Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 00 (2021) 000–000

Procedia Computer Science

www.elsevier.com/locate/procedia

The 10th International Workshop on Agent-based Mobility, Traffic and Transportation Models, (ABMTRANS) March 22 - 25, 2022, Porto, Portugal

Simulation-based investigation of transport scenarios for Hamburg

Tilmann Schlenther[a], Peter Wagner[b,a], Gregor Rybczak[a], Kai Nagel[a], Laura Bieker-Walz[b], Michael Ortgiese[b,a]

[a]*Technische Universität Berlin, Chair of Transport Systems Planning and Transport Telematics, Straße des 17. Juni 135, 10623 Berlin, Germany*
[b]*Institute of Transportation Systems, German Aerospace Center (DLR), Rutherfordstr 2, 12489 Berlin, Germany*

Abstract

This simulation work investigates new means to decrease the modal share of motorized transport (mt) in a large urban area in Hamburg, Germany. This was deemed necessary to cut CO_2 emissions. The five scenarios simulated with the MATSim [12] framework including an adapted mode choice model strongly suggest that making public transport (pt) more attractive is not sufficient to the reach this goal, the results display a meager 3%-point change in the share of mt. With introducing additional means to repel mt, an 8%-point change may be within reach. The results also show that by making bike riding more safe, a considerable higher share of biking is possible (+8%-points).

Keywords: Future mobility; Agent-based Simulation; Impact Assessment; Mobility-On-Demand; Autonomous Vehicles

1. Introduction

Future transport systems may look different from today's. There are at least two noteworthy trends that may shape our future mobility, and this is the quest for a smaller carbon footprint of the transport system, and a strong pull toward more digital services, either in the form of mobility as a service or the development of autonomous vehicles (AV) [10, 16, 17]. Especially the latter may change public transport for the better, but if we are not careful, it might also change the whole system into one that consumes more resources [5].

The city of Hamburg has a huge investment in the modernization of it's transport system, aiming for neutralizing the carbon footprint and creating a more livable city. In the recent past, several pilot projects were conducted that included a real technology laboratory [22], banning private cars from neighbourhoods at day time [8] or even entirely

* Tilmann Schlenther, Tel. +49 30 314 21 514
E-mail address: schlenther@vsp.tu-berlin.de

from a major road in the city center [7]. In this study, we investigate several future scenarios for the transport system of the Hamburg city and it's surroundings, proposed by Bieker-Walz et al..

The remainder of this text consists of three parts: section 2 describes the set-up, in section 3 are the results of this study, and section 4 summarizes and concludes this work.

2. Methodology

With Hamburg being the second largest German city in terms of inhabitants and representing one of the largest transshipment ports in the world, one needs to account for the surrounding areas, commuter flows and freight transports when trying to understand the transport system. In this study, we aim to assess the impact of a large roll-out of future mobility systems such as Mobility-On-Demand (MoD) shuttles, sharing fleets and city-wide major improvements of the bicycle infrastructure. In the past, agent-based transport simulation frameworks have proven an adequate tool to investigate impacts of such large changes without the need of implementing substantial experimental projects in reality. The usage of activity- and agent-based simulation allows us to model the behavior of single travellers and still account for the entire metropolitan region of Hamburg. This section first gives an introduction into the simulation framework used, before the derived model and the scenarios under investigation are described.

2.1. Simulation tool

We decide to use MATSim [12] as simulation framework for this study, as it has been successfully applied to various scenarios for diverse research questions in multiple countries already [15, 23, 2]. MATSim comes with built-in modules that enable the user to model impacts of autonomous vehicles, both privately owned [21] and organized in MoD fleets [18, 4], as well as car- and bike-sharing [2] and environmental impacts of transport such as the carbon footprint [12, chapter 36] Moreover, MATSim is extensible, allowing to add features such as a mobility budget for travellers, a parking pressure model (see section 2.2) or accident cost analysis based on [20], which uses cost rates proportional to vehicle mileage and disregards public transport (pt).

2.1.1. The MATSim framework

In MATSim, the transport demand is modeled by a synthetic population represented by agents, each of which holds an initial plan that describes its course of a typical working day. The plan consists of activities like home, work, errands or leisure and legs in between them, representing changes of location. In a physical mobility simulation, all agents perform their plan. Depending on the traffic state resulting from the interaction of demand and supply, agents might experience congestion or long waiting times, come late to activities or travel smoothly. After the mobility simulation, each plan is assigned to a score depending on its recent performance. For this, time spent while performing an activity is assumed to be perceived positive whereas time spent for traveling is accounted for negatively, leading to the effect that agents try to minimize travel time. Additionally, different transport modes can be assigned different parameters that model prices, comfort, safety perception etc. After the scoring, the simulation enters a re-planning phase, where a certain share of the agents is allowed to mutate their plan. This allows to model mode choice, route choice and departure time choice. By re-iterating over these steps several hundreds of times, a co-evolutionary algorithm is performed, meaning that agents optimize their scores and a stochastic user equilibrium is approximated [12].

2.1.2. Mode Choice Model

For the setup of the Hamburg transportation model, we use a mode choice model (ChangeSingleTripMode) that mutates one single trip at a time. In contrast to another mode choice model available in MATSim, that typically changes the transport mode for all trips of a subtour, ChangeSingleTripMode does not guarantee so-called mass conservation. A subtour is considered a sequence of trips that start and end at the same location, e.g. home-work-leisure-home. Mass conservation is the phenomenon that (non-autonomous) vehicles can not pop up out of the blue, meaning that one can only take a trip with a car when it was parked near the origin before. In the example above, that would mean that the corresponding agent can not travel by car from work to leisure if it had not taken the car for going to work. Moreover, the agent had to take the car to get back home as well, as otherwise the car would not be there at the start of the next day. In order to account for the effect that in reality, most parts of the population do not have an autonomous car (yet) and do not hand over vehicles with others during the day, we add a scoring penalty of the equivalent of roughly half the daily fixed costs of a car for each mass conservation violation. This has not been done to the knowledge of the authors, yet. The value of the score penalty results from rough calibration and yields a percentage of less than 7% of subtours violating mass conservation in the Base2019 scenario (see 2.2 for a description and mode-choice calibration results).

2.2. The scenarios

Bieker-Walz et al. define future mobility scenarios for Hamburg that are taken as the basis for this study. The set of scenarios is composed of a base case representing the state of the transportation system in late 2019, before the Corona pandemic, and four scenarios describing possible future states in the year 2030. For all the of the modeled scenarios, the overall transport demand stagnates, meaning that we do not account for forecasts on the demographic development for the region. The person demand is based on multiple data sources including mobile phone trajectories and represents the private transport demand on a typical working day for the city of Hamburg and a larger surrounding area. Figure 1 displays the locations of the first activities of the day (typically of type home) of all agents as blue dots. Note that for all of the following analysis including the calibration, we filter agents living in the red and green areas. We also include commercial traffic that is generated from data provided by Hamburg's Authority for Transport and Mobility Change. For this work, we run a 10% sample of the transport demand consisting of 371,998 person agents and 102,372 freight agents.

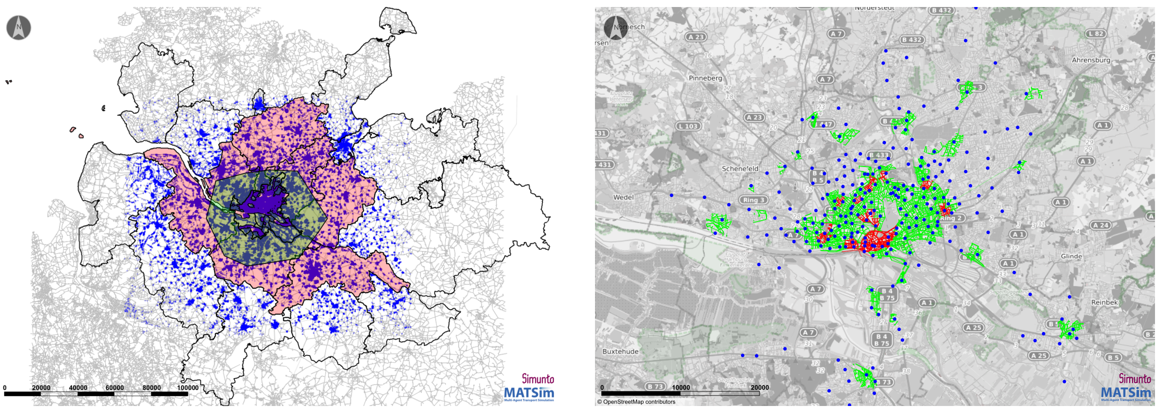

Fig. 1: (a) Spatial scope of the model and the DRT service area; (b) Roads with increased parking pressure and HVV Switch points for 2030

Base2019 For the base scenario, we consider the transport modes car, bike, pt, walk and ride, which represents private car passengers and is not included in mode choice. The modal split and the modal distance distribution is calibrated against survey data from [6]. Figure 2 shows the results. Moreover, we validated car travel times and distances with the help of data from a navigation service provider. The road network is based on OpenStreetMap [19] while the pt schedule is generated from GTFS data. We model parking pressure with generalized costs representing monetary and time efforts based on data from Hamburg's larges pt operator Hamburger Hochbahn AG. Figure 1 displays roads with high parking pressure in red, modeled by a score deduction of 1.0 for each parking procedure, and roads with medium parking pressure (score deduction of 0.7) in green.

RealLab2030 In this scenario, we model the implementation of several technologies tested in the RealLabHH project [22] and apply them to the entire city. Specifically we include the following measurements in this future scenario:

- A monetary incentive to abandon private cars, called mobility budget within the project. Agents receive €2.50 if they used car in the base case, but never do so in the policy case.
- City-wide bike and car sharing, both modeled as free-floating services. Fleet sizes and user prices are based on available services in 2021. Additionally, we place vehicles at 249 fixed stations (a projection of HVV Switch Points [9] for 2030) at the start of the day (see blue dots in Figure 1).

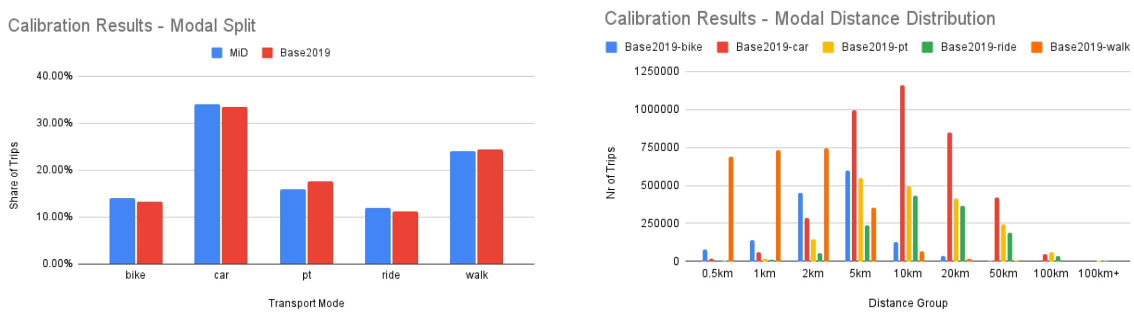

Fig. 2: (a) Modal Split: reference data [6] vs. simulation; (b) Modal distance distribution in the simulation

- An MoD shuttle service, also called DRT for demand-responsive-transport, to and from pt. The service area is shown in green in Figure 1 (a) and does not cover the city center. The shuttle must not be used for direct transport and costs roughly € 1.00 per ride.
- We model scenario-wide bike infrastructure improvements based on stated-preference data [11], which suggests that a change from no bike lane to bike lane as well as the change from a bike lane to a protected bike lane increase the safety perception of users. This effect is modeled by adjusting the alternative-specific constant (ASC) for the mode-choice model.

RealLab2030plus In addition to the measurements implemented in RealLab2030, we insert a projected pt schedule for 2030, provided by the current operator. The schedule represents a significant improvement of the current public transport system in terms frequencies, network expansion and density. The city has started with its implementation, but will not finish before 2025 [3].

ProClimate2030 In addition to RealLab2030, we implement the following measures to reduce the attractiveness of private motorized transport:

- City-wide increase of parking pressure (reduction parking space and increase of fees). We increase the generalized parking costs by 0.7 score points
- City-wide speed limit of 30 kilometers per hour on all roads except for primary roads and for motorways.
- On primary roads, capacity is reduced by one lane where two or more were in place.

DRT2030 This scenario is the same as RealLab2030 except that the DRT shuttle service allows for direct passenger transport in the entire service area, also in the city center. The user price is € 0.40 per kilometer with a minimum of € 2.00 per ride. Intermodal trips receive a refund of € 1.00.

3. Results

To compare the different scenarios on a highly aggregated level, the most important metrics have been compiled into Figure 3. The left graphic (a) displays the resulting modal split for all of the scenarios. Note that the mode ride is spared out, as it is not mutated by the mode choice model. Moreover, note that the bike and car sharing services are only available in Hamburg city, whereas we analyze all trips of people living in the region (see above, red area in Figure 1).

The scenario-wide bicycle infrastructure improvement has a strong effect, with the share of bike trips jumping by roughly 7%-points from Base2019 to RealLab2030. However, 70% of the agents switching to bike come from the walk mode and only about 18% from car. Note that modeling the infrastructure improvement via ASC has the effect that the attractiveness of bike is disproportionately increased for short trips. The model derived from [11] does not allow for time- or distance-dependent modeling. This would be not only more realistic but also, according to our experience, have the effect that induced bike trips would be longer and substitute more pt and possibly car trips, relatively seen.

The introduction of an improved pt schedule has no strong effect on the modal split in the simulation, increasing the modal split of pt by 1%-points from RealLab2030 to RealLab2030plus. While a point-to-point DRT service larger than the city boundaries can reduce the share of car trips significantly, results suggest that it substitutes the same number of pt trips, both former modes representing roughly 42% of the DRT trips in DRT2030. From earlier research in other areas we know that setting a minimum fare helps to obtain low shares of agents transferring from bike and walk to DRT [13]. The ProClimate2030 scenario has the lowest car share of all scenarios and the highest pt share, with 7%-points more than DRT2030, which is roughly equivalent to the share of DRT trips in DRT2030. Note, that pt has no capacity constraints in the model.

While demand and supply are typically scaled linearly in transport models (i.e. proportional to the sample size), Kaddoura and Schlenther suggest that for pooling services, as considered here, the fleet size and mileage should not be scaled linearly. Based on this, we estimate the DRT fleet size for DRT2030 to roughly 20,000 vehicles including a 10% buffer for maintenance, charging etc. This fleet would serve the upscaled demand of 1,106,270 rides with 5.8 million veh-km. The mean of all fares for a ride in the simulation is €2.63.

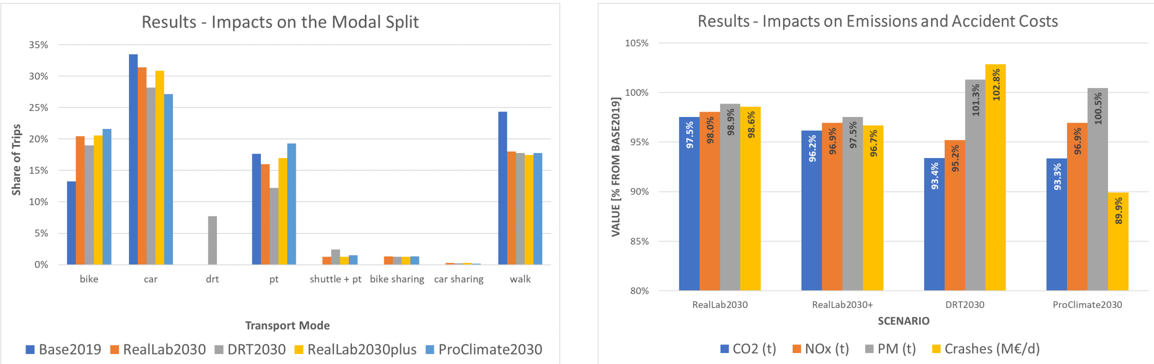

Fig. 3: Results per scenario. (a) Modal Split; (b) Emissions and accident costs, relative to Base2019

The right graphic in Figure 3 displays the outcomes in terms of emissions and accident costs, relative to Base2019. Thus, for the latter, all metrics are valued with 100% and are not displayed here. It could be seen that there is a very heterogeneous picture where some of the metrics ceases to decline. Note, that we assume the same distribution of propulsion technologies in all of the scenarios for private cars, while DRT shuttles are assumed to work electrically. By doing so, we separate the effects that are due to the scenario technologies alone from effects that come from future propulsion technology market shares. Moreover, the DRT shuttles could in principle be AV, and in this case using the accident cost rates given in [20] is certainly not correct. AV can be expected to have a lower accident rate, meaning that we tend to overestimate the total accident costs in the future scenarios with regard to automation, especially in DRT2030. On the other hand, for the accident cost analysis, the DRT mileage was scaled up linearly.

4. Conclusion and Outlook

The two RealLab scenarios clearly demonstrate that it is difficult to decrease the modal split of the motorized traffic by these technologies alone, the motorized traffic just decreases by 3%-points. Only when stronger, but politically much less opportune measures are introduced it seems possible to convince one third of the car drivers to switch to other modes of transport (from 24% to 16% within the city boundaries for the ProClimate scenario). While the sum of carbon and NOx emissions is directly related to the share of private cars, the additional mileage performed by electric DRT shuttles increases the particle emissions and, if operated by a human driver, the accident costs.

In the future, we will analyse the results in a more detailed way, looking into tempo-spatial effects of the investigated metrics as well as on additional metrics. For the outlook, one might consider to combine DRT2030 with the pull measures implemented in ProClimate2030 as those scenarios have the strongest impacts.

Acknowledgement

This work was funded by a future grant from the German Federal Ministry of Transport and Digital Infrastructure, which is gratefully acknowledged here. We want also to thank all the partners in the RealLab Hamburg project for their generous sharing of their data and their knowledge – it was a real pleasure to work with them. The German National Platform Future of Mobility, and there especially the Working Group 3 (Digitalisation for the mobility sector) has been instrumental for starting this project and was constantly monitoring its progress. In addition, we would like to express out thanks to Zhuoxiao Meng and Ihab Kaddoura [3] who helped to set up the simulations, and to Nikhil Vinod Mallela, Christopher Schlüter-Langdon, and Luca Löffler from the T-Systems company for their many discussions related to the visualization of the results. They have built a beautiful dash-board of the project results, see [1].

References

[1] , . T-Systems. https://reallabscenarios.dih.telekom.net. Accessed: 2021-12-09.
[2] Balac, M., Hörl, S., 2021. Simulation of intermodal shared mobility in the san francisco bay area using matsim, in: 2021 IEEE International Intelligent Transportation Systems Conference (ITSC), pp. 3278–3283. doi:10.1109/ITSC48978.2021.9564851.
[3] Bieker-Walz, L., Kaddoura, I., Meng, Z., Ortgiese, M., Wagner, P., 2021. Future Mobility Scenarios for Hamburg, Germany. VSP Working Paper 21-03. Institute of Transportation Systems, DLR and Transport Systems Planning and Transport Telematics, TU Berlin.
[4] Bischoff, J., Führer, K., Maciejewski, M., 2019. Impact assessment of autonomous DRT systems. Transportation Research Procedia 41, 440–446. URL: https://www.sciencedirect.com/science/article/pii/S2352146519304910, doi:https://doi.org/10.1016/j.trpro.2019.09.074.
[5] Bischoff, J., Maciejewski, M., 2016. Simulation of City-wide Replacement of Private Cars with Autonomous Taxis in Berlin. Procedia Computer Science 83, 237–244. doi:10.1016/j.procs.2016.04.121.
[6] Follmer, R., Pirsig, T., Belz, J., Brand, T., Eggs, J., Ermes, B., Gruschwitz, D., Kellerhoff, J., Roggendorf, M., 2019. Mobilität in Deutschland – MiD Regionalbericht Metropolregion Hamburg und Hamburger Verkehrsverbund Gmb. resreport. infas, DLR, IVT and infas 360.
[7] hamburg.de GmbH & Co. KG, 2021a. Jungfernstieg. URL: https://www.hamburg.de/innenstadt/14362130/jungfernstieg/. (accessed December 8, 2021).
[8] hamburg.de GmbH & Co. KG, 2021b. Ottensen macht platz. URL: https://www.hamburg.de/altona/ottensenmachtplatz/. (accessed December 8, 2021).
[9] Hamburger Hochbahn AG, 2021. hvv switch punkte hamburg. URL: https://www.hvv-switch.de/de/hvv-switch-punkte/. (accessed December 8, 2021).
[10] Hancock, P.A., Nourbakhsh, I., Stewart, J., 2019. On the future of transportation in an era of automated and autonomous vehicles. Proceedings of the National Academy of Sciences 116, 7684–7691. URL: https://www.pnas.org/content/116/16/7684, doi:10.1073/pnas.1805770115, arXiv:https://www.pnas.org/content/116/16/7684.full.pdf.
[11] Hardinghaus, M., Papantoniou, P., 2020. Evaluating cyclists' route preferences with respect to infrastructure. Sustainability 12. URL: https://www.mdpi.com/2071-1050/12/8/3375, doi:10.3390/su12083375.
[12] Horni, A., Nagel, K., Axhausen, K.W., 2016. The Multi-Agent Transport Simulation MATSim. Ubiquity Press, London, GBR.
[13] Kaddoura, I., Leich, G., Nagel, K., 2020. The impact of pricing and service area design on the modal shift towards demand responsive transit. Procedia Computer Science 170, 807–812. doi:10.1016/j.procs.2020.03.152.
[14] Kaddoura, I., Schlenther, T., 2021. The impact of trip density on the fleet size and pooling rate of ride-hailing services: A simulation study. Procedia Computer Science 184, 674–679. URL: https://www.sciencedirect.com/science/article/pii/S1877050921007213, doi:https://doi.org/10.1016/j.procs.2021.03.084. the 12th International Conference on Ambient Systems, Networks and Technologies (ANT) / The 4th International Conference on Emerging Data and Industry 4.0 (EDI40) / Affiliated Workshops.
[15] Kickhöfer, B., Hosse, D., Turner, K., Tirachini, A., 2016. Creating an open MATSim scenario from open data: The case of Santiago de Chile. VSP Working Paper 16-02. TU Berlin, Transport Systems Planning and Transport Telematics. URL http://www.vsp.tu-berlin.de/publications.
[16] Maurer, M., Gerdes, J., Lenz, B., Winner, H., 2016. Autonomous driving: Technical, legal and social aspects. URL: https://elib.dlr.de/108176/, doi:10.1007/978-3-662-48847-8.
[17] Morita, T., Managi, S., 2020. Autonomous vehicles: Willingness to pay and the social dilemma. Transportation Research Part C: Emerging Technologies 119, 102748. URL: http://www.sciencedirect.com/science/article/pii/S0968090X20306616, doi:https://doi.org/10.1016/j.trc.2020.102748.
[18] Nagel, K., Bischoff, J., Leich, G., Maciejewski, M., 2019. Simulation-based analysis of the impacts of fleets of autonomous vehicles on urban traffic. Technical Report. TU Berlin.
[19] OpenStreetMap, accessed 2021-06-23. http://www.openstreetmap.org.
[20] PTV, TCI, Mann, H.U., . Methodenhandbuch zum Bundesverkehrswegeplan 2030 (Entwurf).
[21] Schlenther, T., Martins-Turner, K., Bischoff, J.F., Nagel, K., 2020. Potential of private autonomous vehicles for parcel delivery. Transportation Research Record 0, 0361198120949878. URL: https://doi.org/10.1177/0361198120949878, doi:10.1177/0361198120949878, arXiv:https://doi.org/10.1177/0361198120949878. bmvi-pave.
[22] TU Berlin, Transport Systems Planning and Transport Telematics, 2021. Reallabhh. URL: https://www.vsp.tu-berlin.de/menue/forschung/projects/2020/reallabhh/. (accessed December 8, 2021).
[23] Ziemke, D., Kaddoura, I., Nagel, K., 2019. The MATSim Open Berlin Scenario: A multimodal agent-based transport simulation scenario based on synthetic demand modeling and open data. Procedia Computer Science 151, 870–877. doi:10.1016/j.procs.2019.04.120.