Brunswick simulation scenario for virtual-stops based DRT service with SUMO

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Abstract

This paper presents a general simulation scenario with SUMO of the City of Brunswick, Germany, was set up using traffic network data from OSM and the traffic demand from TAPAS (TAPAS 2017). In this paper the developed simulation scenario is published for other researchers to use and extend. A simulation scenario has been set up and evaluated. The developed scenario includes a simulation of the whole city area of Brunswick.
Furthermore, key performance indicators (KPIs) have been chosen to find optimal positions for virtual bus stops for autonomous shuttles. The simulation scenarios give findings of the effect of the position of a virtual bus stop on the traffic flow and the traffic safety. In combination with the walking time to this stop these KPIs give a decision basis for the position of the stop.

Keywords: *Intelligent transport systems (all modes), Simulation environments and new modeling tools*

1. Introduction

Autonomous shuttles can have a positive impact on traffic safety and efficiency in large cities. Flexible public transport stations can reduce the walking distances and waiting times for passengers and therefore improve the attractiveness of this traffic mode. The projects SHOW[1] and ViVre[2] are investigating the influence of autonomous shuttles on the traffic state, evaluating real world test sites and simulating the traffic scenarios with the microscopic traffic simulation "Eclipse SUMO" (Alvarez et al., 2018). The simulation framework SUMO is able to simulate different traffic modes e.g. cars, bikes, pedestrians. SUMO is developed since 2001 and is open-source. Therefore, it is used in many traffic research projects.

But also, the best simulation software is useless without a realistic traffic scenario. A lot of effort in traffic research is used for the set up of simulation scenarios. To make it easier for researchers to focus on their research studies and do not waste time for preparing a scenario, the Brunswick simulation scenario of this paper is made publicly available.

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[1] https://show-project.eu/ last access 14. May 2021
[2] https://verkehrsforschung.dlr.de/de/projekte/vivre-virtuelle-haltestellen-fuer-den-automatisierten-verkehr-der-zukunft last access 14. May 2021

1.1 Virtual stops

A virtual stop is a non-fixed (as in flexible, unestablished and movable) place where vehicles are able to briefly stop in order to pick-up or drop-off passengers. These sites are not necessarily tied to any infrastructure (hence the name *virtual*), do not have to be structurally recognizable and may vary according to passenger- or vehicle requirements / needs.
On principle, virtual stops can be placed almost everywhere a vehicle and pedestrian have access to. A large variety of places may be preferred, such as bus stops, dead ends, access roads, auxiliary lanes, public parking areas, etc.; it does not mean that every available stopping site automatically qualifies as a virtual stop, some conditions must be met. These conditions vary on a use-case basis, and could be broadly classified under user, vehicle, scheduling and traffic requirements / preferences. If for a certain area multiple potential virtual stops can be identified, a ranking of the stops should be performed, according to the desired conditions, weighting each requirement correspondingly.

1.1.1 Advantages and disadvantages

Using demand-responsive stops can have multiple advantages. Stopping places being now a variable, may allow some route optimizations -this is especially appealing to demand-responsive transports (DRTs) and shared DRTs (SDRTs)- reduce walking distances, offer more attractive and secure stops for people with special needs, and so on. Not being committed to a fixed location also enables the ability to consider real-time traffic, road and meteorological conditions, and modify the stopping places accordingly. Reducing *service time* (time spent boarding and de-boarding) is now possible by grouping nearby passengers into one virtual stop (here known as *meeting point*) rather than having multiple door-to-door stops, this is beneficial for SDRT services (Czioska, P. *et al.*, 2019).
On the other hand, by not relying on well-established, known and marked stops, it may occur that in some cases users would find themselves not able to locate the stops. In addition, well curated and updated data in order to select and rank the virtual stops is also crucial.

1.1.2 Assessing a virtual stop

In order to reckon the suitability of a certain virtual stop, some key aspects may be evaluated and compared to other virtual stops and to preset values. Depending on the case, some features will prevail over others. This assessment occurs on a case by case basis and depends on the desired requirements for an optimal virtual stop, for each case. Some aspects to consider can be (according to different points of view):
User-related (passenger)
- Be easy to find and access, convenience, short walking distance, safe and easy to hop on / get off, seating availability, proper lighting, safety, accessibility-related needs, roofing, etc.

Vehicle-related
- Have enough space to stop, stopping is permitted, easy to locate, etc.

Scheduling-related
- Short routes, fewer detours, fewer stops, high occupancy, etc.

Traffic-related

- Cause little to no obstruction, low impact to other road users, have good visibility, safety, etc.

1.1.3 Applications and future use cases

Virtual stops are going to be the key to optimize SDRT systems, no matter using autonomous shuttles or not. Operational efficiency (dead mileage, idle hours, number of vehicles used) could be improved as shown by the simulation experiment by Czioska, P. (2018), who also considered the city of Brunswick, where he found that the higher the demand, the more appealing are the benefits for SDRT systems to switch to a meeting point based model of operation instead of the currently used *doorstep*-model.

In the case of autonomous SDRT systems, a database of possible virtual stops, a well thought ride booking system and real-time data will be essential to determine and rank the stop-candidates and choose the one that best suits all actors involved (mainly the users and the vehicle). Data here is crucial, autonomous vehicles cannot take decisions without very clear input.

As for the users, they would benefit from having stops selected to fulfill all their special needs and preferences. In the future, local public transport could offer such a SDRT service using virtual stops, requiring balancing user comfort and influence on surrounding traffic, on a much bigger scale.

2. Simulation Scenarios

2.1 Brunswick Scenario

The scenario simulates the motorized individual traffic for a typical working day in the city of Brunswick, Germany. The scenario is publicly available on the GitHub site of the Transportation Systems institute (DLR-TS)[3]. In order to build a simulation scenario with SUMO, it is necessary to define a network file, containing the information about the roads, intersections and traffic infrastructure, and a route file with the traffic demand.

2.1.1. Traffic Network

The network of the Brunswick scenario was imported from OpenStreetMap (OSM) using the SUMO tool Netconvert. The initial import from OSM into a SUMO network is fast, but the manual correction, especially for large traffic networks, is very time-consuming. OSM contains different geo data, which are not all relevant for traffic networks. Netconvert enables the user to filter the data that should be imported in SUMO and how it should be processed, in case of lack of information in some elements.

The first important modification is the use of a SUMO edge type file. This file specifies which OSM road types should be imported and assigns default values to certain attributes of the road type. If an OSM element does not contain information about an attribute, the specified default values will be used.

[3] https://github.com/DLR-TS/sumo-scenarios/tree/master/brunswick/miv last access 14. May 2021

Besides, multiple options for the processing with Netconvert can be given. For example, if a scenario of only car-based modes is to be set, the option keep-edges.by-vclass allows keeping only the edges that allow the vehicle class passenger.
Sometimes, the imported network in SUMO is not precise enough or the information in OSM contains errors and manual modifications are needed. Netconvert allows working with patch files, where the changes needed to be done in the network can be specified and will be taken by Netconvert. For each element of the network (i.e., edges, nodes, connections and traffic lights, which are defined as tllogic), a file is needed. For example, if the number of lanes of an edge have to be changed, this must be specified in the edge-files. Since the SUMO networks imported from OSM are geo referenced, the editing of the network is easier thanks to the fast searching of the area to edit in a web mapping tool (e.g. Google Maps, Bing Maps).
Other infrastructure elements like public transport stops and lines can also be imported from OSM. While the quality of street networks for vehicles is very good in OSM, the available information of pedestrian and bike infrastructure is sometimes lacking. Another option to build such lanes, would be to add restrictive lanes for pedestrians or for bicycles to certain types of edges. This can be specified in the SUMO type file using the attribute sidewalkWidth.
Since the Brunswick scenario simulates motorized individual traffic, only the edges allowing this classes and trams were imported. The tram infrastructure was imported for a more realistic model of the intersections. The SUMO network is shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** and consists of 5,361 nodes and 11,773 edges. The yellow boxes in the network represents the induction-loop detectors, which will be explained in section '2.1.3 Simulation'.

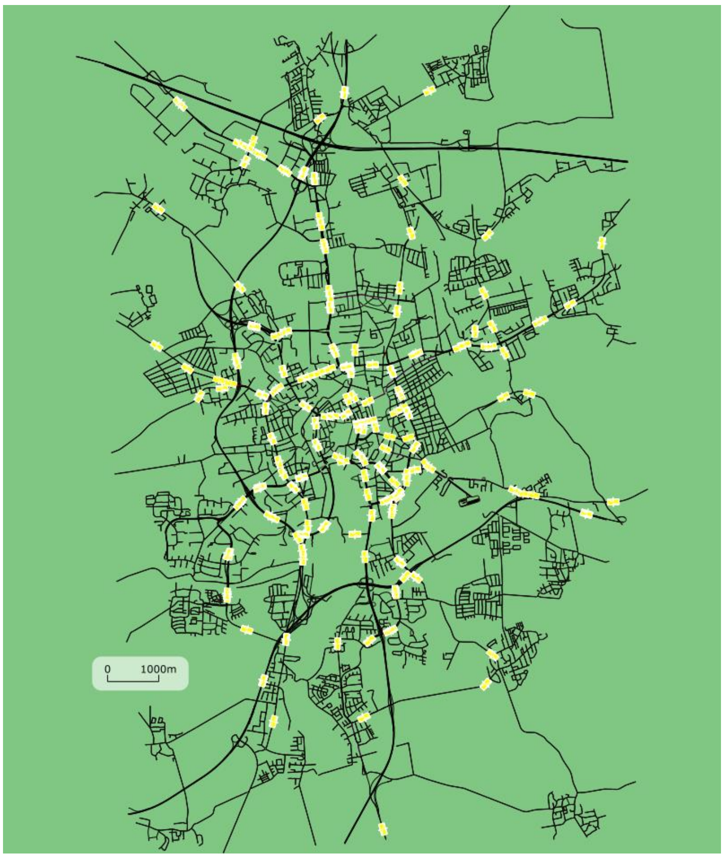


Figure 1 Brunswick scenario: sumo network

2.1.2 Traffic Demand

The traffic demand of the Brunswick scenario was modeled with the agent-based simulation model "TAPAS" (Hertkorn, 2005; Heinrichs et al., 2016). The model was done in a mesoscopic level and for a major region, which includes the city of Brunswick. TAPAS describes the mobility behavior of a modeled population. Each person of the population contains socio-demographic attributes and follows an activity plan. For each activity that the person aims to perform, the destination and the transport mode are determined. The result is a trip chain along the day for every modeled person, where each trip consists of the departure time and the georeferenced origin and destination points.
Once the traffic network for the Brunswick scenario was ready, the TAPAS demand was imported and adapted to the scenario using the SUMO tool cutRoutes.py. For the Brunswick scenario, only the trips with the mode motorized individual traffic were considered. The demand consists of 637,703 trips, with the first trip departing at 3:40 am and the last one at 4:03 am of the next day.

2.1.3 Simulation

As mentioned before, the demand of the Brunswick scenario is defined as trips, consisting of a departure time and origin and destination points. The actual route of each vehicle is determined using the oneShot Dynamic Traffic Assignment with the re-routing option. Each vehicle calculates at its time of departure the fastest-path considering the current traffic state. If the traffic condition changes along the route and the vehicle can find another faster route to its destination, the vehicle will perform a rerouting decision and change its route.
To analyze the performance of the simulation, the simulated traffic volumes were compared to the traffic volumes of 2019 from traffic counters. Traffic flow data from 231 counters in the area of Brunswick was available. The traffic volumes for each traffic counter were analyzed and aggregated in 30 minutes interval. Since the counters have different frequency, the adoption of a 15 minutes interval for all counters was not possible. After the analysis of the data, only 129 counters from the 231 had valid data for 2019.
To be able to compare the results of the simulation, each traffic counter was imported as an induction loop detector in SUMO using its geolocation. The detectors are shown in yellow in **Fehler! Verweisquelle konnte nicht gefunden werden.**. According to the SUMO edge-type, 31 detectors are located on tertiary-edges, 60 on secondary-edges, 31 on primary-edges and 7 detectors are located on motorway-edges.
The GEH statistic was used to compare the real-world traffic counts with the simulation. The GEH is commonly used to compare two sets of traffic volumes and considers both the absolute difference and the percentage difference between the modelled and the observed flows. The GEH is calculated according:

$$GEH = \sqrt{\frac{2(M-C)^2}{(M+C)}}, \qquad (1)$$

where M is the hourly traffic volume from the traffic model and C is the real-world hourly traffic count.
Since the GEH compares hourly traffic volumes, both traffic volumes from the real-world and from the simulation were aggregated in an hour interval starting at 5 am.

2.3 Virtual Stops

After preparing the simulation scenario of the City of Brunswick including the OSM-based net and the traffic demand of TAPAS, this scenario can function as a basis for many traffic studies. As an example, the evaluation of the virtual stops is based on this simulation scenario. This evaluation is a first concept and shall concentrate on the positioning of the virtual stop and the impacts on the traffic. Especially the microscopic simulation enables to analyze the impact on the traffic safety, the traffic flow and the itinerary of the user. Of course, there are further aspects as the covered distance of the shuttle, but this paper concentrates on the previous mentioned.
To compare two or more alternative stops, the size of the evaluated area should be the same for the measurement of the appropriate values. For this purpose, a radius around the location of a user request is defined which is large enough to include all possible stops and the current traffic. That gives the opportunity to directly compare the results of the measurements. Another possibility is to measure within an area around the stop and compare the result with the use-case without a stop (comparative case). To compare different stops, the differences between the use-cases with stops and their associated comparative use-cases are used. Since the stops to be compared are nearby the first option is sufficient for the examination in this paper.

2.3.1 Traffic Safety

Generally, the standard car-following models used in SUMO are collision-free. That means an evaluation of accidents does not make sense with the simulation. Instead, there are various safety measures which describe critical situations without accidents. As an example, the post-encroachment time (PET) describes the time two vehicles miss at a junction (Laureshyn, 2010). Under a certain threshold the situation is meant to be critical (Qi, 2020). The number of such critical situations are possible to use as a measure of traffic safety. SUMO allows to measure various safety measures with the help of the device for safety surrogate measures (SSM device). Currently, the SSM device can measure the time to collision (TTC) (Laureshyn, 2010), the deceleration rate to avoid a crash (DRAC) (Fazekas, 2017), the post-encroachment time (PET), the brake rate (BR), the spacing (SGAP) and the time headway (TGAP). If the results exist of a scalar value, it would be the easiest case to compare the results for determining traffic safety degree. Then, higher values would mean lower safety degree and vice versa. Many of the safety surrogate measures computed by SUMO are sensitive to similar situations. Therefore, a small selection of safety measures could be enough to describe the effects of the stop locations on the traffic safety. Only the PET describes critical situations for crossing vehicles on junctions. All other measures are sensitive to car-following situations, i.e. it is enough to have only one of these in order not to count the same critical situations multiple times. The measure that suits best to the PET seems to be the TGAP in SUMO. If the acceleration of the vehicle of the PET measure is a=0, both measures describe the time, that the vehicle needs to reach the position of the crossing or leading vehicle, respectively, at that moment. Since, in general, the acceleration is small, it is expected that the difference between the measures of the TGAP, as relation between the spacing and the current speed, and as measured time the vehicle needs to reach the current position, is relatively small. A detailed examination in on going work can confirm this assumption. For the moment, the sum of the number of different situations with critical PET and the number of different situations with critical TGAP defines the traffic safety in this study.

Due to the similarity of the two measures, the same threshold holds for both measures. (Archer, 2005) indicated a threshold for the PET of 1s - 1.5s. (Qi, 2020) tried to determine the threshold for the PET that makes it critical. Although the 15%, 50% and 85% quantile values of the measured values are arbitrarily chosen, the authors get four levels of conflict: *serious conflict* (0-0.7s), *general conflict* (0.7s-1.31s), *slight conflict* (1.31s-2.25s) and *potential conflict* (greater than 2.25s). To make the simulation very sensitive to situations with a conflict, for the simulations study the threshold is set to 3s.

2.3.2 Traffic Flow

To determine the traffic flow, different possible measures are existing. Not all are generalized to all traffic situations such as waiting times at junctions, length of traffic jams, mean speeds etc. and therefore unsuitable for generic scenarios. In contrast, the mean time loss seems to be a good candidate. The time loss at an edge is defined as the sum over the time differences between the time a vehicle needs to drive through the edge with its desired speed and without stopping at junctions and the time that vehicle needs to drive through the edge when encountering other road users. The mean time loss over all vehicles and all edges within the investigated area should well reflect the delays in the traffic flow caused by the stop of the vehicle providing DRT service.

2.3.3 Itinerary of the User

To evaluate the itinerary of the user, different possible measurements can be used. One of them is the length of the itinerary. But this ignores possible waiting times at junctions for crossing. Since a scalar value is desirable for an easier comparison, the duration for the itinerary is used as indicator, which considers both the length of the itinerary and waiting times at junctions. For a later study, an individualization by changing the speed of the simulated user is possible for better reflecting situations in the reality.

2.3.4 Further Measures

There are more possible indicators to evaluate the position of a stop, such as the time the shuttle needs to go to the stop from its origin and subsequently the time the shuttle needs to go to its original destination. For that the route of the shuttle is needed. To prepare and include complete routes would make the study much more complex and is out of the scope of this paper.

2.3.5 Implementation in SUMO

The measures for the traffic safety and the traffic flow strongly correlates with the traffic in the simulation. This traffic should be as realistic as possible to get meaningful results. If there is no data for calibrating the traffic, the result of the TAPAS model gives at least a general input. The overall simulation scenario, mentioned in 2.2, does not include subordinate roads, while many stops locate on side streets. Due to that, the simulation network is extended by adding all subordinate roads and canceling the patches that do not work with these changes. When measuring the itinerary of a user it is actually also needed to consider the respective sidewalks. Since the information about sidewalks are often missing in OSM, walking on subordinate roads is allowed in the simulation.

In SUMO a so-called *busStop* marks the position of a stop in the net. One possibility to define a vehicle's stop within its route file is to specify a predefined *busStop*. Setting the attribute *parking* of the vehicle stop true or false makes the vehicle stop next to the lane (such as stopping at a parking or at an extra lane for a bus stop) or on the lane. If a sidewalk, used by a pedestrian, is not part of the edge with the stop, accesses must be made available to connect the *busStop* and the sidewalk.

During simulation, SUMO writes time loss information to an output file, if the respective configuration file contains so-called *edgeData* definition within the additional files. Setting the *timeLoss* to the attribute makes SUMO to calculate and aggregate the time loss of each simulation step for all edges and output the result to another file. After filtering the edges of the output by the edges within the considered area, the sum of the time loss of these edges is divided by the sum of *left* and *arrived* vehicles of these edges. The number of left and arrived vehicles are also part of the *edgeData*.

To get the safety surrogate measures all vehicles need an SSM device. As example, the following definition of a tripinfo-device within the SUMO configuration file is responsible for that:

```
<tripinfo-device>
   <device.ssm.probability value="1"/>
   <device.ssm.measures value="PET TGAP"/>
   <device.ssm.thresholds value="3 3"/>
   <device.ssm.file value="conflicts.out.xml"/>
   <device.ssm.filter-edges.input-file value="SSMEdges.txt"/>
</tripinfo-device>
```

The specification of an edge input file restricts the measurement of the conflicts to the given list of edges. Since the movements of the vehicles depends on the setting of random numbers and several parameters will be affected, such as the used *speedFactor* or the attribute *sigma* within the car-following model, many simulation runs with different random number seeds are needed. The number of runs depends on the speed of the convergence behavior of the measured values and the needed accuracy. This is planned to be done in a future study.

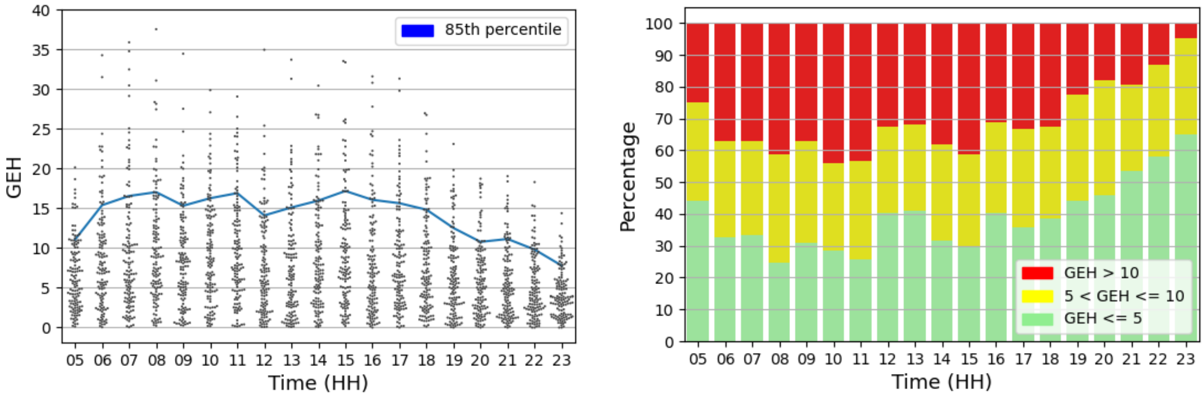
3. Simulation Results

3.1 Overall simulation results

The Brunswick scenario simulates the motorized individual traffic during the 24 hours of a typical working day. During the simulation, 637,703 vehicles were inserted and 49 teleports occurs, with the main cause being yield (vehicle is stuck on a low-priority road and did not find a gap in the prioritized traffic). The entire simulation took 1 hour and 10 minutes, resulting in a real time factor of 21.75.

To evaluate the performance of the simulation, the GEH statistic was calculated based on the traffic flow data of 129 detectors for the year 2019. The points in Figure 2.a show the GEH value of each detector for each hour. The GEH shows a significant variation, reaching values of 37.

According to the literature, a GEH below 5 in at least 85% of the cases is considered as a good performance. A GEH between 5 and 10 indicates that simulated flows may require further investigation and a GEH above 10 shows a poor fit. The 85th percentile is shown as a blue line in the figure. Contrary to the recommendation, these values varying between 7.79 and 17.15 over the simulation time.
Figure 2.b shows the GEHs of all detectors according to the three categories previously mentioned (i.e., GEH <= 5, 5 < GEH <= 10 and GEH > 10) for each hour of the simulation. During the morning peak hour from 7 to 8 am, 43 detectors show values below 5, 38 detectors have GEH values between 5 and 10, and the remaining 48 detectors show a GEH greater than 10.
According to these results, a calibration of the simulation to improve its performance would be beneficial.

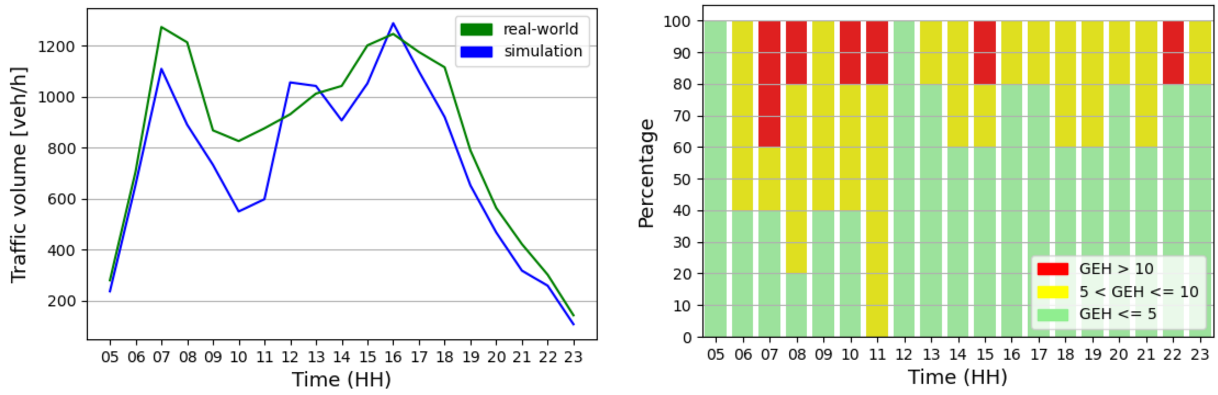


(a) (b)

Figure 2 GEH results for the simulation (a. shows the GEH value for each detector and the 85th percentile; b. shows the percentage of detectors with GEH values according to the three categories)

3.1.1 Virtual-stops scenario:

Traffic flow data from five detectors is available in the selected area for the virtual-stops scenario. The results of the detectors in this area show a better performance. The percentages of each of the three GEH categories mentioned above are indicated in Figure 2.b. The performance of the simulation during the morning hours is significantly lower than for the rest of the day. The peak hour from 7 am to 8 am shows only a 40% of the detectors with a GEH lower than 5. The Figure 2.a shows the simulated and actual traffic volume in number of vehicles per hour for the detector 'MS136'. This detector is located on the same street as the virtual stops under study but about 600 meters further north.



(a) (~~a~~b)

Figure 3 Simulation performance in the area of the virtual-stops scenario (a. shows the hourly traffic volumes for detector 'MS136'; b. shows the GEH of the five selected detectors according to the three categories)

3.2 Calibration

The simulation result, mentioned in 3.1, is based on SUMO's oneshot traffic assignment with re-routing possibility, i.e. each driver uses the fastest route at his departure time and can adjust his route on the way according to the current traffic state and the pre-defined re-routing interval in SUMO. The resultant routes are further calibrated for reflecting the real traffic flows during the peak hour period (7:30 – 8:30 am), considered in the virtual-stops based DRT scenario.
The essential concept of the calibration is to calibrate route choice with the given measured traffic flows. The coupling tool of SUMO and Cadyts (Flötteröd, 2009 and 2017) was used accordingly. With the consideration of the reasonable traffic state not only the trips, departing within the peak hour period, but also the trips, departing 2 hours before the rush hour. In order to calibrate route choice alternative routes are generated by using SUMO's Duarouter with the mesoscopic Gawron assignment method. These alternative routes were used as input together with the network and the corresponding data with 30-minute interval, collected by 150 detectors.

Relative absolute error (RAE) is chosen as evaluation indicator. The calibration result is shown in Figure 5. It is apparent to see that the relative absolute errors of the flows are significantly reduced in comparison to the result before the calibration. Totally, 41% of the simulated flows have a RAE less than 30% before the calibration, while this percentage is improved to 74% after the calibration. Furthermore, 55% of the simulated flows have a RAE less than 15%.

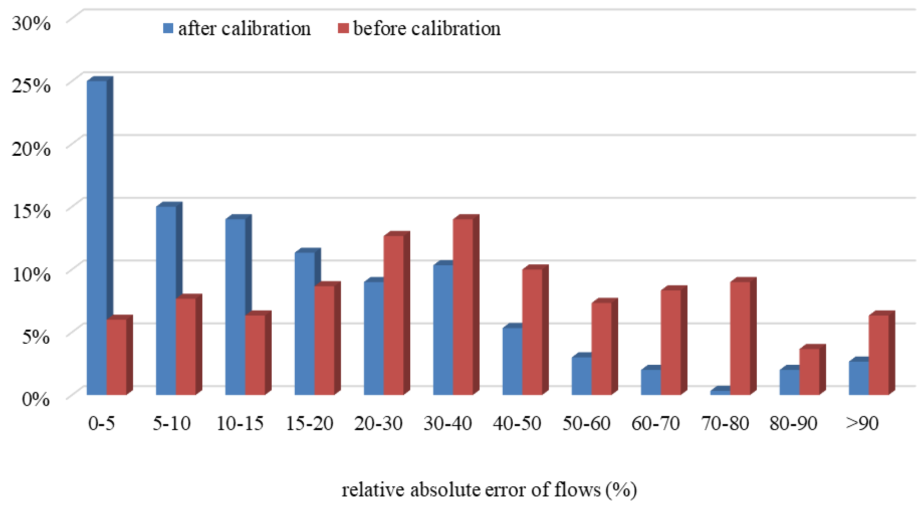


Figure 5 Distribution of the relative absolute errors between the calibrated and detected flows

As mentioned above detected data with a 30-minute interval was used. In order to use GEH to evaluate the result the calibrated flows were further aggregated at hourly level. Table 1 indicates the result comparison. The oneshot- and Duarouter-based assignments results in that 39% and 27% of the evaluated flows have a GEH-value less than or equal to 5 respectively. More than 28% of evaluated flows have a GEH-value either between 5 and 10 or greater than 10. After the calibration, most of the evaluated flows have a GEH-value less than 5 (73%), i.e. they are considered a good match between the simulated and detected flows. This result corresponds to the above-mentioned evaluation, when the RAE threshold is set to 30%. The percentage of the modelled flows with a GEH-value greater than 10 is significantly reduced.

Table 1 Comparison of the GEH-values before and after the route choice calibration

GEH-value	Oneshot with re-routing	Duarouter-based routes before calibration	Duarouter-based routes after calibration
<= 5	39%	27%	73%
5-10	28%	29%	18%
>10	33%	43%	9%

3.3 Virtual Stops

The demonstration of the evaluation of the stops consists of two stops. The first stop is located at the right lane of a two-sided road, whilst the second stop is within a bus stop with an extra lane. The threshold for the safety measures is set to 3 sec. The safety-related parameters will be measured only in a square around the location of a user request with an edge length of 400 m. Accordingly, the whole scenario is reduced to a square as aforementioned but with an edge length of 1000 m. The walking speed is 5.4km/h as SUMOs default. For the warming-up phase the simulation starts 30 min before the shuttle begins to run in the simulation network. The shuttle starts on the edge at the margin of the simulation network at the time 1:07:30:00 (=113400 seconds) and runs to its service stop. It will wait for 3 min for picking up the customer and then continue to run to its pre-defined destination, i.e. a pre-defined edge on the other side of the simulation network. The simulation ends at the time 1:08:00:00 (115200 seconds), when the shuttle already has left the simulation. The values for the traffic safety and the traffic flow are measured only during this 30 min (without considering the warming up phase). Table 2Table 2: shows the results of the simulation with stop at the lane, within stop within the bus stop and without the shuttle.

Table 2: Results of the evaluation of the two stops

Measure	Without shuttle	Stop at lane	Stop within bus stop
Number of conflicts	3968	4063	4009
(#PET, #TGAP)	(160, 3808)	(169, 3894)	(156, 3853)
Mean time loss (s/veh)	5.9	6.6	5.4
duration for the itinerary (s)	-	6	38

Figure 6: Left: violet square: the simulated area, orange square: the measuring range, blue triangle: the user request, red circles: the stop candidates, yellow arrows: the shuttle route. Right: blue triangle: the user request, dotted lines: the user's paths to the stops

4. Conclusions

This paper presented a simulation scenario of the city of Brunswick with the microscopic traffic simulation SUMO. The simulation scenario is open so that other researchers can save a lot of time which can be used for further research.

The route choice calibration with detected flows was carried out for reflecting the real-road condition during the peak period in the aforementioned DRT scenario area. The respective result shows an apparent improvement when evaluating the calibration with both RAE and the GEH statistics. However, further examination and improvement are still needed especially for the flows with large GEH-values.

Additionally, an analysis for virtual stops was presented here as an example what can be evaluated with such a simulation scenario. To get more realistic results many simulation runs should be used to calculate mean values and uncertainties as well as the use of a calibrated simulation scenario is recommended.

5. Acknowledgement

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