	**a80**	**a100**
Type of Vehicle								
Human Vehicle	100%	80%	60%	40%	20%	0%	0%	0%
Cautious AV	0%	20%	40%	40%	40%	40%	20%	0%
Aggressive AV	0%	0%	0%	20%	40%	60%	80%	100%

Regarding the use of automated passenger cars, it is the study-based assumption of the mesoscopic model (Fosgerau, M. 2019 and Ho, C. 2015), that the time spent in an automated vehicle will be perceived as a smaller loss when compared to driving conventional vehicles with their requirement of undivided attention. This differing value of travel time "vTT" allows agent choices dependent on the type of vehicle available.

Changes in the economic situation of the agents can be estimated by considering the national gross domestic product in relation to the inflation rate. In the simulation, this factor can be modeled by changing the marginal utility of money which reflects the value that simulated agents attribute to monetary expenditures (when compared to time expenditures like travel time). As a consequence, circumstantial factors which resemble a direct monetary expenditure (e.g. costs for tickets, toll fees or prices for purchasing a car) will have a stronger or weaker impact on decisions.

Modeling automated urban transport

Within the mesoscopic activity chain simulation, we prepare two application measures for WP5. In the first one, automated urban shuttles are implemented similarly to the measures of the micro-simulation study. Their **use is restricted to the central areas** of the city (inner city and city center as defined in Figure 1 and Figure 2). In the second one, the shuttles operate as **last-mile shuttles**: The operating area is restricted to multiple smaller areas in the periphery of the city (depicted in Figure 3). With at least one public transport hub in each area, an attractive opportunity to change to train or subway services is provided. The vehicles can only be used within each individual area, so that trips across the city using these shuttles are prevented. In each of the SUC, we consider different fleet sizes next to the different car fleet partitioning schemes and the other scenario parameters.

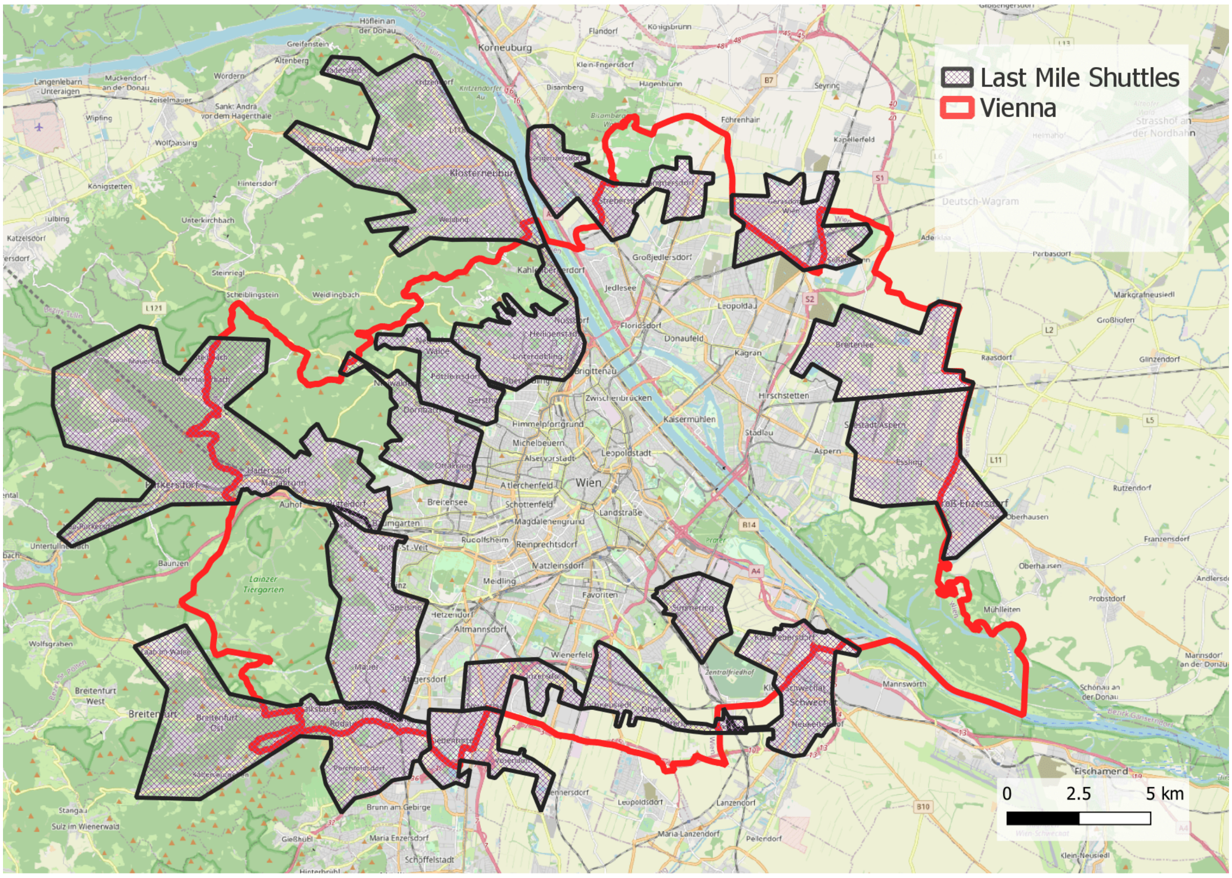

Figure 3: City of Vienna (red) and the zones where the last mile shuttle is operating (black, hachured).

Modeling road use pricing

As the requirements within the project are defined to investigate traffic impacts on the inner city, implementations for RUP were chosen to cover the whole area inside the inner city (Figure 2). Two different implementation schemes are investigated. Firstly, as a **static toll on vehicles** to be paid on entry into the tolling area and secondly as **dynamic toll on vehicles** that is paid per unit distance of traversal on roads within the tolling area.
Several levels of toll-pricing are defined to vary cost conditions next to the different car fleet partitioning schemes and the other scenario parameters to analyze the impacts.

Examples of MATSim for impact assessments

MATSim has proven to be a useful simulation framework to evaluate impacts for automated urban transportation solutions. The dynamic routing vehicle problem (dvrp) module is the basis for implementing demand-responsive transportation (drt) options

such as AUSS with its main capability to flexibly assign agents to vehicles (Maciejewski et al., 2017).
Examples of its application can be found the following articles:

- Viergutz and Schmidt (2019): The authors compared a conventional public bus route with alternative drt services in rural areas. They found that drt service is not necessarily more efficient from an economic perspective, as labor costs increase when drt service is provided by drivers.
- Ben-Dor et al. (2019): The paper examines the optimal fleet size to meet the demand for the Tel Aviv metropolitan area. They conclude that about 100k vehicles can serve the expected demand and lead to a ride request rejection rate of less than 2%.
- Kaddoura et al (2020): the authors compare different pricing schemes and operating areas for a drt service in the Berlin metropolitan area. A key finding is that low prices lead to higher shifts in walking and bicycling trips towards drt trips, while higher prices and larger operating areas substitute more car trips.
- Bischoff et al. (2017): the authors analyze a shared cab service in their simulation and find that miles traveled can be reduced by 15-20%.
- Kaddoura and Schlenther (2021): the authors tested different vehicle sizes for an urban and a rural area. They found that the effect of pooling (ridesharing) is disproportionately smaller in areas with lower trip densities compared to larger trip densities.
- Meyer de Freitas et al. (2016): Different toll levels in Zurich were simulated until a reduction of 20% vehicle kilometers traveled was reached.
- Kaddoura and Kickhöfer (2014): Application of road pricing to the MATSim Sioux Fall scenario.
- Simoni et al (2019): The authors applied road pricing strategies in combination with AV vehicles.

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