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Effects of different mobility concepts in new residential areas

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ABSTRACT

Growing cities need new residential areas, which are often either not connected to the existing transport infrastructure or are poorly connected to it. A fast way to connect these areas is the construction of roads. However, this generates a car-depending mobility among the inhabitants, which is in conflict with several sustainability goals. Moreover, the impact of the implementation of new public transport options is only partly known and this fact reduces the willingness to invest in expensive public transport measures. In this work we examine different mobility concepts, including shared mobility, bicycle highways, a high-frequency bus service, suburban trains and car limitations in a new residential area of 2000 households in Berlin, Germany, which is currently under construction. The households and inhabitants are created synthetically using statistical data derived from a survey among the first people moved in. The age and size structure of these households turn out to be different from the neighboring households. Then, we implement all measures in a microscopic travel demand simulation and quantify the potential modal shifts for four different mobility concepts. The results show that weak and short-term mobility concepts show no significant change in mobility behavior. Only highly integrated projects like bicycle highways into the inner city combined with suburban trains can reduce the need for car-dependent mobility. Shared mobility only fills in the gaps for special occasions but not for daily mobility due to the high costs. In a final step we examine the usage of the introduced public transport services and compare the change in the occupation of the buses and trains. Here our work shows that interchanging from bus to subways and suburban trains drastically reduces the attractiveness of public transport. Introducing a new sub-urban train changes this situation and the whole region shows a drop of 40% of car trips.

1. Introduction

New residential areas need a working mobility concept to fulfil the personal mobility as well as environmental goals of the municipality. The difficulty of new residential area is, that these areas are poorly integrated into the existing infrastructures. Beside extra time to reach the next train stations local infrastructure like schools and super-markets are often not close to the new residential locations. Car-based mobility offers the flexibility and accessibility needed for the daily mobility. However, the individual use of cars produces traffic jams and necessitates a huge amount of parking space in the residential area. To compensate these effects short-term measures like increased bus frequencies and bike lanes are often introduced. The question is: Is this enough? Modelling the travel demand is a feasible way to quantify the effectiveness of several measures. In this work we show the potential of modal shift towards public transport and bikes via different measures.

2. Theoretical background

Managing travel demand via political measures has been done for a long time. However, its implementation should be done carefully, to achieve a broad acceptance among the population in the affected region (Eriksson et al., 2006). This task can be achieved by modelling the travel behavior of a synthetic population to analyze, if the expected outcome of the measures is achieved and the mobility needs of the population are meet. Modelling the travel demand in urban areas by approximating human behavior by the economic concept of utility functions is a common task for travel demand models (McFadden, 1974). Classic 4-step transport models have been dominating the operational use for traffic simulation, measure assessment and decision making for a long time, especially commercial software like ptv Visum or Bentley Cube. But flow-orientated modelling has certain limits, such as hardly achievable consistencies of trip chains or of shared resources as cars in the same household. Especially, when car ownership should be limited due to

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spatial and environmental reasons, modelling the availability of limited resources becomes crucial for a qualified interpretation of the data. This led to the idea, that transport is the sum of trips of individual persons with individual decisions, resulting in microscopic demand models (McNally and Rindt, 2012) which are often called agent based models. This class of models is successfully used for evaluating different policy measures e.g. (Zill et al., 2022) and (Cyganski et al., 2018). Recently, more and more large-scale urban areas are modelled and effects of car ownership on household level, demographic change and interdependent travel diaries are realized in practice to aid city planning (Huynh et al., 2014). Additionally, these models are used for future scenarios addressing city development especially commuting patterns and infrastructure transformation (Marini et al., 2019). A characteristic disadvantage of this approach is the need of a higher spatial resolution and coverage of the input and validation data, to get valid modelling results for large scale urban simulations (Melnikov et al., 2016). A further comprehensive review on different microscopic and agent-based models including the used ones in this work can be found in Bastarianto et al., Hancock and Choudhury (2023).

3. Methodology

In this work we model a synthetic population of Berlin expanded by the new population of the examined study area. The synthetic population of Berlin is generated by a tool called Synthesizer to fit official census data with respect to inhabitants, household size, age and gender (see Section 3.1). Four different scenarios with different mobility concepts to emphasize a modal shift from car-based mobility to other modes of transport are developed to measure their effects (see Section 3.2). These scenarios are parameterized to be used in the simulating framework consisting of the two models TAPAS and SUMO (see Section 4). Finally, the simulation results of the travel demand and traffic modelling are presented and the potential of the scenarios to reduce car-based mobility is discussed.

3.1. *Study area and synthetic population*

The study area is located in the north-west of the city of Berlin in the district Spandau on a peninsula and consists of a part of existing buildings, mainly single-family houses built in the late 90′s/early 2000, and the new development area, which was partly finished in 2019. In the

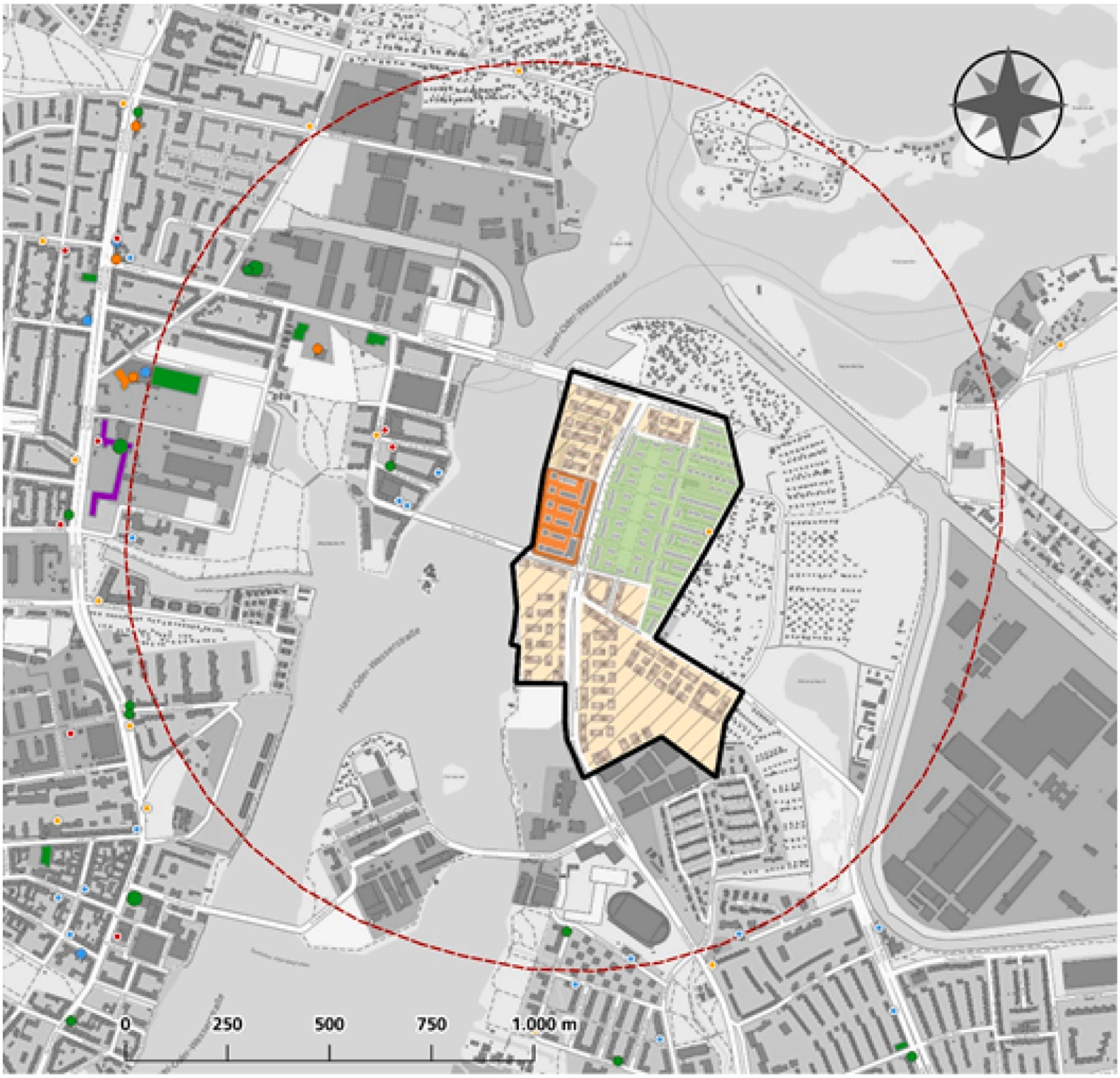

Fig. 1. Black line: study area, green: existing buildings, orange: finished buildings in 2019, yellow: buildings finished after 2020, red line: 1 km radius.

vicinity of 1 km there are almost no shops, schools or medical services (see Fig. 1). In total 2000 new apartments inhabited by 3400 persons with 1500 cars are expected to populate the new area.

The next subway station (Haselhorst) is 1.8 km away. There is one main road (Daumstraße) where three bus lines are operated with a frequency of 10 min per line during the main operating hours.

Synthetic populations are usually generated with the tool Synthesizer. This tool uses socio-economic data from a microdata sample and marginal totals to create a microscopic representation of the population of a given area. On the one hand, a disaggregated microdata sample is available for one percent of the German population and provides information about households and individuals. On the other hand, we use aggregated marginal totals at the neighbourhood-level from the company Nexiga for 2017 (reference year). Mobility-related data, such as the ownership of a driving license, stem from the survey Mobility in Germany from 2017 called MiD2017 (Nobis and Kuhnimhof, 2021). Future scenarios are set for the year 2030. The forecast population is available from the Berlin State Statistical Office at the district-level. This technique was evaluated together with other competing techniques described in von Schmidt et al., Cyganski and Krajzewicz (2017) and is based on hierarchical iterated propotional fitting (Müller, 2011) and iterated proportional updating (Ye et al., 2009). In the context of this research, the population for the whole city was created using the usual procedure. However, for the study area a more accurated population was generated.

At the project start, construction in the study area was in progress. For this reason, an a priori comparable neighborhood in structure (reference area) was chosen to conduct a resident survey. With the resulting evaluation of the survey the structure of the population was extracted and used to generate a synthetic population. The number of households, persons and the majority of address locations within the study area were extracted from the ongoing building project plan. Some of the addresses were already available from official data sources. The extracted household and person counts were used as marginal totals. Finally, persons were grouped into households, aligning with the population structure observed in the reference area (see Table 1).

3.2. Scenarios

In this work we examine four scenarios. The first scenario is called “null” and has no further measures except the new population in the study area. This scenario is only used for comparison of the change in public transport demand. The second scenario represents the planed short-term measures, which are performed with minimum time and effort. These measures include an additional bus service, linking to the closest subway station with only one additional stop, and installing parking cages for private bikes at the buildings and at the closest subway-station. All these measures cost almost nothing and can be implemented in short time. They represent the typical actions, if available resources are very limited. This scenario is called business as usual (BU) and used as the reference for the demand modelling. The third scenario called Future Way (FW) includes all measures from BU and adds an additional bus lane to the street, where applicable. The bike lane to the next subway-station is designed cross-free to speed up the trip by one minute. Additionally, a parking fee of 1€/hour for non- residents is introduced. This scenario represents a typical set of pull measures, which make alternatives to cars more attractive without penalizing cars. In Germany the number of residential permits for free parking of cars is usually not limited and very cheap (40–100€/year). Therefore parking-fees are usually not affecting the residents. Besides, the car ownership for the study area was set to 0.7 cars per household for the scenarios Null, BU and FW.

Finally, a maximum scenario called Extreme Boost (EB) is examined. In addition to the previous ones a new suburban railway station is introduced. For supporting bike traffic, the existing bike highway net of Berlin is extended from the city-center to the study area, increasing the travel speed by 2km/h in average due to less stops and good surfaces. The local parking permits are reduced to 0.5 cars per household in average resulting in a reduction of 440 cars. This scenario is chosen to show effects of strong measures: high costs arise due new infrastructure. Fixing the amount of free-parking permits penalizes car ownership and is a easy to implement measure to legally reduce the number of cars in the area. Table 2 gives an overview of the scenarios.

There are several possible measures, which are not considered in this setup. First, the influence of electric bikes wasn’t considered. Manly, because TAPAS cannot differentiate between normal and electric bikes as explained in Section 4.2. The authors thought about integrating e-bikes my changing the average biking speeds, but realistic fleet-share, maximum speed, change in availability, change in age-structure of the owners haven’t been available. Second, multiple bridging options between the scenario FW and EB where considered: Electrification of the main bus line (M36), connection to the tramway system, express bus lines. However, due to the limitation of funding for work concentrates on the maximum scenario, which was the preferred long-term option of the local government at that time. All “in between measures” are assumed to show intermediate results between the last two scenarios.

4. Simulation framework

4.1. Overall simulation TAPAS/SUMO-coupling

The daily mobility of a simulated population is usually modelled by travel demand models. In this case, we used the agent-based travel demand model TAPAS (https://github.com/DLR-VF/TAPAS), and the

Table 2
Scenarios and main characteristics.

Transport means Scenario	Public transport	Bicycle	Car
Null	No change: two bus lines	No change: regular bike lane	No change
Business as usual (BU)	Additional bus service	Parking cages in study area and in the closest subway station	No change
Future way (FW)	+ Additional bus lane	+ Cross-free bike path to the closest subway station	+ 1 €/h-parking fee for non-residents
Extreme boost (EB)	+ City centre connected through a new urban rail line	+ Fast bike lane	+ Parking permits reduced to 0.5 cars/household

Table 1
Household structure.

Household size	Households in survey	Percentage	Households in reference area	Persons in reference area	Households in study area	Persons in study area
1	49	23.90	245	245	525	525
2	93	45.37	465	929	996	1992
3	36	17.56	180	539	385	1156
4	21	10.24	105	420	225	899
5 or more	6	2.93	30	150	64	321
total	205	100	1025	2283	2195	4893

traffic flow simulation software SUMO (https://github.com/eclipse/sumo), (Alvarez et al., 2018). Both models are described in more detail below.

While TAPAS models the travel demand, meaning the amount of trips to fulfil the daily mobility, SUMO extracts the car and public transport trips from this demand to simulate the routing and the capacity constrained usage of the road- and train-networks resulting in an update for expected travel times. The commuting traffic from outside the modelled region is integrated via external traffic inputs, in this case counts of commuting traffic for public transport and detection loops in the main roads. Finally, the new travel times are fed back into TAPAS and a new iteration of the simulation is started, if there is a significant deviation between the updated travel times and the times from the last iteration. The interaction of the tools can be seen in Fig. 2.

4.2. TAPAS

TAPAS simulates the activity patterns for each person in a synthetic population. To simulate diverse scenarios a variety of input data is necessary. This includes data such as activity locations, a synthetic population or travel time matrices. TAPAS searches for matching locations to perform the activities, considering accessibility with respect to the current location via the available modes, and the capacity of the destination. All persons in this study area, which commute to other parts in Berlin are constrained by the capacities of the specific destinations. Since the whole city is simulated, all persons living in Berlin compete for these locations. Finally, it selects a mode of transport and performs several feasibility checks. Modes of transport considered by TAPAS are car, car as co-driver, walking, bike and public transport. E-bikes are excluded due to the current lack of research in travel modelling for this mode, and because electricity costs are negligible from a cost sensitivity perspective and the effect of age on mode choice is not analysed yet for electric bikes in TAPAS. A detailed description of the used mode choice model can be found in Heinrichs et al. (2017). Cars are distributed on a household level and double booking of the same car for the same timeslot is prohibited. The result of TAPAS is a detailed list of location-changes for each scenario consisting of person-id, activity type, start time, end time, start location, end location, mode of transport, duration of activity and in case of a car trip the ID of the used car. The basic program functionality is shown in Fig. 3.

In this work, we simulate the whole city of Berlin, Germany, because this way it is possible to consider commuting and capacity constraints due to people living outside the region. Commuting traffic from outside Berlin is included via external traffic od-matrices, which remain static for all runs: Commuters from outside Berlin are treated as bulk traffic and do not change their modal choice and destination choice. The capacity of work locations in Berlin is adjusted to serve both, commuting and local capacity needs.

TAPAS was calibrated by running a reference population of 2017 and adopting purpose-specific search radiuses for appropriate locations to fit the reported trip-lengths in MiD2017. The result is then validated against the modal splits. The results of the calibration are shown in Table 3.

4.3. SUMO

SUMO is an open source tool for microscopic, agent-based traffic modelling and simulation developed and maintained at the Institute of Transportation Systems of the German Aerospace Center. It enables multi-modal mobility simulation and hence includes road vehicles, pedestrians and public transport (see https://www.eclipse.org/sumo/). While its initial focus was on urban traffic simulation, its application field has widened in recent years towards other means of transport, e.g. harbors, aerial transportation and railway operation. Generally spoken, SUMO simulation models can be used to predict the effect of numerous changes in parameters, e.g. different infrastructure, traffic demand or means of mobility. In this work it is used to generate a digital twin of the new neighborhood of Berlin Spandau (see above), meaning that infrastructure, road users and surrounding traffic are modelled in microscopic detail. The bounding box used was 13.1907, 52.529, 13.3053, 52.566 (lon, lat, lon, lat).

The data for traffic demand, being generated with TAPAS as shown above, is converted to so called *trips* in SUMO, each representing a simulated person’s itinerary. A major challenge in SUMO demand modelling emerges from a frequently observed discrepancy between input demand data area and SUMO simulation observation area. This specifically results in the problem of correctly modelling commuter or “drive-through” traffic, that happens to traverse the observation area but might not start and/or end within it. This also applies to the SUMO-TAPAS-coupling as described in Section 3.1 and is tackled as follows: To represent this commuter and background traffic, the trip requests are initially created for the whole Berlin region in TAPAS. They contain start

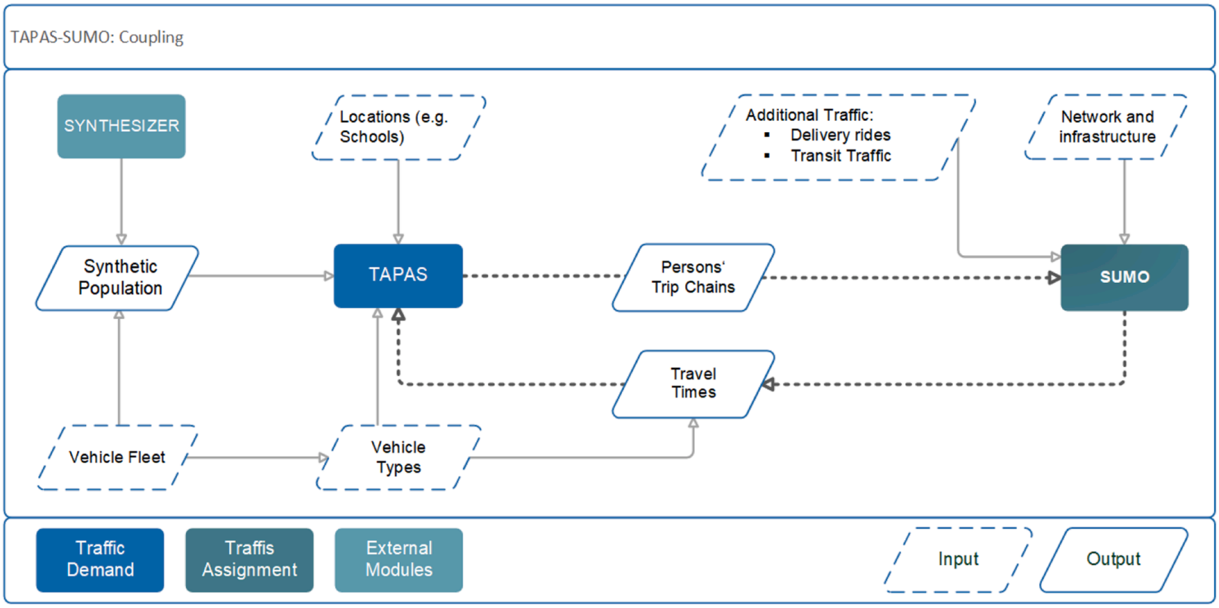

Fig. 2. Setup of the different simulation components.

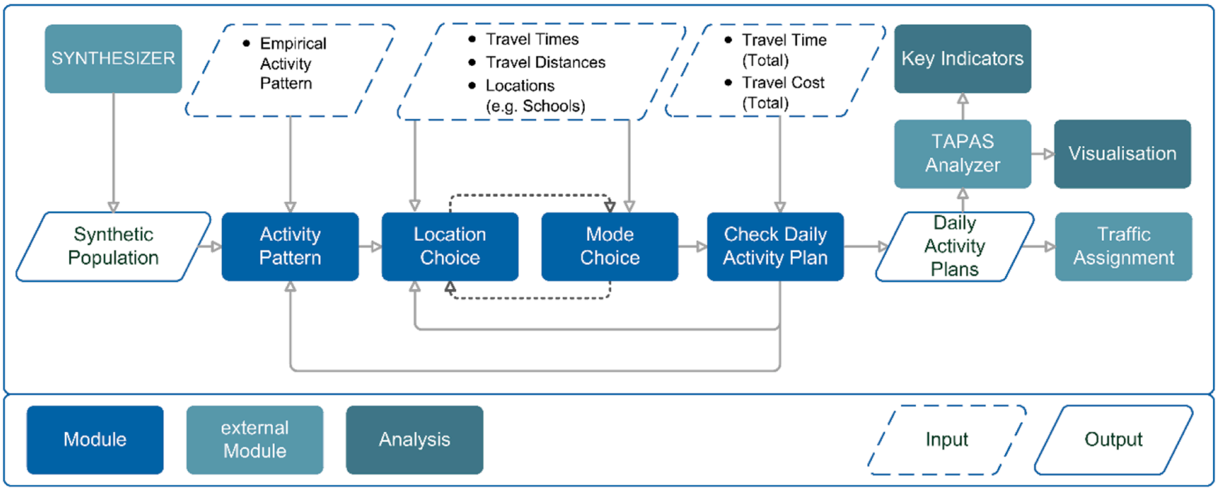

Fig. 3. Workflow of the simulation framework TAPAS.

Table 3
Calibration results of TAPAS.

	MiD2017	TAPAS 2017
Trip distance in m		
School	3923	3829
Study	10,687	9793
Work	10,356	8171
Private matters	5302	5357
Shopping	3129	4622
Free time	7288	7216
Other	5390	5162
Back home	6429	6586
Modal Split		
Walk	27.8%	29.2%
Bike	15.8%	17.1%
Car	22.0%	20.2%
Car passenger	8.9%	9.7%
Public Transport	25.5%	23.8%

and end points, starting time and mode of transport. Because the analysis of the infrastructure changes only affects a certain area around the new residential area itself, a simulation area was defined that includes the greater Spandau area. This area was cut out of both the infrastructure and the trip requests. Traffic leaving or entering this area was accumulated in cordon points to simplify the simulation. In the simulation itself all trips are represented by *agents* (cars, trucks, pedestrians, trains, busses) that move along the streets, following their desired route and interacting with both one another and infrastructure elements such as traffic lights or pedestrian crossings. For public transport, the resulting *trips* can contain numerous vehicles as well as ways on foot. Routing in SUMO was performed by means of an A* approach, while other routing modes could principally be implemented as well (cf. (German Aerospace Center (DLR) and others I, 2024). Table 4 shows the accordingly used routing and rerouting configuration.

Travel times in SUMO depend on the used vehicle/agent type and the corresponding movement modelling. Here, default values were used according to German Aerospace Center (DLR) and others III (2024), values established in a worldwide community.

Table 4
SUMO routing configuration.

configuration key	configuration value
routing-algorithm	astar
device.rerouting.probability	0.6
device.rerouting.period	300
device.rerouting.pre-period	10
device.rerouting.adaptation-weight	0.5
device.rerouting.adaptation-interval	10
device.rerouting.threads	16

The traffic-related infrastructure is imported from Open Street Map (Open Street Map, 2024) and leads to a corresponding faithfulness to reality and detail level. See (German Aerospace Center (DLR) and others II, 2024) for a deeper description on how to import open street map data to SUMO. To ensure meaningful results of the simulation, the research is done by comparing different scenarios that are based on the same infrastructure data. The only supplements to the infrastructure for the analyzed traffic measures are described in Section 4.2.

SUMO provides a variety of output possibilities. In order to evaluate passenger volumes and routes across the public transport network, a combined approach is taken: SUMO *tripinfo-output* contains information on the actual trip of a simulation agent (which can, at times, deviate from the planned trip e.g. due to missed connections). Details on taken public transport vehicles such as busses were extracted and combined with SUMO *stop-output* functionality, which counts passengers both entering and leaving a public transport vehicle per stop. As a result, passenger volumes between two stops aggregated over all vehicles within all means of transport can be extracted and visualized in order to analyze effects of the different described scenarios on passenger volumes in public transport.

5. Results

In the following, the methodological framework as described in Section 3 is applied on the different scenarios as defined in Table 2. Following a step-wise, yet integrated approach, at first demand modelling is executed, resulting in both aggregated modal-share information and detailed itineraries on an origin-destination-level. The latter are subsequently transferred into trips and then again used as an input for traffic simulation which results in passenger volumes and scenario-based differences. Afterwards, the results of both steps are jointly discussed.

5.1. Demand modelling

The results of the demand modelling software are given in Fig. 4, Table 5 and Table 6. For the mode-share the total mode-share of the city of Berlin is given in the first row as comparison. One sees, that the BU and FW scenarios show a high share of car trips and a very low share of bike trips. The other modes are almost the same compared to the shares of Berlin. All measures in these two scenarios only influence the travel time due to speed-up along the bus and bike lane and less time for

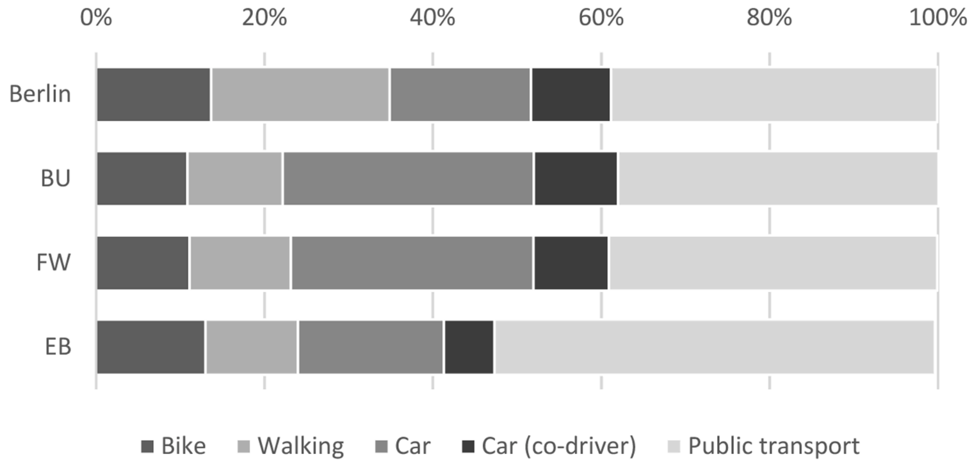

Fig. 4. Mode-share of different scenarios.

Table 5
Average trip length and durations of the different scenarios (black) and for the rest of the city of Berlin (blue). All values in one column are derived from the same simulation, but with different filters.

	Average trip length in km			Average trip duration in minutes		
Transport means	BU	FW	EB	BU	FW	EB
Bike	6.8 | *5.7*	6.7 | *5.7*	6.5 | *5.9*	37.7 | *32.1*	37.3 | *32.1*	34.5 | *31.7*
Walking	2.3 | *1.8*	2.3 | *1.9*	2.3 | *1.9*	31.6 | *27.2*	31.9 | *27.2*	32.2 | *28.3*
Car	10.3 | *9.2*	10.6 | *9.2*	10.5 | *9.2*	33.7 | *31.2*	34.2 | *31.2*	34.1 | *31.1*
Car (Co-driver)	11.1 | *9.9*	11.1 | *9.9*	11.2 | *9.7*	34.9 | *32.6*	35.3 | *32.6*	35.6 | *32.2*
Public transport	14 | *12.7*	13.8 | *12.7*	13.5 | *12.5*	59.2 | *54.1*	57.8 | *54.1*	55.4 | *53.3*

locking the bikes (see Table 2). Since these changes are around 0–5 min and therefore rather low, the utility function for mode choice has only marginal changes. The EB scenario shows strong modal shift from car and co-driving to public transport, while bike usage still remains at a low level. The number of car trips is reduced from 30% in the BU scenario to 17% in the EB scenario, resulting in a relative reduction of 43% of all car trips. This drastic reduction is caused mainly by the reduced car availability and the good long-distance alternative due to the additional train lane. The utility function for public transport is dominated by the number of exchanges on long trips, which is used as a proxy for the quality of public transport service. A new suburban train reduces the number of exchanges up to two in this specific region for all trips to the city center. Therefore public transport becomes very attractive in this scenario. The later increases the attractiveness of public transport not only by reducing travel times but also by reducing the average number of stepovers, which is a proxy-variable for the quality of local public transport service.

The main reason for the low bike share can be found in Table 5: The average trip length for bike trips is about one kilometer longer compared to the city average (blue values in Table 5). This can be observed for the other modes as well. Taking a closer look at the trip lengths for different purposes in Table 6, one sees that trips to necessary infrastructure are significantly longer, indicating that the study area has a reduced accessibility to shops, schools and work-locations. This can also be seen by the high trip durations in Table 5 on the right side.

Next, we look at the traffic simulation of public transport to see the net-effects of the change of the demand.

5.2. *Traffic simulation*

The SUMO traffic simulator was used to model the effect of demand changes of the changes described in section 2.2 on urban traffic, specifically on public transport, and hence puts the changes of trips in an operationalized context. Using the trips generated with TAPAS demand modelling for the whole city of Berlin, the observation area of the resulting SUMO model is defined to Berlin-Spandau as depicted in Fig. 5. The simulation output parameters *tripinfo-output and stop-output* - as described in section 3.3. – are aggregated in order to visualize possible shifts in passenger volumes between he compared scenarios. Therefore, the respective volume information is mapped on georeferenced station data including path shapes of public transportation routes. Fig. 5 depicts the resulting network passenger volumes for the reference scenario *Null*.

The red lines indicate public transport passenger flows scaled by thickness where narrow lines mean low traffic volumes and broad lines represent high traffic volumes. The underlying data is aggregated over one day on a segmented, station-to-station basis. This means that occupancy between two neighboring stops is accumulated over all public transport vehicles serving these two stops per day. It can be seen that the horizontal line with the highest thickness clearly marks the metro line U7 going from Spandau main station (located in the bottom left corner) towards Berlin downtown. This does not surprise as track-bound transportation vehicles have far higher capacity and passenger volumes. Other, more narrow lines mainly represent bus lines, functioning as

Table 6
Average trip length for various trip purposes of the different scenarios (black) and for the rest of the city of Berlin (blue).

	Average trip length in km for primary shool			Average trip length in km for shopping			Average trip length in km for shopping		
Transport means	BU	FW	EB	BU	FW	EB	BU	FW	EB
Bike	2.4 | *2.9*	4.1 | *2.9*	4.1 | *2.9*	5.6 | *4.4*	5.3 | *4.4*	6.7 | *4.4*	5.6 | *4.4*	5.3 | *4.4*	6.7 | *4.4*
Walking	1.7 | *1.1*	1.4 | *1.1*	1.7 | *1.1*	2.0 | *1.7*	2.4 | *1.7*	3.0 | *1.7*	2.0 | *1.7*	2.4 | *1.7*	3.0 | *1.7*
Car	n/a	n/a	n/a	7.3 | *6.6*	6.9 | *6.6*	8.9 | *6.6*	7.3 | *6.6*	6.9 | *6.6*	8.9 | *6.6*
Car (Co-driver)	n/a | *5.3*	6.0 | *5.3*	10.3 | *5.3*	6.7 | *6.7*	6.6 | *6.7*	9.5 | *6.7*	6.7 | *6.7*	6.6 | *6.7*	9.5 | *6.7*
Public transport	6.4 | *7.0*	5.1 | *7.0*	10.4 | *7.0*	9.4 | *8.4*	9.4 | *8.4*	12.5 | *8.4*	9.4 | *8.4*	9.4 | *8.4*	12.5 | *8.4*

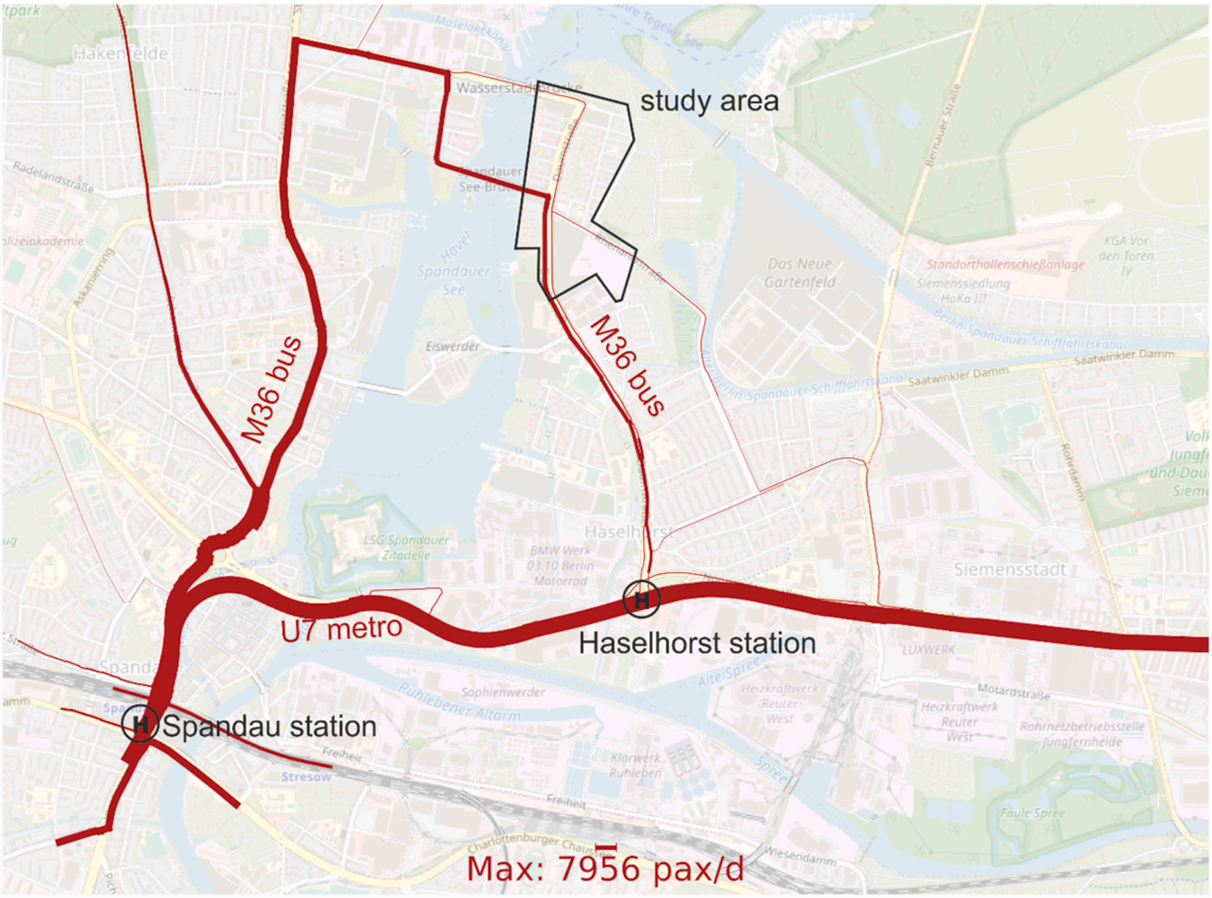

Fig. 5. Public transport passenger volumes scenario Null.

connecting vehicles to rail mass rapid transport. Hereby the line M36 is of special importance for the new residential area, going north from Spandau station, then turning right to cross the river Havel and afterwards turning south again to end at Haselhorst Metro station, located in the very center of the figure. It is worth noticing that, analogously to traffic demand from TAPAS, public transport lines in SUMO were "cut" at the border of the simulation observation area, as can be seen to the bottom left of the figure.

In order to understand the effects that the scenarios shown in Table 2: have on passenger volumes in the SUMO simulation model, differences in passenger volumes are calculated for these three scenarios:

The BU scenario "business as usual" only has slight changes in public transport, specifically reducing the interval of the bus line M36 by half (from every 10 to every 5 min). It leads to only small shifts in passenger volumes, e. g. a rise of approximately 200–300 passengers/day for metro line U7. Moreover, passenger volumes for the M36 bus slightly decrease on the west side of river Havel but marginally rise on the east side. This can possibly be explained by the better connection to the metro via Haselhorst station coming from the north, avoiding the longer and more congested route via Spandau station.

Scenario FW shows only slight changes in passenger volumes as well: The additional bus line affects only slightly higher passenger volumes for bus line M36, comparable to the described changes in the BU scenario. While the additional bus line can avoid traffic congestions it is still prone to implications from traffic lights.

In contrast to the two scenarios FW and BU, the EB scenario results in considerable additional passenger volumes for public transport: while building a completely new metro line does mean large investment and long construction time, it does also result in substantial rises in passenger volumes, as shown in Fig. 6: it clearly shows the additional passenger volumes for the newly built metro line in comparison to Fig. 5 above. Note that the volume of the bus M36 has not declined, meaning, that all traffic on the new subway line is indeed from the modal shift towards public transport.

6. Discussion and conclusion

The analysis shows the effects of planning new residential areas without contributing to large-scale infrastructure changes to improve public transport and shortcomings in local infrastructure lead to higher demand, and therefore traffic, in the existing modes of transportation. With longer distances that have to be travelled, as shown in Section 4.1, the modes of transportation shift from walking and biking to car and public transport. The public transport will only serve as an alternative for these longer distances, if the travel times and direct lines are inviting enough, as can be seen in the EB scenario.

In this work we model the region using two years: The reference year for calibration and the projected scenarios for 2030. This approach simplifies the population generation, because two independent populations are used for the simulation. However, if annual updates are used, the cohort effects for socio economic development like education, employment, marriage, birth and death as well as mobility options like driver license, seasonal tickets and car ownership could be analyzed in a more precise way, which could help decisionmakers to adopt the measures to the changing needs of the population.

Even though, the presented work leads to the conclusion, that large infrastructure and public transport projects are necessary for large residential projects, to lead to the use of ecological means of transport. Otherwise, the individual needs of fast transportation will be served by

Fig. 6. Public transport passenger volumes scenario EB.

motorized transport. Public transport projects take usually much longer planning and building processes than the residential areas themselves. These considerations have to be part of an integrated residential planning. Intermediate options, like express buses can help to bridge the time gap of finishing extensions of a railway system, but busses suffer from congested roads where separate bus lanes are not available. However, sufficient supply of local shopping facilities and schools can reduce this problem because of emphasizing short-range modes like walk and bicycles, except for commuting trips, which are a domain of public transport and cars due to the longer distances to workplaces from new residential areas.

In this work we presented the simulated results of several mobility measures for a newly built residential area. We showed that short term measures cannot compensate the difficult geographical layout of the study area. On average the trips are substantially longer compared to the city average. Promoting bike trips is not enough because of the limited range of bikes. Public transport has many advantages for long trips into the city center because of no traffic jams and no searching for parking lots. Therefore, the last scenario including a new suburban train shows the biggest change in modal shift. Looking at the passenger counts on the multiple bus and train lines we see similar effects. To summarize, it can be stated that extensive measures such as building new metro infrastructure are needed to achieve noticeable and effective change in public transport passenger volumes: Connecting the bike lanes to a city-wide network and extending the high-performance public transport enables the people in the study area to perform their daily mobility by public-transport without reducing bike trips and reducing car-based mobility by more than 40%. For future work, it would be interesting to evaluate the simulated mobility behavior with the reported mobility behavior in near future and to compare the performance of the implemented mobility measures with the ones presented in this paper.

CRediT authorship contribution statement

Matthias Heinrichs: Writing – review & editing, Writing – original draft, Project administration, Conceptualization. **Stefanie Schöne:** Writing – review & editing, Writing – original draft, Visualization, Validation, Conceptualization. **Jakob Geischberger:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Conceptualization. **María López Díaz:** Writing – review & editing, Writing – original draft, Validation, Software, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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