Simulation of a Demand Responsive Transport feeder system: A case study of Brunswick

Maria Giuliana Armellini[1] and Laura Bieker-Walz[2]

[1] German Aerospace Center (DLR), Berlin, Germany
maria.armellini@dlr.de
[2] German Aerospace Center (DLR), Berlin, Germany
laura.bieker@dlr.de

Abstract

Public transport systems in rural and peri-urban areas are in many cases characterized by long travel times, low frequencies and irregular services. Because of this, motorized private transport is often the only practicable mode of mobility in this regions. The use of Demand Responsive Transport (DRT) as feeder systems to mass public transport modes presents a great potential for improvement. This paper investigates the potential of such a system applied to a case-study of a peri-urban area of Brunswick, Germany. For that, the current bus line was replaced by a Bus Rapid Transit (BRT) line with DRT as feeder systems. In order to evaluate the performance of the proposed system and provide a benchmark against the current public transport offer, multiple trips to the city center with the different transport modes were simulated. The agent-based microscopic simulation Eclipse SUMO (Simulation of Urban MObility) was used as framework. The scenario of the DRT systems was simulated by SUMO coupled to a developed dispatching algorithm. The results show the potential of the proposed system due to the lower travel times, higher frequency and grater service area. Travel times were even comparable with the travel times of private car-based modes, which could lead to a potential increase in demand.

Contents

1 Introduction

The demographic and social changes that have taken place in recent decades pose increasing challenges to classic public transport in rural and peri-urban areas. The increasing migration to the cities mainly by young people as well as the increasing motorization of the population has generated a centralization of public administration, social infrastructure and service offers [38]. As a result, many supply structures in rural areas have collapsed [45].

Public transport in these areas, if provided at all, are characterized by long travel times, low frequencies and irregular service [41]. Its main function is often reduced to school transport, which accounts for 50 % of the demand in many districts and up to 90 % in some areas [13, 22]. The motorized private transport is often the only alternative to mobility in these regions, because of the low density of supply and the long distances [18].

To address this problem, since 1970 different demand-based forms of public transport have been tested in rural and peri-urban areas in Germany [27]. In practice, it has been shown that the costs of flexible offers surpass the cost of classic public transport due to human resource planning costs and generally lower vehicle capacity. This is particularly pronounced if the necessary bundling and collection effects cannot be achieved and trips are limited to the transport of individual passengers [8].

In recent years, technological advances and improvements in computer power and digitization have made it possible to develop new forms of demand-based mobility, which are a booming market and are already being used or tested in several cities worldwide. Demand Responsive Transport (DRT) also referred to as ride-sharing services like "UberPool" and "Lyft Shared" are an example of latter. This shared service without fixed routes seeks to bundle requests in minimizing the number of vehicles and route lengths without compromising passenger travel times. Resulting, according to various simulations, in a more efficient service compared to taxi and ride-hailing services ("Uber" or "Lyft") [7, 28, 40]. A significant impact on vehicle mileage and traffic in general only occurs if many customers switch from individual car-based transport. According to Feigon et al. [20], only New York City has so far published sufficient data on DRT systems to analyze and evaluate their impact. Based on the latter data, Schaller [37] found that in fact only 20 % of the trips are shared and that the majority of the customers switched from non-vehicle-based modes of transport (e.g. public transport, bicycle and walking). Additionally most of the times the service is only used by one person, which leads to an increase in traffic instead of the planned reduction. The acquisition of passengers from public or non-motorized transport is a critical point, since DRT systems are not well suited for high-demand connections [29]. Conventional high capacity public transport, such as trains, subways or Bus Rapid Transit (BRT) are best suited for this purpose due to their higher operational efficiency [33]. Hence, the combination of both systems by using the DRT as a feeder system for high capacity transit would be the first best solution.

The objective of this paper is to evaluate the optimization potential of public transport in peri-urban areas through the use of DRT as feeder systems for a BRT line. This is done by assessing the performance of the conventional and proposed public transport system using the microscopic traffic simulation Eclipse SUMO (Simulation of Urban MObility). As a case-study an area near the city of Brunswick (Germany) was chosen.

The paper is organized as follows. First the case study is described in detail. Then the adopted methodology is outline. Next, the simulation results are presented and discussed. At last the main conclusions derived from this study are summarized.

2 Study case

The study area includes six villages located in the west of the city of Brunswick along the federal highway B1 (Figure 1). With 250,361 inhabitants, the city of Brunswick is the second largest city in the state of Lower Saxony. The number of inhabitants of the villages varies between 552 in Vechelade and 6,108 in Vechelde with most of the area being residential or of mixed use

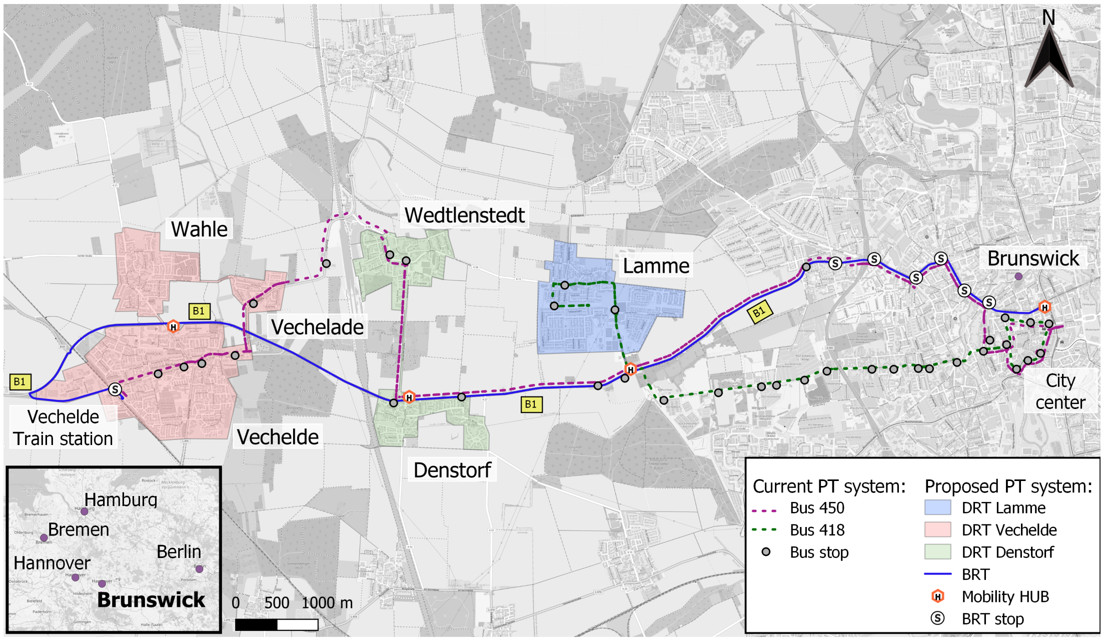

Figure 1: Study case: current and proposed public transport system

[10, 43]. Less than 10 % of the inhabitants of the villages live and work in the same place, while 48 % are working in Brunswick [23]. The short distance to the city center (about 13 km from Vechelde) and the limited local supply of education, health care and leisure activities result in a high number of daily trips to Brunswick.

The private vehicle constitutes the main mode of transport due to the fast and easy access to the city along the federal highway B1 and the limited public transport offer. The bus line 450 is the main public transport service in the area connecting most villages, with the exception of Wahle and Lamme, with the center of Brunswick (purple line in figure 1). The bus line 418 (green line in figure 1) connects Lamme with the city center while Wahle currently does not have a public transport service connection to Brunswick. Both bus services are characterized by an indirect route through secondary streets and mixed traffic lanes, long travel times, high bus stop density and low frequency (30 minutes at peak times) [44]. Vechelde also has a regional train service to Brunswick main station with a travel time of 10 minutes but with a low frequency of 1 hour [5].

The study area shows a high potential for growth and expansion due to its relatively short distance to the city and the availability of free areas [23]. However, due to the lack of measures to improve public transport offer, this growth will be associated with an increase of private car trips and its negative effects, such as noise and air pollution, traffic congestion and growing demand for parking space.

In relation to this problem, this work investigates the optimization of the current public transport service through a BRT line with DRT as feeder systems. The BRT service was planned to offer a direct and fast connection from and to the city center with a frequency of 15 minutes (blue line in figure 1). The route of the BRT line starts at the Vechelde train station and runs along the federal highway B1 and in the urban area along a BRT corridor with dedicated lanes to the last stop in the city center. Between Vechelde and the urban area the BRT line has only three stops, which were designed as mobility hubs. The location of each mobility hub was determined considering the bus acceleration, accessibility, safety and available area.

For the first/last mile, from the mobility hub to the respective home, three different DRT feeder systems with a door-to-door service are proposed. Figure 1 shows the service area of the DRT system Vechelde in pink, Denstorf in green and Lamme in blue. The DRT feeder systems are designed primarily to serve the BRT line, hence trips to or from the mobility hub have priority and a good transfer with short waiting times should be guaranteed. The DRT system fleet was set based on a previous study that analyzed the efficiency of each DRT system under different fleet configurations [4]. Therefore a fleet of 3 vehicles was adopted for the DRT system Vechelde and a fleet of 2 vehicles for the DRTs Denstorf and Lamme. Each DRT vehicle has a capacity of 6 passengers.

In addition to the DRT feeder system, the usage of non-motorized modes as first/last mile option is contemplated. This requires a good cycling infrastructure, including safe cycle paths and adequate parking facilities in the mobility hubs.

2.1 Simulated scenarios

In order to compare the current with the proposed public transport system two different simulation scenarios were built. The Scenario 0 represents the current mobility situation in the study area simulating the bus lines 450 and 418. The scenario 1 simulates the proposed DRT and BRT systems as well as the bicycle trips for the first/last mile. In the following the construction of both scenarios and the use data is explained.

The network was generated based on an existing SUMO network from the project "Intelligent Mobility Application Platform" (AIM) [39]. Missing network areas and bus stops were added using data from ©OpenStreetMap, ©Google Maps and the transport company Braunschweiger Verkehrs-GmbH.

Both scenarios simulate the demand of a typical working day type Tuesday/Thursday. The surrounding traffic in the sub-urban area was modeled based on the average daily traffic volume from existing traffic counters [35] and distributed spatially according to the number of inhabitants. The temporarily distribution was made according to data from a permanent counting station near Vechelde [6]. For the surrounding traffic in the city area the existing data from the AIM project was used [39].

In order to analyzed the current and proposed public transport system 10 different demand profiles of trips with origin in the respective home and destination in the city center between 5:30 and 20:00 were generated. First the daily demand of trips from each location to Brunswick were estimated. This was done with the calculation method of Bosserhoff [9] based on

- the number of inhabitants in each town,
- the proportion of the O-D pair town-Brunswick, and
- the modal split of the trips.

The trips with destination in Brunswick were determined according to commuter traffic data from [23]. The modal split was estimated on the basis of the trip distance and the characteristics of the transport network, taking into account several analyses of traffic behavior [32, 21, 24]. Secondly, the daily demand was distributed temporally using a typical daily traffic flow profile for peri-urban areas [19]. Lastly, the spatial distribution was done by assigning a random point in the service area to represent the respective home.

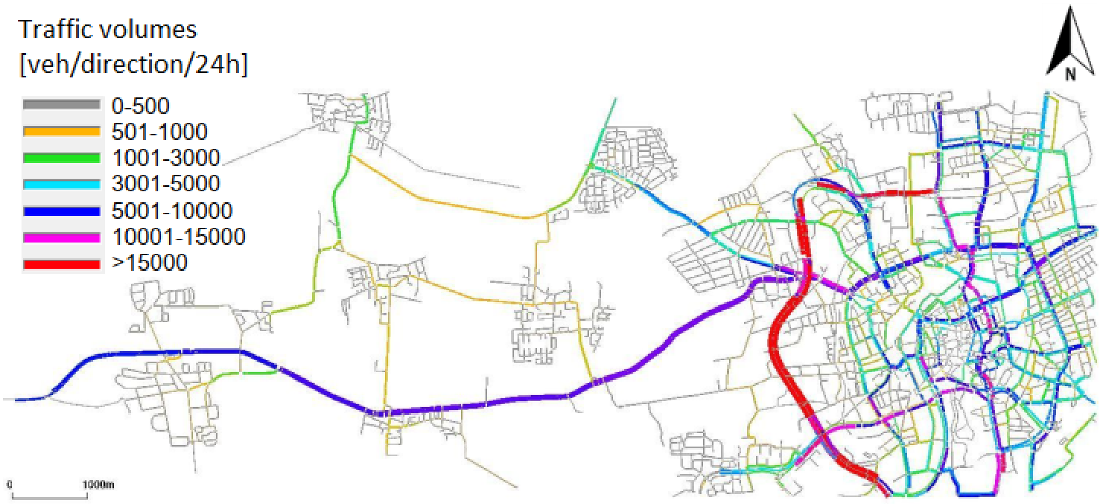

Figure 2: Simulated daily traffic volumes

Figure 2 shows the simulated daily traffic volumes in the entire network. The maximum number of vehicles in a simulation step is around 2,200. The simulated traffic volumes proved to be comparable with the daily traffic volume published by the city of Brunswick [11]. The potential decrease in traffic due to the implementation of the proposed system will not be taken into account.

3 Methodology

For the simulation of DRT services it is necessary to know the start time, origin and destination of each request, as well as the capacity and location of each vehicle in the fleet. A dispatching algorithm then distributes the travel requests among the available vehicles. This requires the use of a microscopic and agent-based simulation model. Most of the microscopic traffic simulations do not provide a link between freely operating vehicles and several passengers that are assigned to them at different times [33], requiring the development of an algorithm. The traffic simulation Eclipse SUMO [3] proves to be the best option in this context, since it allows the simulation of large road networks with different modes of transport on a microscopic level and its open source license allows the implementation and testing of new algorithms. The main features of the developed algorithm allows to simulate the DRT, which is explained in detail in the following section.

Different measurements were evaluated in order to compare the improvements between current and proposed transport system. To assess the bus line and BRT service the travel time between the start and end point of the route were determined. The proportion of stopping time at bus stops and time-losses, for example due to congestion or stopping at traffic lights, were also analyzed. Other service parameters, such as frequency, bus stops density, capacity and vehicle fleet were also considered. To evaluate the service from the passenger point of view, the travel times with the different transport modes from the respective home to the city center were evaluated.

3.1 DRT modeling

The fleet management of a demand responsive transportation system is often referred to as a Dial-A-Ride Problem (DARP) [17]. The DARP consists of designing vehicle routes and schedules for n requests or users that specify travel requests between an origin and destination point. The objective is to plan series of vehicle routes that can accommodate the largest number of requests under certain conditions [16]. Due to the wide and varied constrains that a DARP can present, there are different methods and models for solving them either approximately or exactly.

For the present study it was assumed that all requests are known in advance and that the DRT vehicles start and end each trip at the respective mobility hub. On-street parking is not allowed while waiting for next request. The DRT service is planed as a feeder system, so the connection with the BRT buses must be guaranteed. Each DRT vehicle starts its trip when a BRT bus arrives at the mobility hub and has a maximum time of 12 minutes (BRT frequency minus 3 minutes for transfer) to serve the requests and be on time at the mobility hub for the next BRT bus. To find the best route for each vehicle, a static DARP will be solved. If a request can not be served, it will be rejected and removed, not taken in consideration for future trips. These model simplifications are possible as this study seeks to analyze the capacity and travel times with the system and not to simulate real situations of the service, such as waiting for the passenger or passenger "no-show", cancellation of requests, etc.

To solve the described DARP, an algorithm based on the exact resolution method of [2] was developed. The algorithm was written in Python 3 and uses the SUMO tool DUAROUTER to calculate the routes of each vehicle and passenger. The steps performed by the algorithm are explained briefly below.

First, the algorithm loads the necessary inputs. These are the network, the mobility hub location, the desire pick-up time and origin/destination edge of each request as well as the capacity, the maximum travel time and the cost of each vehicle. The cost parameter of the vehicle prevents the random use of the vehicles of the fleet by trying to use the vehicles with lower costs.

The second step is to generate a pairwise graph with the possible combinations between vehicles and requests and between two different requests. The shortest route and corresponding travel time between the objects in a pair is calculated using DUAROUTER.

Based on the pairwise graph, all possible combinations of pairs forming a trip are searched. A trip is possible if the vehicle capacity is not exceeded at any time, all passengers are taken to their destination and the maximum travel time for each passenger and vehicle is not surpassed.

The next step is to find the best trip for each vehicle that minimizes the cost. This is done by solving an integer linear programming (ILP) using the Python tool "Pulp" [31]. The objective function minimizes three costs: the first one represents the travel time (including stop time for pick-up/drop-off). To penalize the rejection of a request, a high and constant cost is defined. Finally, a small and constant cost is introduced to avoid the use of several vehicles when the same requests can be served at a comparable cost with fewer vehicles. There are two constraints to the problem: each vehicle has no more than one route and each request is assigned to only one vehicle or is ignored. Finally, the best routes found for each vehicle and request are saved as a SUMO route file, which can be used as input for further simulations.

4 Results and discussion

The results of the simulations for each scenario are first presented and then discussed. The six different towns were grouped into three areas for an easier visualization of the results. In the following the results of Vechelde includes the towns of Vechelde, Vechelade and Wahle. The towns of Wedtlensted and Denstorf are grouped together as Denstorf and Lamme refers to the town with the same name.

4.1 Scenario 0: current public transport system

According to the simulation a complete trip with the bus line 450 with direction Vechelde-Brunswick takes in average 40 minutes. The bus is only 45 % of this time in motion without disturbances, 32 % of the time standing at bus stops and the remaining 22 % of the time is driving below the ideal speed. The bus line has a frequency of 30 minutes and a round trip of approx. 80 minutes, which requires a fleet of minimum three vehicles. The capacity of the bus line is approx. 200 passengers per hour and direction (adopting standard buses of 12 m) and the service area has a total of 26,347 inhabitants.

In the simulation different person trips from the respective home to the city center with the bus line 450 or 418 in case of Lamme were analyzed. Denstorf and Lamme show similar results for walking time to the nearest bus stop with average 5 minutes and maximal length of 800 m. Vechelde (Wahle not inclueded) shows higher values with 9 minutes average and a maximal length of 2,250 m. These results exceed the commonly adopted values of 400 m or the equivalent of 5 minutes as an acceptable walking distance [34, 14, 26]. Trips to the bus stop by bicycle were not considered as there is no existing parking infrastructure. The travel time with the respective bus line to the city center is on average 33 minutes from Vechelde, 27 minutes from Denstorf and 24 minutes from Lamme.

In this scenario, private car trips between the respective home and the city center were also evaluated. The travel times vary for this mode between 14 and 17 minutes. The parking search time should be as well consider. This value is in average 6 minutes according to the results from [15], in which the time lost in searching for a parking space in 10 cities in Germany were analyzed.

4.2 Scenario 1: proposed public transport system

The travel time for a complete trip in direction Vechelde-Brunswick with the BRT is on average 21 minutes. 56 % of this time the BRT bus is in motion without disturbances, 28 % of the time is standing at bus stops and the remaining 28 % of the time is driving below the ideal speed. For the adopted frequency of 15 minutes a fleet of at least four vehicles is required. The service area of the proposed system comprises 43,538 inhabitants thanks to the incorporation of Wahle and Lamme. The BRT system was designed to operate with articulated buses and has a capacity of 620 passengers per hour and direction.

The use of each DRT vehicle varies significantly. The DRT Vechelde uses one vehicle only 6 % of the time, whereas two vehicles are needed 46 % of the time to cover the demand. Finally, the complete fleet of three vehicles are used the 47 % of the time. In Lamme 46 % of the time the use of the two vehicles was mandatory. The results for the DRT Denstorf show lower values, with the use of the two vehicles only the 16 % of the time. These differences in the fleet utilization arise mainly from the function of the algorithm to avoid the use of multiple vehicles, when similar costs with one vehicle can be achieve. According to the simulations, the DRT systems show a good shareability potential. The vehicles of the DRT Lamme and Vechelde

Metric	Current system	Proposed system
Frequency [min]	30	15
Travel time (one-way) [min]	40	21
Fleet size [veh]	3	4
Capacity [p/h/d]	200	620
Service area [inhab]	26,347	43,538

Table 1: Current bus line vs. BRT

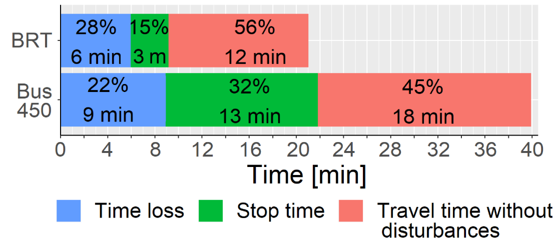

Figure 3: Travel time distribution for buses

transport at least four passengers more than 60% of the time. Up to 9 requests for Vechelde and 7 requests for Denstorf and Lamme could be combined in one trip. Regarding the low demand values of the DRT Denstorf, the system serves four or less passengers the 85% of the time.

In the proposed public transport system a trip to the city center consists of two legs. The first leg is the trip from the respective home to the mobility hub, which is made by bicycle or with the DRT feeder service. The second leg represents the trip with the BRT line from the mobility hub to the city center. The average cycling time varies between 4 and 6 minutes depending on the location. Vechelde shows the longest trip with a length of 3 km and a travel time of 10 minutes. Most bike-and-ride users are willing to travel about 2.5 km (and up to 5 km for faster modes) to a public transport stop [42, 1, 30]. However, this willingness is strongly associated with cycling facilities and safety, which underlines the importance of investment in cycling infrastructure. The three DRT feeder systems showed similar results. The travel time takes on average 5 minutes and has a standard deviation of 3 minutes. The waiting time at the mobility hub was on average 4 minutes with a 3 minutes standard deviation. All simulated persons could transfer without problems from the DRT to the desired BRT bus. The travel time with the BRT line is on average 17 minutes from Vechelde, 15 minutes from Denstorf and 12 minutes from Lamme with standard deviations of less than a minute.

4.3 Current vs. proposed transport system

Based on the simulation results, the BRT line shows a more efficient service compared to the current bus line 450. The travel time for a complete trip with direction Vechelde-Brunswick was reduced by 52 %, from 40 to 21 minutes. This is primarily due to an important reduction of the number of scheduled stops. This travel time improvement allows to double the frequency with only one more vehicle in the fleet. Thanks to the connection of Lamme and Wahle to the BRT line the service area increased by 67 % (17,191 inhabitants). The construction of a BRT corridor in the city center makes the system independent of congestion and other disturbances that could cause delays. Lower travel times could be achieved by the implementation of transit signal priority. Figure 3 and table 1 summarize the main characteristics of both public transport lines.

The proposed transport system also includes the DRT service. The DRT simulation results show that the entire fleet is used only half the time. The DRT Denstorf shows, due to its low demand values, worse results with a use of both vehicles only 16 % of the time. The decrease of the number of vehicles (even by adopting vehicles with higher capacity) is not possible, as the ability to combine requests and therefore the capacity of the entire service would be strongly reduced. A possible option to improve the use of vehicles and the trips shareability would be to group orders in 30 minute intervals instead of 15. This would, however, mean an important decrease in the service quality for the user. Another proposal would be to evaluate the performance of the service by defining a single service area, with a single fleet serving all 3 hub stations independently. Regarding the higher operating costs due to drivers, several studies considered that autonomous vehicles could provide considerable cost and service advantages [25, 36]. However, other authors assume that these advantages will in turn be lost due to increased maintenance and cleaning costs of these vehicles [12].

The travel times from the respective home to the city center show important improvements. Figure 4 summarizes the average travel times with the different transport modes depending on the origin of the trip. Regarding the difficulty of defining their values, the waiting times at stops and the parking search time for trips with the private car were not considered. In all three cases, the travel times with the proposed public transport system were significantly reduced, being even competitive with the private car. This was possible due to the implementation of the BRT corridor in the urban area, allowing buses to avoid congestion. In the case of Vechelde, the average travel time was reduced by 45 % from 40 minutes with the bus line 450 to 22 minutes with the proposed system. For Denstorf the travel time reduction resulted in 33 % and for Lamme in 38 %. The use of the DRT system or bike for the first/last mile shows similar travel times. Although the average cycling times for Lamme and Denstorf are slightly higher than the walking times to the current bus stops, the overall values show an increase in the transit area of influence. The maximum walking distance recorded was 800 m, which is higher than the conventional willingness value of 400 m. In contrast, the registered cycling distances are up to 2.4 km, being lower than the range of 2.5 to 5 km associated with the willingness to cycle.

Another important difference between both systems is the implementation of mobility hubs. Due to the limited supply of services in the study area, the incorporation of service amenities in the mobility hubs, such as mail/courier services, ATM and kiosks, makes traveling via the offered mobility services efficient and convenient.

5 Conclusion and future work

The increase in the number of private vehicles has led to a sharp rise in traffic and environmental pollution as well as a lack of appropriate public space management in cities. In rural and peri-urban areas, the private vehicle is still the main mode of traffic. This is mainly due to inefficient public transport services, which are characterized by long and indirect routes, limited schedules and low frequency. This situation could be enhanced by the implementation of DRT as a feeder system for high capacity public transports.

In this paper the optimization potential of the public transport service in a peri-urban area of the city of Brunswick (Germany) was analyzed. As proposal, the existing bus service was replaced by a BRT line with DRT feeder systems. For the comparison of both public transport service, simulations were conducted using the microscopic traffic simulation SUMO. The simulation of the DRT feeder was performed by coupling SUMO with a developed algorithm. This determined the best vehicle routes based on the requests, the available vehicles and the network. As metrics the average travel times on a typical Tuesday/Thursday day with the different transport modes were used. For that, a series of trips with origin at the respective home and destination in the city center were generated using different demand profiles. The demand was modeled only on the basis of demographic characteristics. To compare the current bus line and the BRT line, the travel time between the route start and end was evaluated. Other design parameters like capacity and frequency were also assessed.

The simulation results show the potential and advantages of the proposed public transport system. The travel times from the respective home to the city center were on average reduced

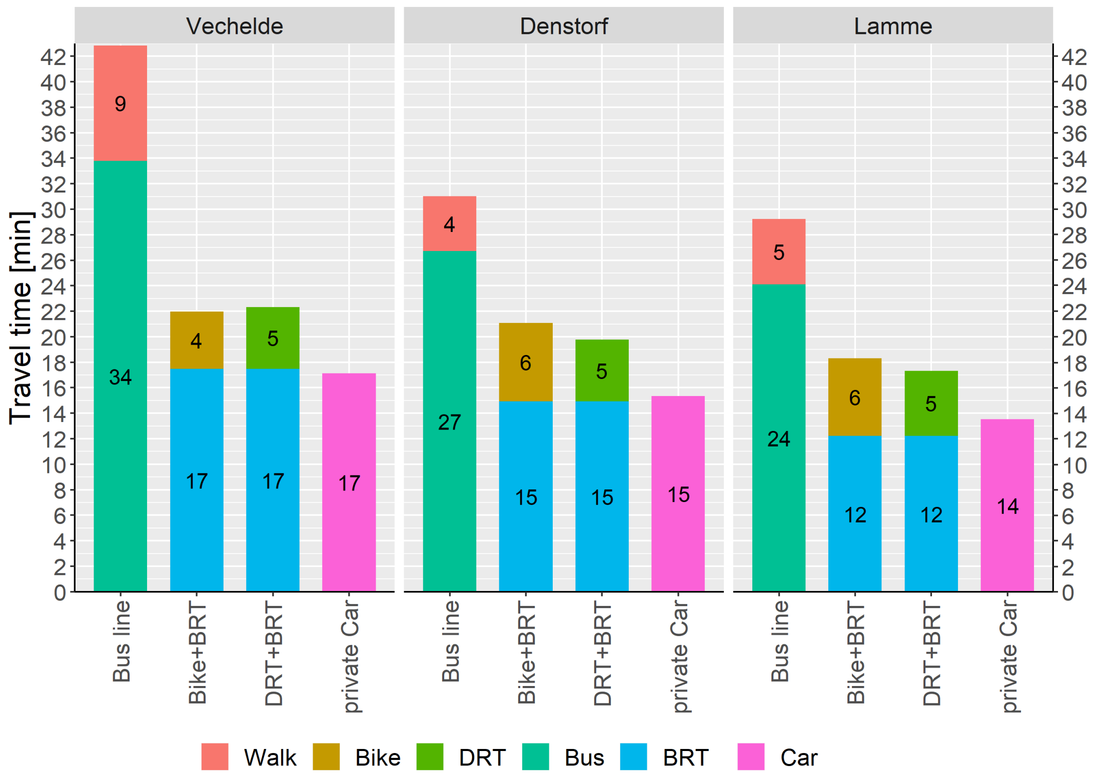

Figure 4: Travel times home-city center with the analyzed transport modes

by 45 % for Vechelde, 33 % for Denstorf and 38 % for Lamme. Considering the time-loss due to searching a parking spot, the travel times with the proposed public transport are similar to the travel times with the private car. The increase in frequency from 30 minutes to 15 minutes and the implementation of mobility hubs with different amenities (e.g. secured bike parking, parcel lockers and kiosks) make the system more attractive for costumers. The reduction of the round trip travel times of the BRT line allows for a frequency of 15 minutes with only 4 buses. The construction of a BRT corridor in the urban area provide for a fast route without time-losses due to traffic and it can be served by multiple bus routes. Travel times could be still reduced by integrating transit signal priority.

According to the simulations, the three adopted DRT feeder systems show low travel times to the mobility hub and waiting times for the BRT line. This paper assumed a specific service area for each DRT feeder system, so they work independent from each other. In this respect, further analysis of the DRT feeder systems under different service areas or working as a unique system are relevant for further optimization.

The higher costs of the proposed transport system due to the bigger fleet and the increased mileage could be counteracted by a potential increase in ridership. This not only given because of the larger service area by the append of two more towns, but also by a better quality of service due to faster and comfortable connections. To asses the economic viability of the system, a cost-benefit analysis should be done. Therefor a detailed modeling of the demand and a mode choice model should be developed.

The proposed system is not intended to operate alone but to be a part of an extensive BRT network with DRT feeders for the city of Brunswick. In consequence a viability analysis of such a system network in a macro- or mesoscopic level is also recommended.

Acknowledgement

The present paper was written in the framework of the HubChain project, which is funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) under the Electromobility program "IKT für Elektromobilität". Further information about the project can be found at www.hubchain.de.

References

[1] Federal Transit Administration. Final policy statement on eligibility of pedestrian and bicycle improvements under federal transit law. 2011.

[2] J. Alonso-Mora, S. Samaranayake, A. Wallar, E. Frazzoli, and D. Rus. On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment. January 2017.

[3] P. Alvarez Lopez, M. Behrisch, L. Bieker-Walz, J. Erdmann, Y. Flötteröd, R. Hilbrich, L. Lücken, J. Rummel, P. Wagner, and E. Wießner. Microscopic traffic simulation using sumo. In *The 21st IEEE International Conference on Intelligent Transportation Systems*. IEEE, 2018.

[4] M. G. Armellini. *Optimierung der Buslinie 450 in Braunschweig durch On-Demand-Zubringer*. Master thesis. Fachhochschule Münster, July 2019.

[5] Westfalen Bahn. *Fahrpläne und Liniennetzpläne*. https://www.westfalenbahn.de/fahrplaene/linienfahrplaene/. Accessed: 03.05.2019.

[6] BASt. *Dauerzählstelle: Groß Lafferde 2018*. Bundesansatalt für Straßenwesen. https://www.bast.de. Accessed: 08.03.2019.

[7] J. Bischoff, M. Maciejewski, and K. Nagel. *City-wide shared taxis: A simulation study in Berlin*. IEEE 20th International Conference on Intelligent Transportation Systems (ITSC), 2017.

[8] BMVI. *Mobilitäts- und Angebotsstrategien in ländlichen Räumen: Planungsleitfaden für Handlungsmöglichkeiten von ÖPNV-Aufgabenträgern und Verkehrsunternehmen unter besonderer Berücksichtigung wirtschaftlicher Aspekte flexibler Bedienungsformen*. Bundesministerium für Verkehr und digitale Infrastruktur (BMVI), 2016.

[9] D. Bosserhoff. *Ver_Bau: Abschätzung des Verkehrsaufkommens durch Vorhaben der Bauleitplanung mit Excel-Tabellen am PC*. 2012. https://www.dietmar-bosserhoff.de/Programm.html.

[10] Stadt Braunschweig. *Einwohnerzahlen nach Stadtbezirken*. https://www.braunschweig.de/politik_verwaltung/statistik/ez_stadtbezirke.html. Accessed: 03.03.2019.

[11] Stadt Braunschweig. *Verkehrsmengenkarte für Braunschweig*. https://www.braunschweig.de/leben/stadtplan_verkehr/verkehrsplanung/verkehrsmengenkarten.html. Accessed: 11.03.2019.

[12] P. Bösch, F. Becker, H. Becker, and K. Axhausen. *Cost-based analysis of autonomous mobility services*. Transport Policy (64), 2018.

[13] W. Canzler. *Warum wir vom Auto abhängig sind. Neuere Ergebnisse aus der sozialwissenschaftlichen Mobilitätsforschung*. TUM-Vortragsreihe Verkehr aktuell, München, June 2008.

[14] R. Cervero. Walk-and-ride: Factors influencing pedestrian access to transit. *Journal of Public Transportation*, 3:1–23, 09 2001.

[15] G. Cookson and B. Pishue. *Deutsche Verschwenden 41 Stunden Im Jahr Bei Der Parkplatzsuche*. INRIX Research (21), 2017. http://inrix.com/press-releases/parking-pain-de. Accessed: 15.04.2019.

[16] J. Cordeau and G. Laporte. *The dial-a-ride problem: models and algorithms*. Annals of Operations Research (153), September 2007.

[17] P. Czioska, R. Kutadinata, A. Trifunović, S. Winter, M. Sester, and B. Friedrich. *Real-world Meeting Points for Shared Demand-Responsive Transportation Systems*. 2017.

[18] DLKG. *Dörfer ohne Menschen!? - Zwischen Abriss, Umnutzung und Vitalisierung*. Deutschen Landeskulturgesellschaft (DLKG), Würzburg, 2009.

[19] EAR. *Empfehlungen für Anlagen des ruhenden Verkehrs - EAR 05*. Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), Köln, 2005.

[20] S. Feigon, C. Murphy, and T. McAdam. *Private Transit: Existing services and emerging directions*. The National Academies Press, Washington, DC, 2018.

[21] J. Feilbach. *Der Weg zur Arbeit: Verkehrsmittelnutzung in Berlin im Kontext soziostruktureller Merkmale*. Zeitschrift für amtliche Statistik Berlin Brandenburg, Berlin, 2018.

[22] M. Gather, A. Kagermeier, and M. Lanzendorf. *Geographische Mobilitäts-und Verkehrsforschung*. Geographische Rundschau (55), 2009.

[23] GEWOS. *Wohnraumversorgungskonzept für den Landkreis Peine*. Institut für Stadt-, Regional- und Wohnforschung GmbH (GEWOS), 2016. https://www.landkreis-peine.de/media/custom/2555_3584_1.PDF?1504185657. Accessed: 23.01.2019.

[24] C. Helmert and K. Henninger. *Mobilitätsbefragung: Untersuchung zum werktäglichen Verkehrsverhalten der Bevölkerung in der Stadt Duisburg*. February 2016. https://www2.duisburg.de/micro2/pbv/medien/bindata/Kurzbericht_Duisburg.pdf. Accessed: 23.01.2019.

[25] HSL. *Kutsuplus-Final Report*. Helsinki Regional Transport (HSL), 2016. https://www.hsl.fi/sites/default/files/uploads/8_2016_kutsuplus_finalreport_english.pdf. Accessed: 19.02.2019.

[26] J. Larsen, A. El-Geneidy, and F. Yasmin. Beyond the quarter mile: Examining travel distances by walking and cycling, montréal, canada. 01 2010.

[27] G. Löcker and B. Friedhelm. *Differenzierte Bedienungsweisen : Nahverkehrs-Bedienung zwischen großem Verkehrsaufkommen und geringer Nachfrage*. Düsseldorf : Alba-Fachverl., 1994.

[28] M. Lokhandwala and H. Cai. *Dynamic ride sharing using traditional taxis and shared autonomous taxis: A case study of NYC*. Transportation Research Part C: Emerging Technologies, December 2018.

[29] J. Mageean and J. Nelson. *The evaluation of demand responsive transport services in Europe*. Journal of Transport Geography (11), 2003.

[30] K. Martens. The bicycle as a feedering mode: Experiences from three european countries. *Transportation Research Part D: Transport and Environment*, 9:281–294, 07 2004.

[31] S. Mitchell, M. OSullivan, and I. Dunning. *PuLP : A Linear Programming Toolkit for Python*. 2011. https://github.com/coin-or/pulp.

[32] Stadt Münster. *Verkehrsverhalten und Verkehrsmittelwahl der Münsteraner: Ergebnisse einer Haushaltsbefragung im Herbst 2013*. https://www.stadt-muenster.de/sessionnet/sessionnetbi/vo0050.php?__kvonr=2004037493. Accessed: 06.04.2019.

[33] M. Mörner. *Sammelverkehr mit autonomen Fahrzeugen im ländlichen Raum*. Dissertation. Technischen Universität Darmstadt, Darmstadt, 2018.

[34] C. Mulley. Explaining walking distance to public transport: The dominance of public transport supply. *Journal of Transport and Land Use*, 6, 01 2011.

[35] NWSIB-NI. *Online-Auskunft der Straßeninformationsbank Niedersachsen*. Straßeninformationsbank Niedersachsen (NWSIB-NI). https://www.nwsib-niedersachsen.de/application.jsp.

[36] M. Pavone. *Autonomous mobility-on-demand systems for future urban mobility*. Springer, 2015.

[37] B. Schaller. *The New Automobility: Lyft, Uber and the Future of American Cities*. 2018. Available at http://www.schallerconsult.com/rideservices/automobility.pdf.

[38] G. Schöfl, M. Schöfl, and S. Speidel. *Kommunales Flächenmanagement im Ländlichen Raum: die*

Aktivierung ungenutzter Gebäude und Bauflächen am Beispiel MELAP, volume 71. Flachenmanagement und Bodenordnung (71), 2009.

[39] L. Schnieder and K. Lemmer. *Anwendungsplattform Intelligente Mobilität - eine Plattform für die verkehrswissenschaftliche Forschung und die Entwicklung intelligenter Mobilitätsdienste*. Deutsches Zentrum für Luft- und Raumfahrt e.V., Braunschweig, April 2012.

[40] J. Schwieterman and C. Smith. *Sharing the ride: A paired-trip analysis of UberPool and Chicago Transit Authority services in Chicago, Illinois*. Journal of the Transportation Research Forum (57), November 2018.

[41] B. Steinrück and P. Küpper. *Mobilität in ländlichen Räumen unter besonderer Berücksichtigung bedarfsgesteuerter Bedienformen des ÖPNV*. Arbeitsberichte aus der vTI-Agrarökonomie, 2010.

[42] D. Taylor and H. Mahmassani. Analysis of stated preferences for intermodal bicycle-transit interfaces. *Transportation Research Record Journal of the Transportation Research Board*, 1556:86–95, 01 1997.

[43] Gemeinde Vechelde. *Einwohnerzahlen Vechelde*. https://www.vechelde.de/allgemeine-informationen/einwohnerzahlen. Accessed: 16.04.2019.

[44] Braunschweiger Verkehrs-GmbH. *Fahrpläne und Liniennetzpläne*. https://www.verkehr-bs.de/fahrplan/fahrplaene-und-netzplaene.html. Accessed: 15.01.2020.

[45] R. Winkel. *Öffentliche Infrastrukturversorgung im Planungsparadigmenwandel*. Informationen zur Raumentwicklung, 2008.