Investigating different strategies for within day bus parking using a agent-based traffic simulation - A Case Study of Berlin

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1. Motivation and problem statement

The tour bus is, from the perspective of CO_2 emissions per passenger-kilometer, an environmentally friendly mode of transportation. However, idling engines and long search times for parking negatively impact the otherwise eco-friendly profile of this mode of transport. In the absence of a coordinated tour bus strategy, such as assigning parking spaces and specifying routes for tour buses, uncoordinated tour bus traffic in the city center of Berlin leads to pollution, noise, and space congestion. This, in turn, results in conflicts among commuters, residents, and bus tourists.

Therefore, this work aims to develop a unified tour bus concept to reduce pollution, noise, and congestion caused by tour bus traffic and prevent conflicts among various stakeholders, including commuters, residents, and tourists. Throughout the work, a simulation will be used to model various forms of organizing tour bus traffic in Berlin. Based on this simulation, the reduction in CO_2 emissions and particulate matter emissions, as well as the more efficient transportation of tourists, can be determined for bus operators. It will also identify suitable routes, parking areas, and drop-off points.

The focus of this work is not solely on tour bus traffic itself, but rather on inefficient operational structures, such as unnecessary trips during the search for parking and ways to avoid them.

2. Methodology

An agent-based traffic simulation will be created to investigate the problem. The following section describes all the steps involved in creating such a simulation.

2.1 Transport Simulation

The implementation of the model is carried out within the open-source traffic simulation software MATSim (Multi Agent Transport Simulation) (Horni et al. 2016). This software is an agent-based traffic simulation. This means that each simulation component such as people, vehicles, but also roads and intersections are represented by a synthetic element. Individuals, also called agents, have certain characteristics and additionally a daily plan based on activities, e.g., “home – work – shopping – home”. Each of these activities has a defined location and end time. As a result, all agents have to travel the distances between their

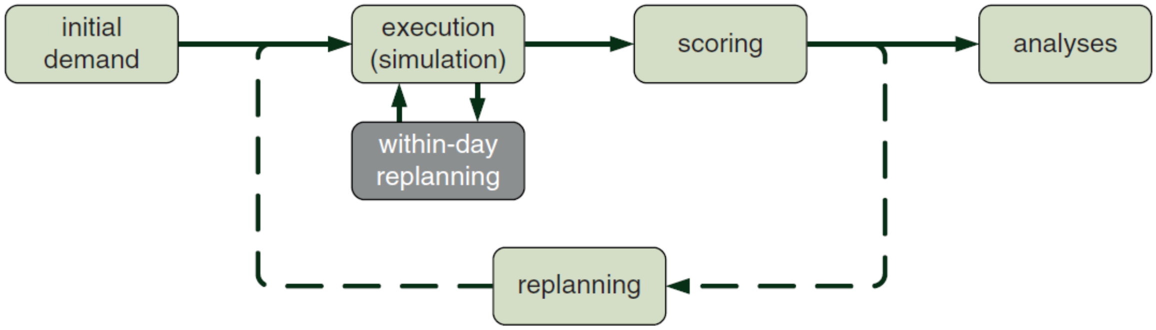


Figure 1: (Iterative) within-day replanning MATSim loop (Dobler et al. 2016)

activities by one of the available means of transportation Horni et al. 2016. For our work, a plan with one exit for the passengers can be "tourStart – exitAtAttraction – parking – getInAtAttraction – tourEnd". Furthermore, it is clear that only the car mode is utilized, and no alternative modes of transportation such as bicycles or public transportation are accessible.

The main development part for the simulation is a realistic modelling of parking search with given parking facilities. In this area, this work extends the existing functionalities of parking search in MATSim (Waraich 2016; Bischoff et al. 2017) [1]. Compared to the typical MATSim loop, (Horni et al. 2016) this work uses the within-day replanning functionality (see **Figure 1**). Thus, it is feasible to modify the bus tour plans within a single iteration. This is necessary because the buses should react intermediately to occupied parking facilities. Changing parking facilities and the resulting duration for the parking search also has an impact on the parking duration because the duration of the stay of the passengers at one attraction is constant. Because of this functionality, for this work only one MATSim iteration is simulated.

2.2 Model Generation

The primary objective for the creation of the simulation, which is crucial for this undertaking, entails the generation of daily plans. Therefore, it is necessary to derive these daily plans for each individual bus tour. This chapter will provide a detailed description of the necessary steps for this process.

As the data foundation for the existing data, we are using the year 2019. This choice is because the data of the years 2020, 2021, and 2022 were not typical due to the COVID-19 pandemic. Therefore, the year 2019 is established as the most appropriate reference year, as it provides a complete data basis without the influence of the pandemic.

2.2.1 Survey

To gain insight into the issue from the perspective of bus drivers and bus operators, we conducted a survey. Another goal of the survey was to gather missing data regarding the typical

1. see https://github.com/matsim-org/matsim-libs/tree/master/contribs/parking/src/main/java/org/matsim/contrib/parking/parkingsearch

flow of a tour, which could be integrated into the simulation. With the assistance of the Berlin Chamber of Commerce and Industry (IHK Berlin) in distributing the survey, we were able to obtain responses from 111 participants, thereby acquiring valuable insights.

2.2.2 Number of Tours

To estimate the average number of tours conducted in Berlin per day, the data from the Amt für Statistik Berlin-Brandenburg (2020) is used. From the total number of passengers in occasional traffic, we determined that there were 4,115,000 passengers in the year 2019. Since we aim to provide a projection for the coming years, we used a forecasted figure for 2030. For this, we assume that in 2023, the number of tourists will return to pre-pandemic levels. For the following years, we calculate with an average annual increase of 3.53%, which is the average of the past years (*Tourismus in Zahlen* 2023). This results in a projected passenger count of 5,246,061 for the year 2030.

Considering a passenger capacity of 50 passengers per tour bus and an average passenger occupancy of 70% (as per survey results), passengers are distributed across an annual total of 149,887 tours. Assuming an even distribution throughout the year, this results in 411 tours conducted per day.

2.2.3 Tour Generation

Based on the simulation requirements for MATSim, it is now necessary to create an individual daily plan for each of the tours to be simulated. The information required for the daily plans is described in the following section.

Start of the tour
In the simulation, each of the considered tours begins at a hotel where passengers board. There are no additional boarding points at the start of the tour. This assumption is supported by the survey, in which it was indicated that approximately 90% of tours start at a hotel. The locations of all hotels in Berlin were generated from OSM (OpenStreetMap (2023)) and integrated into the simulation as a list of possible locations for tour starts (see **Figure 2**). To ensure that the locations of tour starts reflect the real tourist demand, we use overnight stay statistics for the Berlin districts from the year 2019 (Amt für Statistik Berlin-Brandenburg 2019). We use the information on arrivals rather than the total number of overnight stays, assuming that each guest, for example, takes a tour regardless of the length of their stay. Based on this percentage distribution by districts, the locations of tour starts within Berlin are also distributed. This means that, for instance, approximately 43% of the hotels for tour starts in the simulation are located in the district Mitte, as the share of arrivals in hotels in Mitte is also 43%. Within the districts, a random hotel is then selected since there is no individual hotel data available, such as the number of beds, to assign a higher probability to larger hotels.

In addition to the location, each tour start must specify a start time and a boarding duration. The start time is randomly selected between 10 AM and 2 PM, and a default boarding duration of 30 minutes is assumed. It is also presumed that the bus has a suitable stopping location or is situated directly in front of the hotel for boarding. Parking search during this process

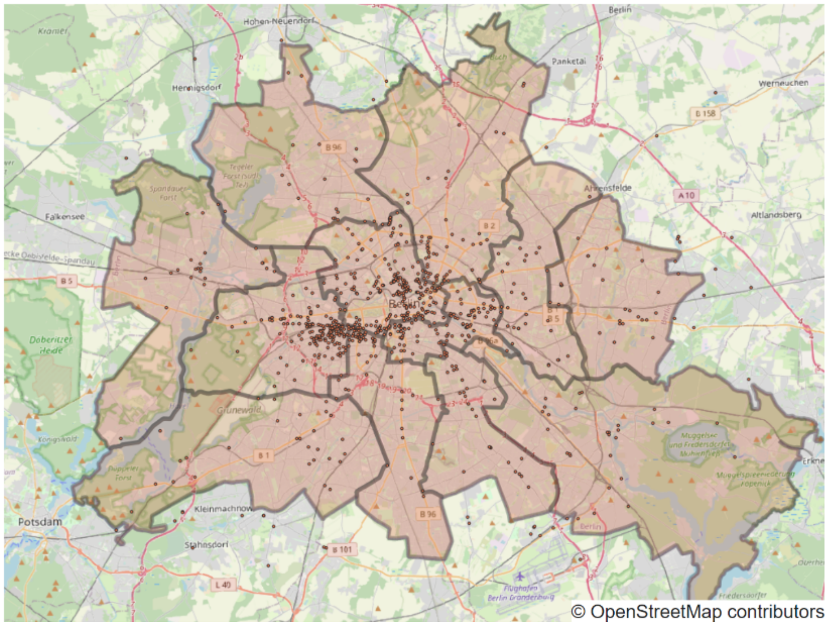


Figure 2: Hotel locations in Berlin, data source: OpenStreetMap 2023

Number of Stops	0	1	2	3	4	5	$\overline{n}$
Share	—-	5%	26%	37%	15%	17%	3.13

Table 1: Resulting distribution of the number of stops per tour

is not part of the simulation. It should be noted that the bus starts directly at this hotel, and therefore, no simulated travel is required for pickup.

Number of exits per tour
Since the work focuses on examining tours with exits, it is necessary to determine how many exits each tour has. This is done based on insights from the conducted survey (see **Figure 3**).

Based on these results, the percentage distribution of tours with different numbers of stops could be calculated (see **Table 1**). For example, it is found that 26% of the tours have two stops, and on average, a total of 3.13 stops are made. These data obtained from the survey are used identically in the tour generation process. Based on the number of stops for each tour, the following elements of the daily plans are repeated accordingly.

Passenger interaction at an attraction
From discussions with bus companies, it has become clear that passenger exits typically occur directly in front of the attraction, even if it involves potential violations of traffic regulations. Therefore, passenger exits take place at the nearest possible road connection to an attraction. The locations of these attractions are generated in a manner analogous to the hotel locations from OSM. These attractions include museums and points of interest (POIs) such as the TV tower or the zoo.

The locations of selected attractions for exits are distributed based on mobile phone data

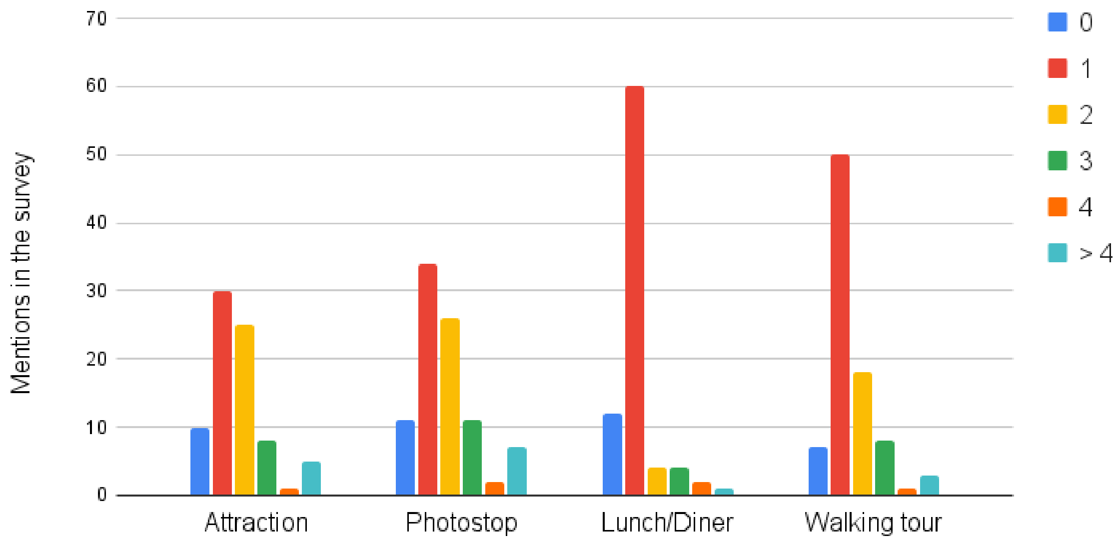


Figure 3: Survey result of the average number of stops per tour of the corresponding categories (survey participants: 111)

	Attraction	Photostop	Lunch/Diner	Walking tour
Share	28%	29%	19%	24%

Table 2: Proportion of stop types while the tour

kindly provided by *Visit Berlin* (2023)(see **Figure 4**). This data contains the share of the tourism activities for a certain area compared to the complete tourism activities in Berlin. Within the simulation, a hotspot for this stop is selected with a corresponding probability. Then, a well-known tourist spot in the immediate vicinity is randomly selected, and the next street to this attraction is designated as the drop-off spot.

Subsequently, the duration of each stop must be determined. To achieve this, results from the survey were again analyzed. First, the frequencies of stop types were determined based on **Figure 3** and shown in **Table 2**. For example, 28% of all stops are of the type attraction.

Corresponding to the stop types, survey data on the durations of stops were also evaluated. All resulting distributions can be found in the related repository (Ewert et al. 2023). From the individual distributions of stop durations, the duration of each individual stop is then determined, so that in the sum of all tours, the distributions of stop types and their corresponding stop durations are accurately represented in the simulation.

For the simulation, we have assumed a duration of 15 minutes for each passenger exit and boarding process.

Parking while passengers stay at an activity
According to the assumptions in this work, after an exit of the passengers, the bus driver looks for a parking space. The behavior for finding a parking space is a crucial factor in this process. However, the parking behavior is not considered in the creation of the daily plans,

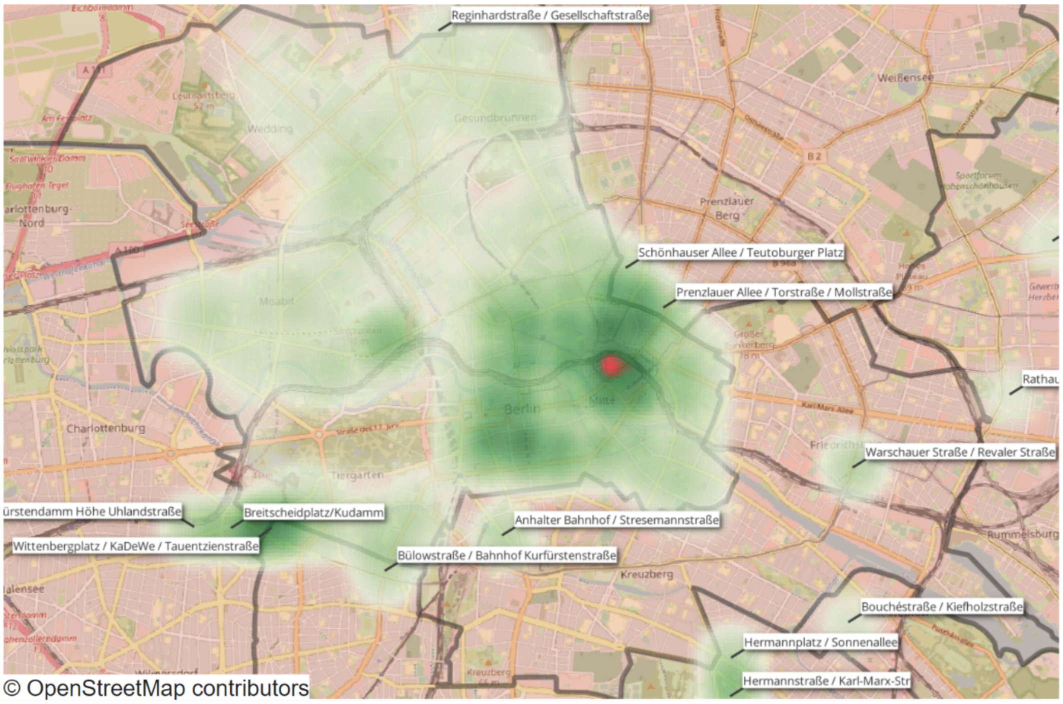


Figure 4: Visualization of the available hotspot data (only city center), data source: *Visit Berlin* (2023)

as no parking space is yet defined in this phase. Therefore, no parking duration is set at this stage. The various parking strategies will be described in detail in **Section 2.3**.

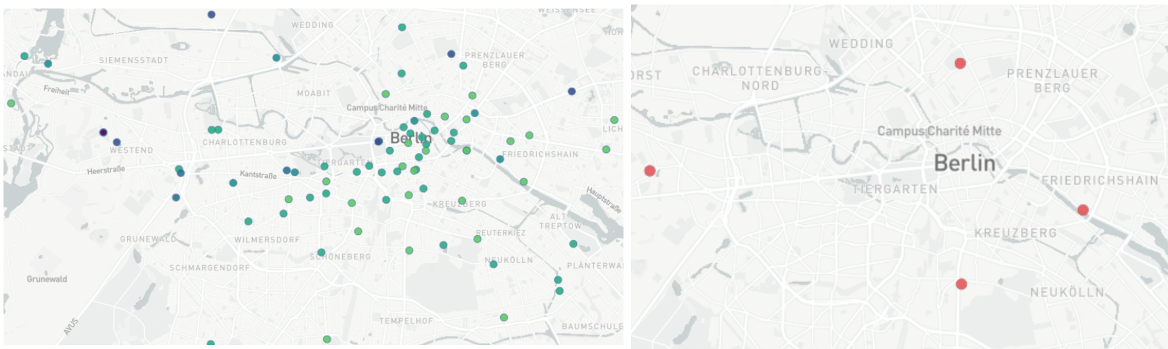
End of the tour
The end of the tour occurs at the same hotel where the tour began. The duration of this process is set at 15 minutes. After passengers have disembarked, the bus journey also ends at that location. Therefore, there is no simulation of a journey to a possible depot.

2.2.4 Parking Infrastructure

At the current stage of the work, we differentiate between a decentralized and a centralized parking infrastructure. Both variants are briefly presented below.

Decentralized (Current Situation):
The decentralized parking infrastructure refers to the current situation. It is characterized by a multitude of parking spaces with sometimes limited capacities (1-2 parking spaces). These parking spaces are obtained from the BusStop Plan by VisitBerlin (Berlin Tourismus & Kongress GmbH 2016). Information on opening hours and the number of parking spaces is available for each individual parking spot in this plan, which has been integrated into the simulation. The locations of these parking spaces are shown in **Figure 5a**.

Due to limited capacities, there is a risk that buses may arrive at a parking space that is already occupied, requiring the bus driver to continue searching for another spot.



(a) Decentralized (b) Centralized

Figure 5: Location of the bus parking spaces

Centralized:
The centralized parking infrastructure refers to a situation where only a few parking spaces are available, but they have sufficient capacity. It is assumed that every bus will find a parking space if needed. For scenarios with a centralized parking infrastructure, we assume four parking spaces with sufficient capacity at 4 locations in Berlin (see **Figure 5b**). These locations are not directly in the city center, but still inside the city.

2.3 Parking Behavior

In this section, the configurations for how bus drivers search for parking spaces in the simulation are briefly explained.

2.3.1 Parking space capacity detection

This configuration refers to whether the bus driver can check for available parking spaces without delay. An appropriate implementation for this would be a mobile application (app) that provides real-time data on parking availability. With this option, the bus driver can reduce the probability of arriving at an occupied parking space. However, in theory, the parking space could still be occupied upon arrival if another bus has parked there meanwhile. Real-time data can help minimize the chances of encountering an occupied parking spot, but it cannot guarantee parking availability at all times due to dynamic changes in the parking situation.

2.3.2 Parking space reservation

If the bus driver can reserve an available parking space, it eliminates the possibility of arriving at occupied parking spots entirely. A reserved parking space will always be free and won't be occupied by other buses. In the simulation, complete adherence to this rule is assumed, meaning that once a parking space is reserved, it remains available for the designated bus and won't be allocated to other buses during the simulation.

2.3.3 Behavior of choosing a parking space

Based on the available parking spaces (as described in **Section 2.2.4**), the bus driver can choose a possible parking spot. It is assumed that the bus driver exclusively selects from the available bus parking spaces and does not utilize other parking options (e.g., parking in the second row, violating parking restrictions or circling). Additionally, no personal experiences or preferences of the bus driver are integrated into the simulations (e.g., choosing a parking spot based on experience where they typically find a spot).

The basic implemented strategy is that the bus driver chooses the closest available parking space to park. According to the simulation, the closest means the parking space with minimal expected travel time from the current location to the parking space and back to the exit location of the passengers. Depending on the configuration of parking capacity detection and the option for parking space reservation, this may lead to a different parking space selection. For example, without both options, the bus driver chooses the nearest parking space from all available spaces, while with the option of capacity detection, they select the nearest still vacant parking space.

3. Scenarios

3.1 Base case

The Base Case scenario reflects the current real-world situation. This means that buses have access only to the currently available parking infrastructure, and there is no capability for capacity detection of available parking spaces or reservation of parking spaces in this scenario.

3.2 Scenario 1 – Decentralized parking supply with reservation system

In this scenario, buses still have access to the currently available bus parking spaces. As an extension to the base case, it is now possible to pre-reserve an available parking space, ensuring that it is guaranteed to be free upon arrival, thus avoiding further parking search. In the simulation, it is assumed that when a parking space is reserved, it is guaranteed to be available and not occupied by unauthorized vehicles. In actuality, the implementation of such a system would necessitate numerous actions from the relevant authorities, for instance, technical implementation, investments in parking facilities and efficient enforcement.

3.3 Scenario 2 – Centralized parking

In Scenario 2, a centralized parking infrastructure is assumed. This means that buses have access only to the four parking spaces described in **Section 2.2.4**. However, these parking spaces have sufficient capacity to accommodate every bus, so there is no need for a capacity detection or reservation system.

This configuration simplifies the parking situation by providing ample parking spaces at specific centralized locations, ensuring that every bus can find a parking spot without the need for advanced parking management features like capacity detection or reservations. It eliminates the uncertainty of parking availability and streamlines the parking process for buses.

	Base Case	Decentralized Parking	Centralized Parking
Parking Spaces	decentralized	decentralized	centralized
Capacity Detection	No	Yes	No
Reservation Option	No	Yes	No
Driven Distance [km]	14,467	13,486 (- 6.8 %)	17,027 (+ 17.7 %)
Kilometers Parking (between exit/entry) [km]	5,245	4,263 (- 18.7 %)	7,804 (+48.8 %)
Total CO_2 [t]	12.96	11.44 (- 11.7 %)	16.32 (+ 25.9 %)
Average duration for parking search [min]	8.2	5.5	10.1
Average distance for parking search [km]	3.0	2.0	3.7
Number of "Parking space occupied"	909	0	0
Number of parking operations	637	637	637

Table 3: Overview simulation results. The results should be interpreted as daily numbers

4. Results

The results of the presented scenarios are presented in **Table 3**. It's important to note that all scenarios use the same daily plans as input. Since the simulation always represents a typical day, these results should be interpreted as daily values.

Based on the results, it can be observed that in the baseline scenario, approximately 14,500 kilometers of travel are required to carry out tours starting and ending at hotels. Of this, about 36% (5,245 kilometers) accounts for the travel distance between dropping off passengers at an attraction and the subsequent boarding. This "Parking" component includes both the search for parking spaces and the subsequent travel from the parking spot to the passenger boarding location. These daily operations result in approximately 13 tons of CO_2 emissions. The emissions in the simulation are calculated using emission values obtained from the Handbook Emission Factors for Road Transport (HBEFA), a database that is compiled by various European environmental agencies (INFRAS 2019). When analyzing the parking search, it can be seen that there were a total of 637 parking operations, and in 909 instances, a bus drove to a parking space only to find it occupied and had to continue searching.

Comparing the scenarios, it becomes evident that the results generated by the simulation are plausible. In Scenario 1, unnecessary trips to occupied parking spots were avoided due to the reservation option, leading to a reduction in the average distance traveled during parking searches. In Scenario 2, however, the parking search distance increased as the central parking spots are located slightly outside the city center. Nevertheless, due to the assumptions in the scenarios, it was ensured that buses did not undertake unnecessary trips to occupied parking spaces upon arrival.

When comparing all scenarios, it is apparent that Scenario 1 is considered the most effective in terms of required travel distance and resulting emissions. With the help of the booking system, Scenario 1 could achieve a reduction of 11.4% in emissions. In contrast, Scenario 2 would lead to an increase of 25.9% in emissions.

All results of the scenarios are published on our visualization platform SimWrapper (Charlton et al. 2022)[2].

5. Discussion and Outlook

The findings from this analysis suggest that implementing efficient parking solutions can significantly contribute to reducing emissions and improving the overall sustainability of touristic transportation in Berlin. However, there is room for further exploration and improvement in this domain. Further research is required to examine the impact of the number of tours per day on the outcomes for the various scenarios. Another important value is the available parking infrastructure. Currently, the parking spaces are only usable for the buses while parking with-in the tour. In reality, we assume that some parking spaces are occupied by other buses. This would mean that the whole infrastructure can't be used by the buses investigated in this work. Under the border condition in the negative way, which means more buses with less possible parking infrastructure, further studies should investigate if the evaluation of the different scenarios would be changed.

Acknowledgments

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References

Amt für Statistik Berlin-Brandenburg. 2019. *Übernachtungsstatistik 2019.* Accessed: 2023-6-12. https://about.visitberlin.de/sites/default/files/MAM/asset/2020-03/2002%20Bezirkszahlen%20Dezember%202019.pdf.

Amt für Statistik Berlin-Brandenburg. 2020. *Statistischer Bericht - Personenverkehr mit Bussen und Bahnen in Berlin 2019.* https://download.statistik-berlin-brandenburg.de/b056d27e15526e50/324aa0025efe/SB_H01-05-00_2019j05_BE.pdf.

Berlin Tourismus & Kongress GmbH. 2016. *BusStop Berlin.* https://about.visitberlin.de/sites/default/files/MAM/asset/2017-08/BusStop%20Berlin%202016-17.pdf.

2. see https://vsp.berlin/simwrapper/public/de/berlin/projects/bene/visualization

Bischoff, J., and K. Nagel. 2017. “Integrating explicit parking search into a transport simulation.” *Procedia Computer Science* 109:881–886. ISSN: 1877-0509. https://doi.org/10.1016/j.procs.2017.05.414. http://www.sciencedirect.com/science/article/pii/S1877050917310906.

Charlton, W., and B. Sana. 2022. “SimWrapper, an open source web-based platform for interactive visualization of microsimulation outputs and transport data (submitted version).” The 14th International Conference on Ambient Systems, Networks and Technologies (ANT/ABMTRANS) / Affiliated Workshops, *Procedia Computer Science.*

Dobler, C., and K. Nagel. 2016. “Within-Day Replanning.” In Horni, Nagel, and Axhausen 2016, chap. 30.

Ewert, Ricardo, and Kai Nagel. 2023. *MATSim BENE Coach Parking* [in en]. https://doi.org/10.5281/zenodo.8123345. https://github.com/matsim-vsp/bene.

Horni, A., K. Nagel, and K. W. Axhausen, eds. 2016. *The Multi-Agent Transport Simulation MATSim.* Ubiquity, London. https://doi.org/10.5334/baw.

INFRAS. 2019. *Handbuch Emissionsfaktoren des Strassenverkehrs 4.1.* Technical report. See http://www.hbefa.net. INFRAS Zurich Switzerland. www.hbefa.net.

OpenStreetMap. 2023. Http://www.openstreetmap.org.

Tourismus in Zahlen [in de]. 2023. https://www.berlin.de/sen/wirtschaft/branchen/tourismus/tourismus-in-zahlen/. Accessed: 2023-6-2, May. https://www.berlin.de/sen/wirtschaft/branchen/tourismus/tourismus-in-zahlen/.

Visit Berlin [in de]. 2023. https://www.visitberlin.de/de. Accessed: 2023-9-28. https://www.visitberlin.de/de.

Waraich, R. A. 2016. “Parking.” In Horni, Nagel, and Axhausen 2016, chap. 13.