Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 151 (2019) 69–76

Procedia Computer Science

www.elsevier.com/locate/procedia

The 10th International Conference on Ambient Systems, Networks and Technologies (ANT)
April 29 - May 2, 2019, Leuven, Belgium

Demand responsive - vs. conventional public transportation: A MATSim study about the rural town of Colditz, Germany

Kathrin Viergutz[a,*], Clemens Schmidt[b]

[a]DLR Institute of Transportation Systems, Lilienthalplatz 7, Braunschweig 38108, Germany
[b]Martin Luther University (MLU) Halle-Wittenberg, Universitätsplatz 10, Halle 06108, Germany

Abstract

Conventional public transportation (CPT) services in rural areas are among others confronted with the accessibility problem and low traveler quantities. Demand responsive transportation (DRT) is an emerging mainstream concept, which aims to offer flexible mobility services to customers and also to solve the aforementioned problems of CPT providers. Studies and simulations about the comparison of CPT and DRT mostly focus on urban areas. Therefore, this paper is a case study of CPT vs. DRT services in the rural town of Colditz: A stop-based and a door-to-door DRT service is analyzed along with a CPT bus line.

Keywords: Simulation; Agent-Based Modeling; MATSim; Demand Responsive Transportation; Rural Communities

1. Introduction

The conventional public transportation (CPT) sector in the rural areas of Germany and elsewhere has been under pressure for many years. CPT providers are demanded to submit a decent level of mobility to all social groups, while at the same time they are required to practice pollution control and cost efficiency. These three tasks are conflicting objectives and CPT providers are confronted by the Pareto optimum: Low population densities are making it impossible to serve all requests under economic and ecological constraints. On the other side, places without any CPT service are suffering under the accessibility problem and cases of social hardship occur where people without a car or driving license such as children, elderly or disabled people

* Corresponding author. Tel.: +49 531 2952286
E-mail address: Kathrin.Viergutz@dlr.de

10.1016/j.procs.2019.04.013

are isolated. Demographic changes and political decisions to centralize rural schooling further aggravate the challenges for CPT providers and their services.

The idea of demand responsive transportation (DRT) is to offer a flexible mobility service to customers, which also has the effect that service providers can be more cost efficient in regard to their traditional services. Small-sized vehicles (e.g. minivans) serve individual requests while pooling multiple requests according to pre-defined service criteria. In theory this implies the following advantages: a DRT service runs according to the demand, which means that empty vehicle runs are reduced while at the same time fuel and emissions are saved resulting in lower costs for service providers.

This paper analyzes the feasibility of such DRT services to cope with the challenges of the rural CPT sector. To adequately assess and compare the potentials of CPT and DRT services in the town of Colditz, located in the east of Germany, a MATSim study has been conducted. It is the first comparative MATSim study in rural Germany and provides evaluation of the relatively new MATSim drt module. Foci of the paper are the operators, customers as well as societal and ecological perspectives on the different services.

The following section gives a short overview on DRT and related work in agent-based transportation modeling. Hereafter, the methodology of the simulation is presented, containing a presentation of the Colditz model and its three different scenarios. The case study results are demonstrated from an operator, a customer, a societal and an ecological perspective in section four. A short discussion of the results follows and a conclusion is given in the end.

2. Related work

Flexible transportation solutions in the context of rural mobility are far from being novel but have never been applied on a large scale. Since the 1960s community cars have been operating in rural England [1], since the 1970s paratransit for mobility impaired people has existed in the USA [2], since the 1980s Anrufbusse (dial-a-ride busses) have been used in Germany in sparsely populated regions or times of thin traveler flows [3] and also the so-called informal transport in the developing world refers to the topic [4]. However, DRT in the broadest sense of its theoretical concept is going further than all that and wants to provide an universal solution by offering on demand mobility to everyone everywhere at any time. Nevertheless, DRT services can be restricted to only serve specific stops via flexible routing or to serve locations along a core route. The past has shown that the latter was the much more successful variant in rural context (in Germany and internationally) and that the list of failed DRT services due to the trap of offering un-timetabled many-to-many services is long [5].[1] Independently of the serviced region and its stops, the implementation goes along with the deployment of applications for real-time travel information and dispatching as well as online booking and the willingness to share rides on behalf of the passengers. DRT services can be imaged as something in between a traditional bus and a taxi [6]. Ideally, these services are offered by using autonomous vehicles. Some authors speak of the Uberisation of public transportation (pt) [7], especially since the rural town of Innisfil (Canada) commissioned the Uber Inc. company in 2016 to provide on demand mobility to its citizens instead of establishing their own bus lines [8]. However, no DRT service is fully implemented yet and has reliable data to analyze.[2] Therefore, simulation studies are crucial to estimate long-term viability [2].

Simulation studies conducted with MATSim on the usage of DRT instead of CPT services predict cost benefits for pt providers, especially in the case of an implementation with autonomous vehicles [9, 10, 11]. According to these simulations smaller travel times and enhanced accessibility are further advantages of DRT services compared to CPT offers. These MATSim studies were conducted in the urban regions of Berlin and Zurich, and nothing can be deduced from them on the circumstances of rural regions. For that reason, the following MATSim study is dedicated to the DRT vs. CPT usage in the rural town of Colditz, to gain insides into non-urban potentials. Furthermore, there will be taken a look at environmental effects because comparative studies on the respective emissions are rare [12, 13].

[1] One of the recent examples is the abandoned Helsinki Kutsuplus project [3].

[2] Many DRT projects exist, but non of them long enough or in a way to compare each other and do reliable quantitative statistics and cross-validation [6].

3. Methodology

This paper presents a case study in the field of transportation science. It uses the activity-based, microscopic, multi-agent simulation framework of MATSim [14] as the tool to analyze the subject of rural pt. Therefore no MATSim functions were altered or new algorithms programmed, but a new scenario was researched. MATSim version 0.0.10 and its modules drvp [15], drt [9] and pt [16] were used for these simulations carried out in May-June 2018.

3.1. Colditz model

A synthetic MATSim model for the greater rural region of Colditz was programmed. The town located in the German state of Saxony has 8.967 inhabitants distributed over 26 districts resulting in a density rate of roughly 100 inhabitants per km^2. The following equally distributed five groups of agents and their plans were programmed according to demographics [17] and labor statistics [18]:

- Agent plan Home-Work-Home: Employees type one, with 7-9 hours of work activity.
- Agent plan Home-Work-Shop-Home: Employees type two, with shopping activity on the way back home from 4-6 hours of work.
- Agent plan Home-Work-Home-Leisure-Home: Employees type three, with leisure activity after 6-8 hours of work and an interim stop at home.
- Agent plan Home-Education-Home-Leisure-Home: Youth under 25 years of age who either start their education activity at 07:30am or 09:30am for 6 hours and some leisure activity in the afternoon.
- Agent plan Home-Shop-Home-Leisure-Home: Elderly people over 65 years of age with some shopping activity in the morning and leisure in the afternoon.

The aim of the analysis was to investigate the effects resulting of four percent pt users.[3] Therefore, 360 agents were programmed by taking 72 agents from each of the five groups above. Their housing locations are always situated in one of the living districts of Colditz. Leisure and shopping locations are all situated in the core town of Colditz and agents use the closest one to their respective home location. Leisure possibilities are sports, educational or cultural activities. Shopping also includes administrative actions, banking, doctors etc. Work and education locations can be settled in Colditz itself but can also be somewhere else (randomly chosen), so that agents travel outside the area of interest and come back to Colditz in the afternoon/evening. Survey data regarding pt patterns in rural Germany [19, 20], line and timetable data concerning the regional bus services (via GTFS[4]), pt count data, qualitative information from local and regional authorities and personal inquiries on the spot about leisure and shopping places were also incorporated to further foster the model accuracy. The resulting synthetic Colditz population is made up of 60% employees, 20% youth and 20% elderly people [17] and has the characteristics of traveling 3,4 average ways a day [20]. In connection with the GTFS file, Tuesday, the 12th June 2018[5] was chosen as the agents' day in the simulation [21].

3.2. Simulation settings for three transportation scenarios

There is currently no bus line just for the town of Colditz but the town is connected via regional services to the nearby Bad Lausick, Grimma, Rochlitz and some other smaller localities. Therefore, authorities wanted to investigate the feasibility of CPT and DRT services to carefully plan a future market entrance. This is why the simulation study tried to set up the Colditz MATSim model as realistically as possible. To correspond to this aim the simulations had to acknowledge the respective Nahverkehrsplan, a document which regulates the design of local public transport in cities and federal states in Germany. This plan sets the maximum walking

[3] Colditz has roughly two percent pt travelers at the moment and the minimum target was to duplicate that number.
[4] The General Transit Feed Specification (GTFS) defines an exchange format for pt schedule data.
[5] This constitutes an average scheduled pt day in the Colditz pt network.

distance to the next pt station to 600m. This analysis therefore neglects access and egress walks [9] in favor of a realistic comparison, acknowledging the fact that a CPT service is bound to the Nahverkehrsplan but a DRT door-to-door service is not. Also, Colditz is an undulating region and these walks would vary a lot in real life depending on the constituency of a person compared to the synthetic environment in agent-based simulation. Each of the three simulations was conducted for 100 iterations, allowing 10% of the agents to adapt their initial times back and forth within a range of 30min, 10% were allowed to alter their routes and the remaining 80% kept their best scored plan. The time of the operational service was always between 6am and 8pm.

The simulation of a CPT service is a simple bus line, connecting the core town of Colditz to its biggest and closest district Zschadaß. The route has a distance of 3,5km and runs back and forth all day long, serving eight stops in a 30min cycle. A Mini-/Midibus with a capacity of 20 seatings was set as vehicle. The pt module of MATSim was deployed to carry out the simulation as a whole, incorporating the existing regional bus lines as well as the planned town line.

The simulation of a DRT stop-based service in Colditz is a scenario where altogether 14 stops are served without any scheduled time or route (free-floating). The service is done with automobiles, which have a capacity of four seatings. DRT automobiles halt at a stop for 30sec and the maximum of 600m walking distance to the next stop is applied to the using agents as it is for the agents in the pt simulation mentioned above. The drvp, drt and pt modules of MATSim were deployed to carry out the simulation. This is because agents are offered the DRT service only in the core town of Colditz and its district Zschadraß. As soon as agents travel somewhere outside, then they have to use the regional bus lines; the bus line 619 for instance to travel to work in Grimma. The dispatching of vehicles after passenger requests is done by heuristically allocating the nearest idle vehicle [9]. This dispatch heuristic uses the formula stated below where t_r is the time restriction on the side of the passenger inside the DRT vehicle. t^r_{direct} represents the direct single journey. In reference to previous simulation studies was alpha (detour factor) set to the value of 1,5 [22] and in accordance to information of regional and local authorities was beta (additional time for passenger boarding) set to the value of 5min. The maximum waiting time of customers requesting a DRT service is t^{max} and this time restriction was set to 30min in order to compare the service to the 30min cycle of the CPT service. To assure quality of service, only simulation results with an overall request rejection rate below five percent were evaluated.

$$t_r = \alpha t^r_{direct} + \beta$$

The simulation of a DRT door-to-door service now serves all activity locations in Colditz and Zschadraß. Therefore, agents are not willing to walk to a stop anymore but want to be picked up at home and be delivered to the door of their respective activity destination. Still, if they want to travel outside of Colditz core town and Zschadraß, they have to use regional bus services. The service is performed with vans, which have a capacity up to 14 seatings and also stop at pick up for 30sec. Again the drvp, drt and pt modules of MATSim were deployed to carry out the simulation. Dispatching is effected analogously to the DRT stop-based simulation but with the difference that t^{max} is set to 60min. This is because waiting at home (or some other activity location) is assumed to be more convenient than waiting outside at a bus stop [23].

4. Results

The Colditz case study results are in the following sections presented from an operator, a customer, a societal and an ecological perspective.

4.1. Operator perspective

Table 1 shows the relevant simulation data from the view of the operator. The CPT service needs one vehicle to run the offer of a town bus line, connecting the core town of Colditz with Zschadraß in a 30min cycle. The DRT stop-based service requires five vehicles and the DRT door-to-door service needs ten. Moreover, vehicle kilometers (VKM), rides and agents rise substantially from the left side of the table to the right. The rate of empty runs behaves inversely and becomes smaller with the degree of flexibility expansion.

Table 1. Operators' perspective on the comparison of CPT and DRT services.

	CPT scheduled Bus	DRT Stop-based	DRT Door-to-Door
Vehicle(s)	1 Mini-/Midibus	5 Automobiles	10 Vans
Capacity	min. 12 Places	min. 4 Places	6 - 14 Places
VKM (km)	200	644	838
Rides	93	458	512
Agents	59	206	215
Empty runs	51%	37%	34%

The rationale extracted from this data is that agents increasingly use pt services if these operate in their daily sphere of activity. However, this requires vastly more vehicles and produces a substantial amount of excess kilometers. With respect to the difference between the service expansion coming along with DRT stop-based and door-to-door services, it becomes clear that only nine additional agents (paying passengers in reality) can be gained through door delivery but 54 more rides occur. This means that agents already using pt travel more often and use in this scenario DRT instead of walking short distances. The average number of DRT traveling ways rise from 2,2 in the stop-based scenario to 2,4 in the door-to-door scenario. Furthermore, the number of vehicles and by association the number of drivers is five times as much in the DRT stop-based scenario compare to the CPT scenario. On the contrary, the number of agents is three and a half times higher in the DRT stop-based scenario compare to the CPT scenario. Consequently, CPT and DRT services should be carefully evaluated by pt operators in rural areas. The expenses for DRT services, indicated through the provision of additional vehicles and labor, might be out of relation to the intended passenger gains.

4.2. Customer perspective

Figure 1 shows the relevant simulation data from the view of the customer.[6] Their waiting and in-vehicle travel times with the CPT bus line is twice as high as it is using the DRT stop-based service. Waiting and in-vehicle travel times rise again for customers of the DRT door-to-door offer compared to the stop-based service. Nevertheless, considering all travel times[7] the two DRT services are within the same range and both outperform the CPT service. It is assumed that in reality most of the pt customers would like to minimize their traveling ways/maximize their daily activities and would therefore prefer a DRT over a CPT service.

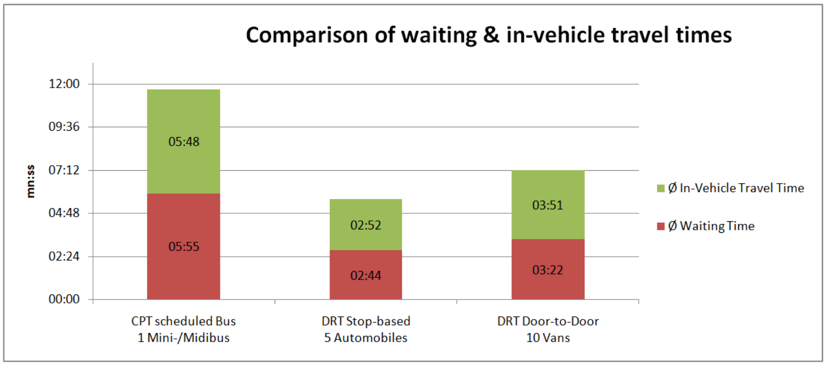

Fig. 1. Customers' perspective on the comparison of CPT and DRT services.

[6] Agents finding no service adequately fitting their daily plan and its respective time restrictions (CPT scenario), or agents whose requests were rejected (both DRT sceanrios) walk their ways in the simulation.
[7] The detailed analysis of the access and egress walks was waived due to the reasons stated in section 3.2.

4.3. Societal perspective

The DRT door-to-door service provides complete spatial accessibility to society as a whole. Figure 2 shows the accessibility for the CPT bus line (left) and the DRT stop-based service (right) on the basis of the served stops. The accessibility gap in the CPT scenario is particularly grave in the north and southwest of the core town of Colditz where an industrial company with more than 400 employees and a whole residential area has no serviced stop reachable within 600m distance. These gaps do not exist in the DRT stop-based scenario and only some remote houses are not serviced. From a societal point of view would both DRT services access the area of interest to a higher degree than this is the case for the CPT bus line.

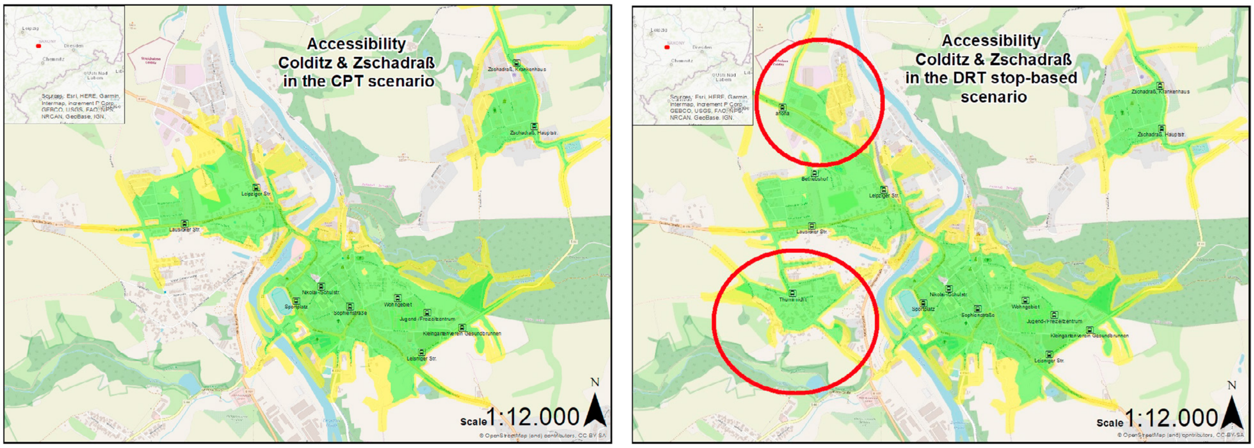

Fig. 2. Spatial accessibility of the serviced area from the view of society as a whole in the CPT scenario (left) and the DRT stop-based scenario (right). Accessibility polygons are shown for walking distances to stops up to 400m (green) and up to 600m (yellow). Accessibility gaps in the CPT scenario are more severe than in the DRT stop-based scenario (red circles). The DRT door-to-door scenario provides complete spatial accessibility to the researched area and therefore an extra third map is not needed.

4.4. Ecological perspective

Ecological effects of transportation services are judged according to their pollutants, summarized as carbon monoxide (CO), volatile organic compounds (VOC) and oxides of nitrogen (NOx), as well as CO_2 emissions and particulate matter (PM) [12]. For this analysis 2020 emission factors were used (concerning a short-term oriented realization) from the Handbook of Emission Factors for Road Transport (HBEFA) [24]. The CPT scenario uses the HBEFA urban bus factors, the DRT stop-based scenario the HBEFA passenger car factors and the DRT door-to-door scenario uses the HBEFA factors of the light duty vehicles/light commercial vehicles category. Emissions were calculated in gram and per agent. Table 2 shows an overview of the emissions in the three scenarios. The DRT stop-based service generates the smallest amount of emissions from all three scenarios.

Table 2. Emissions according to the three MATSim scenario results and HBEFA factors, calculated in gram (g) per agent.

	CPT scheduled Bus	DRT Stop-based	DRT Door-to-Door
Pollutants (CO + VOC + NOx)	11,2g	3,6g	3,4g
CO_2	4.112,2g	476,9g	759,2g
Particulate Matter (PM)	0,06g	0,01g	0,08g

5. Discussion

The results of this case study show that DRT services are the favorable transportation solution from the pt customers' and societies perspective but that these services are currently not necessarily more efficient for pt providers compared to their CPT services. The gain of passengers in the DRT stop-based scenario has to be pitted against the need to acquire four additional vehicles and eight drivers compared to the one vehicle and two drivers in the CPT scenario. Also, a heavy investment into on-the-fly vehicle assignment hard- and software is required, which would further burden the already financially weak pt providers in rural areas. With a possible future era of autonomous vehicles in sight, DRT services can be indeed more efficient and simultaneously guarantee a higher service standard than current CPT services do. However, this does not seem to be the case for a short-term relief of the rural pt sector since additional labor costs exceed (possible) passenger gains.

These simulation results are in line with MATSim studies on the usage of CPT vs. DRT services in urban contexts [9, 10]. It can also be confirmed for the rural context that DRT services reduce waiting and traveling times for customers and enhance the accessibility of a region but charge the providing pt companies with additional costs and efforts.

Consequently, learning from this case study simulation results and the number of failed DRT services means not offering unnecessarily flexible services that jeopardize operating economics by overexerting the capacities of pt providing companies [5]. Publicly unintended, un-timetabled many-to-many services overstrains also customers, especially with regard to App-based booking solutions and different levels of digital capabilities [25]. Therefore, DRT services should not only be thought in terms of route flexibility but also in terms of services operating along a (semi-fixed) core route been flexible in time and stopping. Line-based DRT services are able to concentrate demand in time and geography and have been quite successful in the past [5]. Similar to the German variant of the dial-a-ride [3], future MATSim and other simulation studies should compare DRT stop-based services with DRT line-based services, to evaluate their comparative advantages and disadvantages in regard to CPT services.

6. Conclusion

This case study has shown that ultra-flexible DRT services are not the panacea for the rural pt sector, especially not in the case of a free-floating DRT door-to-door service. DRT in rural context should be conceptualized differently than in urban areas. Both, the accessibility problem through low population density and also low traveler quantities are making it impossible to offer a high DRT service standard at reasonable operational costs. Therefore, future simulations on the DRT usage in rural areas should study accessibility, economics, emissions and quality of service of DRT line-based services, which are flexible in time of service and their stopping along (semi-fixed) core routes. It seems to the authors of this study that the potentials of dial-a-ride services have not been fully exploited yet and much theoretical space is left to study with further agent-based simulations.

References

[1] T. J. Ryley, P. A. Stanley, M. P. Enoch, A. M. Zanni, M. A. Quddus, Investigating the contribution of Demand Responsive Transport to a sustainable local public transport system, Research in Transportation Economics 48 (2014) 364–372. doi:10.1016/j.retrec.2014.09.064.

[2] N. Ronald, R. Thompson, S. Winter, Simulating Demand-responsive Transportation: A Review of Agent-based Approaches, Transport Reviews 35 (2015) 404–421. doi:10.1080/01441647.2015.1017749.

[3] A. König, J. Grippenkoven, From public mobility on demand to autonomous public mobility on demand – Learning from dial-a-ride services in Germany demand – Learning from dial-a-ride services in Germany, Logistik und Supply Chain Management 16 (2017). URL: https://elib.dlr.de/104956/.

[4] R. Cervero, Informal Transport in the Developing World, Technical Report, Nairobi, 2000. URL: http://mirror.unhabitat.org/pmss/getElectronicVersion.aspx?nr=1534&alt=1.

[5] M. Enoch, S. Potter, G. Parkhurst, M. Smith, Why do demand responsive transportation systems fail?, in: Paper for the 85th Annual Meeting of the of the transportation research board, Washington, DC, 2006, pp. 1–17. URL: http://oro.open.ac.uk/19345/1/enochetalTRB2006failed.pdf.

[6] Z. Navidi, N. Ronald, S. Winter, Comparison between ad-hoc demand responsive and conventional transit: a simulation study, Public Transport 10 (2017) 147–167. doi:10.1007/s12469-017-0173-z.

[7] D. A. Hensher, Future bus transport contracts under a mobility as a service (MaaS) regime in the digital age: Are they likely to change?, Transportation Research Part A: Policy and Practice 98 (2017) 86–96. doi:10.1016/j.tra.2017.02.006.

[8] C. Smith, A Canadian town wanted a transit system. It hired Uber., 2017. URL: https://www.nytimes.com/2017/05/16/world/canada/a-canadian-town-wanted-a-transit-system-it-hired-uber.html.

[9] J. Bischoff, K. Führer, M. Maciejewski, Impact assessment of autonomous DRT systems, Transportation Research Procedia (2018) 1–8. URL: https://svn.vsp.tu-berlin.de/repos/public-svn/publications/vspwp/2018/18-04/BischoffFuehrerMaciejewski2018DRTCottbus.pdf.

[10] G. Leich, J. Bischoff, Should autonomous shared taxis replace buses? A simulation study, Transportation Research Procedia (2018) 1–10. URL: https://svn.vsp.tu-berlin.de/repos/public-svn/publications/vspwp/2018/18-05/LeichBischoff2018DRTLastMileHeiligensee.pdf.

[11] P. M. Bösch, F. Becker, H. Becker, K. W. Axhausen, Cost-based analysis of autonomous mobility services, Transport Policy 64 (2018) 76–91. doi:10.1016/j.tranpol.2017.09.005.

[12] M. Diana, L. Quadrifoglio, C. Pronello, Emissions of demand responsive services as an alternative to conventional transit systems, Transportation Research Part D: Transport and Environment 12 (2007) 183–188. doi:10.1016/j.trd.2007.01.009.

[13] D. J. Fagnant, K. M. Kockelman, The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios, Transportation Research Part C: Emerging Technologies 40 (2014) 1–13. doi:10.1016/j.trc.2013.12.001.

[14] A. Horni, K. Nagel, K. W. Axhausen, The Multi-Agent Transport Simulation MATSim, Ubiquity Press, London, 2016. doi:10.5334/baw.

[15] M. Maciejewski, Dynamic Transport Services, in: The Multi-Agent Transport Simulation MATSim, 2016, pp. 145–152. doi:10.5334/baw.23.

[16] M. Rieser, Modeling Public Transport with MATSim, in: The Multi-Agent Transport Simulation MATSim, 2016, pp. 105–110. doi:10.5334/baw.16.

[17] Statistisches Landesamt Freistaat Sachsen, Gemeindeblatt. Zensus 2011. Haushalte, Familien und deren Wohnsituation am 9. Mai 2011. Colditz, Stadt, Technical Report, 2014. URL: https://www.statistik.sachsen.de/download/080_zensus_2011_HFW/HFW_14729080.pdf.

[18] Bundesagentur für Arbeit, Beschäftigungsquoten (Jahreszahlen und Zeitreihen), Technical Report, Nürnberg, 2018. URL: http://statistik.arbeitsagentur.de.

[19] G.-A. Ahrens, Sonderauswertung zum Forschungsprojekt „Mobilität in Städten – SrV 2013“. SrV-Stadtgruppe: Unter-/Grund-/Kleinzentren/ländliche Gemeinden, Topografie: flach, Technical Report, 2015. URL: https://tu-dresden.de/bu/verkehr/ivs/srv/ressourcen/dateien/2013/uebersichtsseite/SrV2013_Stadtgruppe_UnterGrundKleinzentrenLaendlGemeinden_flach.pdf?lang=de.

[20] Infas, DLR, Mobilität in Deutschland 2008: Ergebnisbericht. Struktur – Aufkommen – Emissionen – Trends, 2010. URL: www.mobilitaet-in-deutschland.de.

[21] F. Poletti, Public Transit Mapping on Multi-Modal Networks in MATSim, Strasse und Verkehr (2017) 22–25. URL: https://www.ethz.ch/content/dam/ethz/special-interest/baug/ivt/ivt-dam/news/vss-poletti-matsim.pdf.

[22] J. Bischoff, M. Maciejewski, K. Nagel, City-wide Shared Taxis: A Simulation Study in Berlin, VSP Working Paper (2017). URL: http://svn.vsp.tu-berlin.de/repos/public-svn/publications/vspwp/2017/17-11/BischoffMaciejewskiNagel2017SharedTaxiITSC.pdf.

[23] S. R. Jara-Diaz, A. Tirachini, Urban Bus Transport: Open All Doors for Boarding, Journal of Transport Economics and Policy 47 (2013) 91–106. URL: http://www.ingentaconnect.com/content/lse/jtep/2013/00000047/00000001/art00006.

[24] Infras, Handbook Emission Factors for Road Transport (HBEFA) - Online Version, 2018. URL: http://www.hbefa.net/e/index.html.

[25] N. R. Velaga, M. Beecroft, J. D. Nelson, D. Corsar, P. Edwards, Transport poverty meets the digital divide: accessibility and connectivity in rural communities, Journal of Transport Geography 21 (2012) 102–112. doi:10.1016/j.jtrangeo.2011.12.005.