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Why closing an airport may not matter

The impact of the relocation of TXL airport on the bus network of Berlin

Andreas Neumann

Abstract This paper investigates the closure of TXL airport and its impact on the bus network of Berlin. The results of the scenario are based on a co-evolutionary algorithm for public transit network design. The algorithm is integrated in a multi-modal multi-agent simulation. In the simulation, competing minibus operators start exploring the public transport market offering their services. With more successful operators expanding and less successful operators going bankrupt, a sustainable network of minibus services evolves. In the TXL scenario, the impact of the massive change in demand is found to be locally confined. Only transit lines serving TXL airport directly are affected. Furthermore, transit lines are found to have a higher probability of surviving if connecting two different activity centers, e.g. transit hubs. Following a hub-and-spoke approach by letting the line end in low-demand areas renders a line less attractive because of a reduced connectivity, e.g. to one train station only.

The paper further demonstrates that the underlying minibus model also works for huge scenario areas. In this paper, the model creates a bus network for the city of Berlin. In addition, the model creates similar networks when using a) a reduced sample size of the demand, b) standard buses with an enlarged capacity instead of the eponymous minibuses, and c) the combination of both.

Keywords Demand Responsive · Evolutionary Algorithm · MATSim · Multi-Agent Simulation · Public Transport · Transit Network Design

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1 Introduction

Major changes in travel demand such as are expected with the opening of the new international airport of Berlin and Brandenburg (BER, Germany) are difficult to overcome with traditional expert knowledge. The state-of-practice approach of the stepwise local optimization will not be sufficient to restructure the current transit network that is grown over decades. Especially, the existing airport Tegel will cease operations. Thus, transport planners face a completely new situation. Overcoming old habits, they need to recreate the bus network serving the area around the former airport from scratch. The only information available to them is the travel demand forecast and the road infrastructure that is already in place.

Analytic approaches to solve the transit network design problem include e.g. Ceder and Wilson (1986); Baaj and Mahmassani (1995); Kuah and Perl (1988); Chang and Schonfeld (1991); Chien and Schonfeld (1998), and more recently (Jara-Díaz and Gschwender, 2003). However, most analytic approaches lack the ability of being applied to large-scale scenarios which is why heuristics are often used to solve real-world planning problems (e.g. Axhausen and Smith, 1984).

The minibus model applied in this paper follows Sáez et al (2008), Cortés et al (2009), and Tero et al (2010) in the application of bio-inspired algorithms and metaheuristics (Osman and Laporte, 1996). But rather than solving one system-wide instance, the approach looks at a number of competing elements, each of them evolving according to its own optimization procedure. This is not the same as swarm behavior, where multiple instances cooperate to solve a problem (e.g. Bonabeau et al, 1999), but rather related to co-evolution and evolutionary game theory (e.g. Palmer et al, 1994; Arthur, 1994; Hofbauer and Sigmund, 1998; Drossel, 2001).

In the model, transit line operators compete each other and evolve by applying the genetic operators of mutation and selection to their lines. Mutations include changing the line's route profile, its time of operation, and its service frequency. Selection is represented by each individual line's fitness. Vehicles are removed gradually from unprofitable lines and when no vehicle is left, the line dies out. With more successful operators expanding and less successful operators going bankrupt, a sustainable network of minibus services evolves.

At the end of each day, each operator calculates the revenue generated by each of its lines and the expenses related to these lines. Revenue is generated by collecting fares. The fare system allows for lump sums, distance-based fares, and combinations of both. Expenses consist of fixed costs and distance-based costs. Fixed costs cover expenses related to the vehicle, e.g. official operating license and driver. Distance-based costs, e.g. fuel, are summed up for each kilometer traveled by the operator's vehicles. Each operator provides as much services as it can afford. Operators thus transfer some of their profit to the passenger side. However, this is still far away from social cost pricing (Kaddoura et al, 2015).

The algorithm is set up as a Stackelberg game (von Stackelberg, 2011), with the operators as the leading player and the passengers as the followers. The operators state their quantities in form of the provided capacity. The passengers choose their best response in form of the least cost path. Opposing the schedule by e.g. going the long way on purpose, will usually yield a lower utility for the passenger compared to the least cost path. Thus, this is not a valid option for the passenger side. The leading side of the operators can then proclaim the new quantities of the their schedule well knowing that the passengers have to follow.

The minibus model has been integrated in the multi-modal multi-agent simulation of MATSim (MATSim, 2014; Neumann, 2014). The model has been verified through multiple illustrative scenarios that analyze the model's sensitivity towards different demand patterns, transfers, and the interactions of minibuses and a formal operator's fixed train line (Neumann and Nagel, 2012a,b, 2013; Neumann, 2014). The minibus model's first application to a real world scenario in Neumann et al (2015) focused on the creation and simulation of real minibus networks in South Africa.

This paper is structured in three sections. The following section 2 features the application of the model to a real world planning problem of a public transport company in Berlin, Germany. Instead of reconstructing a bus network from scratch as in the South African case, a major change in the demand and its effects on the bus transit network are analyzed. The relocation of the airport Tegel (TXL) to the new airport of Berlin and Brandenburg (BER) provides a background for this scenario. The second section, section 3, demonstrates that the model also works with a) a 10 % sample of the population, b) standard buses with an enlarged capacity instead of the minibuses, and c) the combination of a) and b). The last section, section 4, features the application of the minibus model to the whole city of Berlin.

2 The impact of the relocation of TXL airport on the local bus network

The content of this section is an edited version of Neumann (2015).

2.1 Scenario description

The Berliner Verkehrsbetriebe (BVG) is Berlin's main public transport company and runs all kind of services with the exception of the S-Bahn urban rail system. This includes bus services, the subway network, the largest tram network of Germany as well as ferry services. As depicted in Figure 1, the scenario area is situated close to the center of Berlin. The detail shows the bus network for the scenario area and the location of TXL. Note that TXL is exclusively served by buses operated by BVG.

In this paper, the BVG-MATSim model for the year 2008 is used (Neumann et al, 2014). In brief, the model contains about 115,000 links, about 15,000

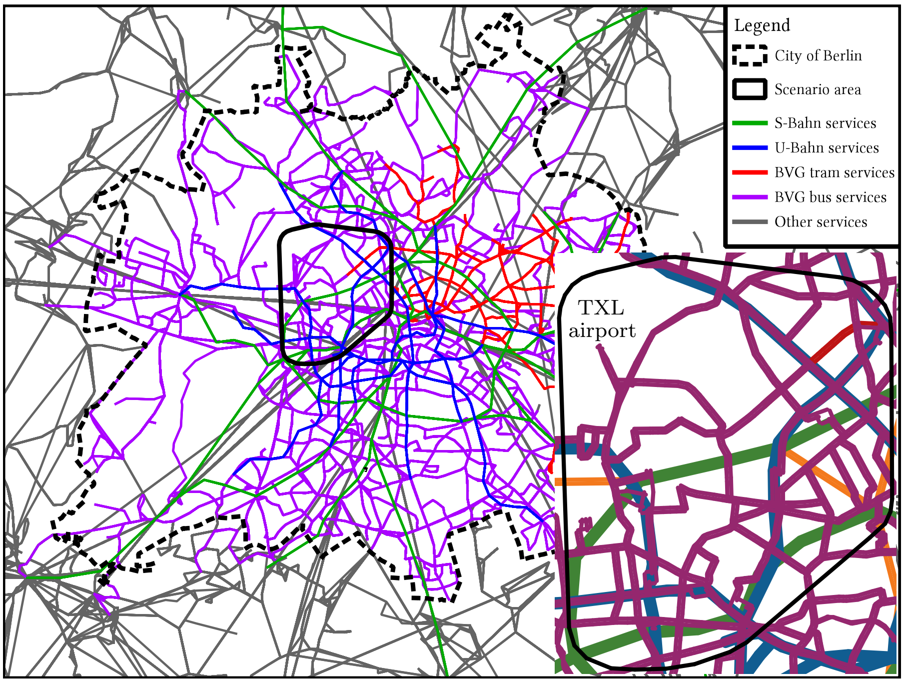


Fig. 1: Location and close-up of the TXL scenario area showing the public transport network — The category “other services” includes bus and tram services not operated by BVG as well as ferry services and non-commuter rail services

directed stops, 6.0 million agents, and 539 public transport lines operated by BVG and other companies of the city of Berlin and the state of Brandenburg.

To keep the running time of the simulation in bounds, the scenario is reduced to a 25 % sample of the population. In addition, all agents not passing through the scenario area are removed from the population. The remaining population consists of 306,842 agents. Since each of these agents actually represents four agents of the full population (100 % sample) the public transport supply is also altered: The capacity of each vehicle type is reduced to one quarter. The fare, the boarding and alighting delays for each vehicle type are increased by a factor of 4 accordingly. For a more detailed configuration of MATSim and the model itself, the interested reader is referred to (Neumann, 2014) and (Neumann et al, 2014).

In the base scenario, TXL is still operational. For further reference, this is called the *TXL* case. In the altered scenario, TXL is supposed to be closed. All activities located at TXL are relocated to BER. This assumes that travelers as well as employees will simply move to the new airport. This furthermore ignores changes in demand that are induced by e.g. a higher projected attractiveness of BER (Bubalo and Daduna, 2012). The altered scenario is referred to as the *BER* case.

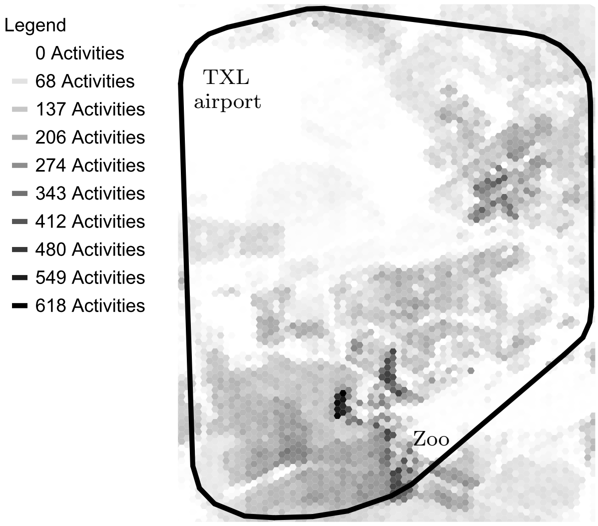


Fig. 2: Distribution of activities within the scenario area — *BER* case. A total of 7,672 activities are relocated from TXL to the new airport BER.

Figure 2 depicts all activities for the *BER* case. A total of 7,672 activities are relocated from TXL to the new airport of BER and are therefore not shown in the figure. In the *TXL* case, these activities form a singular source of demand which would by far dominate in Figure 2. Note that large parts of the scenario area surrounding the airport feature only a low density of activity. Thus, the high density spot at TXL is isolated from the rest of the city, e.g. the City West around the transit hub of Zoologischer Garten (Zoo).

Setups

The same input data and configuration is used with two different setups of the scenario called *Corridor* and *Area*.

Corridor The *Corridor* setup removes all four lines serving TXL from the transit supply. Namely these are 109, 128, the express bus X9, and the airport express TXL, see Figure 3a. Note that 109 and X9 both connect the transit hub at Zoo to TXL. Minibuses can only serve passengers within a 100 m wide buffer around the removed lines. That is, they can serve all formal transit stops within that buffer. They are not restricted otherwise. A minibus operator can decide to ply outside the buffer. In this case, its vehicles are not allowed to pick up or drop off any passengers as long as the vehicle is outside the buffer. In order to test for stability, the four removed bus lines serve as seeds for the initial minibus operators. That is, for each bus line one operator is initialized with approximately the same *route*,

(a) All bus lines serving TXL are removed in the *Corridor* setup. These lines serve as seeds for the initial minibus operators.

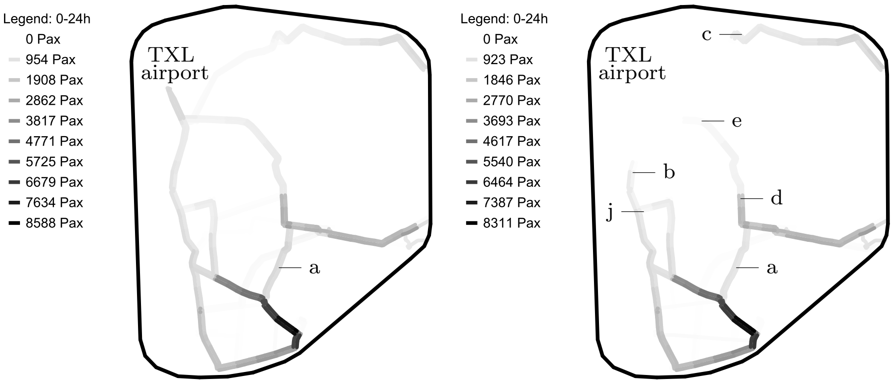
(b) Public transport services in the *Area* setup. All bus lines operated by BVG within the scenario area are removed.

Fig. 3: Comparison of public transport service of the *Corridor* setup and the *Area* setup. Scenario area (black), U-Bahn services (blue), S-Bahn services (green), BVG bus services (purple) and other services (orange).

operating time, frequency, and capacity. Note that the all operators founded in later iterations are created from scratch.

Area The *Area* setup removes all bus lines operated by BVG from the scenario area. That is, lines operating only within the scenario area are removed completely. Lines starting or ending within the area are truncated so that they start and end at the first stop of the scenario area. The departures of the remaining parts of the lines are modified in such a way that the transit supply outside the scenario area isn't altered compared to the original transit schedule. The final transit network of the *Area* setup is shown in Figure 3b. Again, the four removed bus lines function as seeds.

An *ensemble run* is performed for the *Corridor* and the *Area* setup. Each ensemble run consists of ten runs with identical configuration and input data. Only the initial random seed is varied. The heuristic of the minibus model is then able to produce different results with the same initialization. The results of the ten runs of one ensemble run are fused to allow for a more reliable analysis and to identify stable and repeating solutions.



(a) *TXL* case

(b) *BER* case

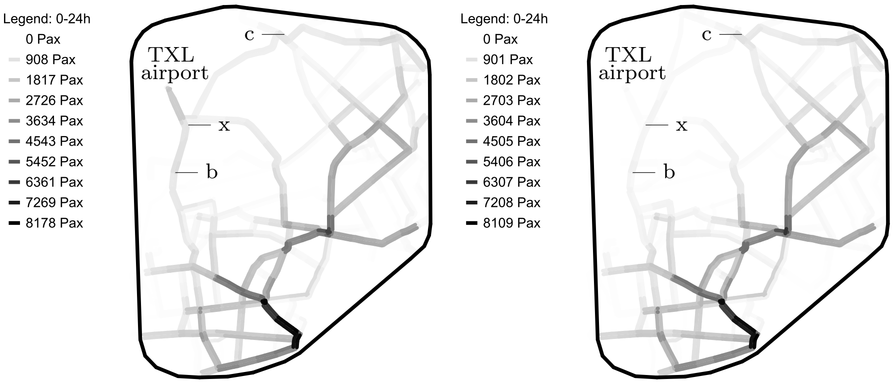
Fig. 4: Comparison of the average number of passengers served per street section of all ten runs — *Corridor* setup

2.2 Results of the Corridor setup

The results of the *Corridor* setup are depicted in Figure 4. For the *TXL* case, all four transformed bus lines serving TXL prevail. In addition, there is a non-stop connection from the corridor of the TXL Express bus to the X9, denoted (a). This implies that from the point of view of the model, the formal service on this corridor, the bus line 245, could be improved. While this is not done, it is vulnerable to competition by minibuses. In the *BER* case, this non-stop connection is operated as well. However, the bus stop at TXL is not served anymore. The terminus of 109 and X9 is relocated to the U-Bahn station of Jakob-Kaiser-Platz (b), compare Figure 3b. The bus line 128 is reduced to the part between the U-Bahn station of Kurt-Schumacher-Platz (c) and its eastern terminus. The airport express is shortened to the S-Bahn station of Beusselstrasse (d) and only about half the capacity is offered onwards to the light industrial park (e). Apart from TXL, the rest of the network is unaffected by the closure of the airport. That is, in both cases, the same demand is served on the same corridors.

Since the opening of BER has been postponed only a few days before the planned opening date, information on the planned bus lines and routes is available. With the closure of TXL on 3 June 2012, BVG had scheduled the following changes for bus lines serving TXL (BVG, Berliner Verkehrsbetriebe, 2012):

109	The terminus is relocated from TXL to the S-Bahn and U-Bahn station of Jungfernheide, denoted (j) in Figure 4b.
128	The terminus is relocated from TXL to the U-Bahn station of Kurt-Schumacher-Platz (c).
X9	This line is canceled.



(a) *TXL* case (b) *BER* case

Fig. 5: Comparison of the average number of passengers served per street section of all ten runs — *Area* setup

TXL The TXL Express bus is substituted by a regular bus line. The terminus is relocated from TXL to the S-Bahn station of Beusselstrasse (d).

Overall, the scheduled changes of BVG match the outcome of the minibus model. However, the minibus model indicates that there is enough demand for maintaining the express bus line X9.

2.3 Results of the Area setup

For the *Area* setup, the results, depicted in Figure 5, are basically the same. Although the minibus operators are allowed to search freely in the complete scenario area, the resulting networks look similar. Again, with the exception of TXL itself, the same demand is served on the same corridors. Differences occur on the branches from TXL to the nearest train station. While the TXL Express bus shows the same pattern as in the *Corridor* setup, the other bus lines do not cease service completely. Recall that in the *Corridor* setup some formal bus lines are still present. These lines provide a direct connection from Jakob-Kaiser-Platz (b) to Kurt-Schumacher-Platz (c). In the *Area* setup, these lines are missing and their demand is served by the minibus.

2.4 Discussion and summary

The *Corridor* setup demonstrates that the closure of TXL does not affect the remaining bus network. Only the branches from TXL to the nearest train station are affected. Essentially, the *Area* setup provides similar results. The remaining network is unchanged showing very stable results with reoccurring solutions throughout the individual runs of the ensemble run. The impact of

TXL on the public transport network is thus locally confined. The comparison with the projected changes of BVG reveal a close match with the minibus model's solution. However, information on the planning instruments and data used by BVG is not available.

Furthermore, the results of the *BER* case indicate that effective bus lines should connect centers of activity. A bus line may pass through low-demand areas, but still be profitable by offering more transfers to the rest of the transit network. Furthermore, this may provide a direct connection, e.g. between otherwise unconnected train stations as in the example of the corridor from (b) to (c). This further increases the connectivity of the network. In contrast, a hub-and-spoke pattern more likely looses this connectivity because of each bus serving only as a feeder. For example, the TXL Express bus terminates in the light industrial park and functions as a one-sided feeder to the train station of Beusselstrasse. It would attract more passengers if the terminus was relocated to a train station in the northwestern part of the scenario area.

3 Going small – Towards a large-scale application

In former studies, the minibus model has been applied using larger samples of the population, e.g. 25 % as in section 2 or even 100 % as in the examples of Neumann (2014). While this delivers the most accurate results the computation time may block practitioners from using the model on a daily basis. This section focuses on reducing the sample size of the population in order to increase the computational performance of the model. In addition, the model is tested with larger regular vehicles transit authorities use in their bus fleets.

3.1 Scenario description

This paper reuses a case study published earlier. For the full description of the case study, the reader is referred to Neumann (2014).

As depicted in Figure 6, the model includes public transport services all over the city of Berlin as well as some parts of Brandenburg. The scenario area is located in the south-west of Berlin. It covers the eastern part of the district of Berlin Steglitz-Zehlendorf and the town of Teltow in Brandenburg.

Based on the relaxed model of the actual state of 2008 (Neumann et al, 2014) a diluted 100 % scenario is created. That is, compared to the original scenario, only the demand changes. Infrastructure like network and public transport supply are used without any further adaptation. For the demand, all agents "touching" the scenario area as depicted in Figures 6 and 7a are kept in the population of the scenario. All agents not "touching" the scenario area are removed. An agent "touches" the scenario area, if it passes over one of the scenario area's street sections. This includes all agents using a private car or one of the public transit vehicles but not agents using one of MATSim's teleported modes, i.e. walking, cycling, and long distance access and egress

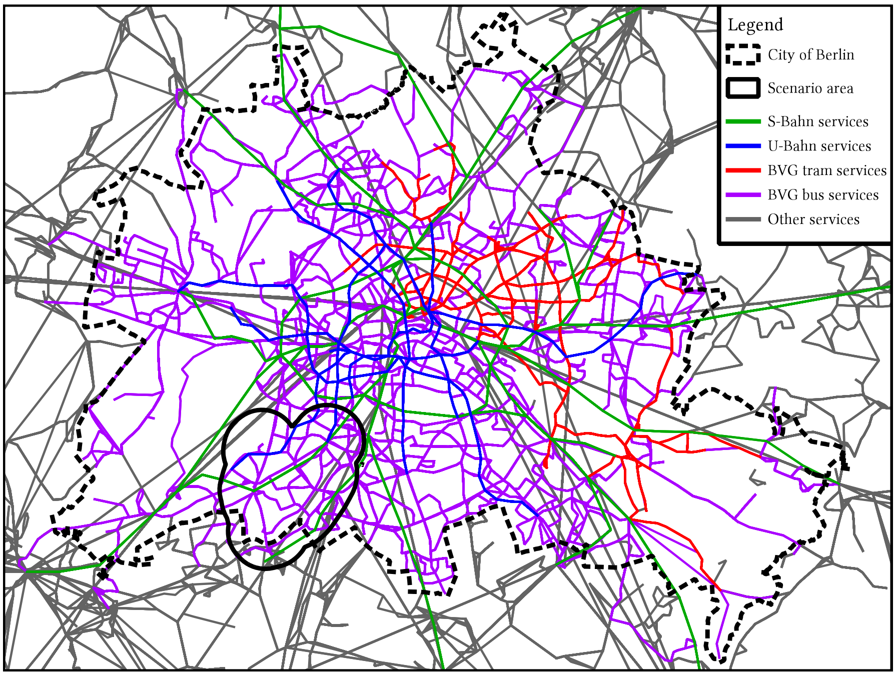
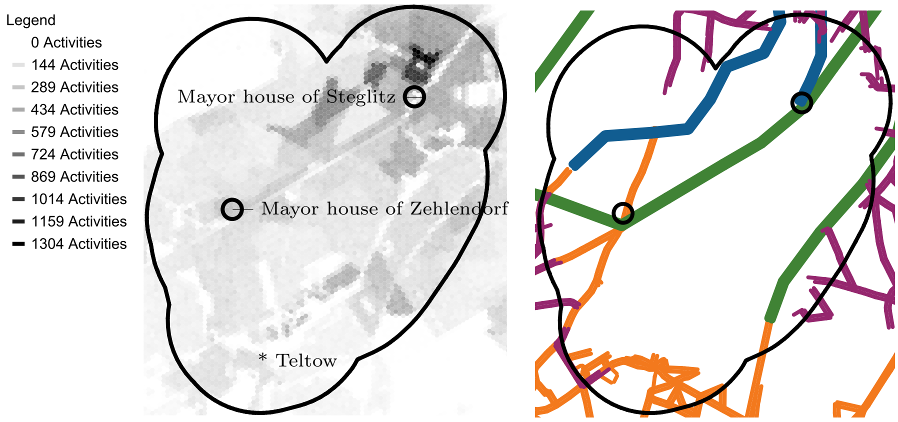


Fig. 6: Public transport network of the city of Berlin — The category “other services” includes bus and tram services not operated by BVG as well as ferry services and non-commuter rail services.

walks to access public transport. This does not automatically include all agents with an activity within the area. For example, activity types defined by the underlying household survey may be linked by walking trips only. In this case, the agent has no impact on other agents and thus can be removed. Contrarily, activities related to public transport, e.g. boarding, transferring, and alighting, imply using a transit vehicle and are thus included. With this definition, the total demand can be reduced to about 10 percent, i.e. from about 6 million to 593,337 agents. Note that this still represents a 100 % sample of the population that “touches” the scenario area according to the above definition.

The setup of the case study removes all bus lines operated by BVG from the scenario area. That is, lines operating only within the scenario area are removed completely. Lines starting or ending within the area are truncated so that they start and end at the first stop of the scenario area. The departures of the remaining parts of the lines are modified in such a way that the transit supply outside the scenario area isn’t altered compared to the original transit schedule. The final transit network is shown in Figure 7b.

The removed BVG bus services leave a market niche which is then filled by the minibus model with new transit services. The minibus model proposes



(a) Distribution of activities within the scenario area

(b) All bus lines operated by BVG (purple) within the scenario area are removed leaving a market niche for the minibus

Fig. 7: Activity distribution and remaining regular public transport service of the scenario area. Scenario area (black), U-Bahn services (blue), S-Bahn services (green), BVG bus services (purple) and other services (orange).

a transit network as depicted in Figure 8a. This transit network acts as the *Reference* case for the following three setups.

3.2 Setups

All three setups use a slightly altered configuration of the *Reference* case study. The following modifications are made:

Standard Bus	This setup replaces the minibuses of the *Reference* case with regular standard buses used by BVG. In this case, the capacity per vehicle is increased from 10 pax to 70 pax. The cost structure is as well taken from BVG. That is, vehicle-related costs per day, per distance, and per time in operation represent planning figures of BVG and can thus not be disclosed. The remaining configuration and input data is the same as in the *Reference* case.
Reduced Population	This setup reduces the population size to a 10 % sample of the population of the *Reference*. Accordingly, the size of the vehicles is reduced from 10 passengers to 1 passenger only. That is, the vehicle is either empty or fully loaded. The vehicle-related costs decrease as well by a factor of 10. Otherwise, the setup is the same as in the *Reference* case.

Combination	This setup replaces the minibuses of the *Reference* case with regular standard buses used by BVG and reduces the population size to a 10 % sample of the population of the *Reference* case. The capacity of the standard bus is thus reduced to 7 pax. The corresponding cost figures of BVG decrease again by a factor of 10. Otherwise, the setup is the same as in the *Reference* case.

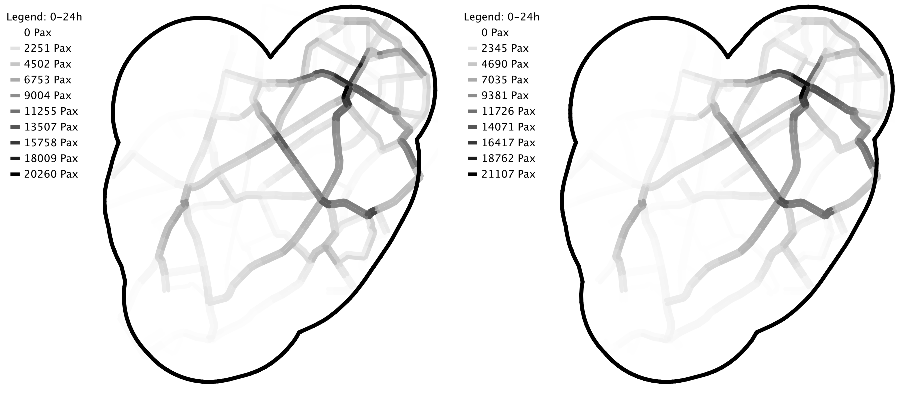
An *ensemble run* is performed for the each setup and the *Reference* case. Each ensemble run consists of ten runs with identical configuration and input data. Only the initial random seed is varied. The heuristic of the minibus model is then able to produce different results with the same initialization. The results of the ten runs of one ensemble run are fused to allow for a more reliable analysis and to identify stable and repeating solutions.

3.3 Results

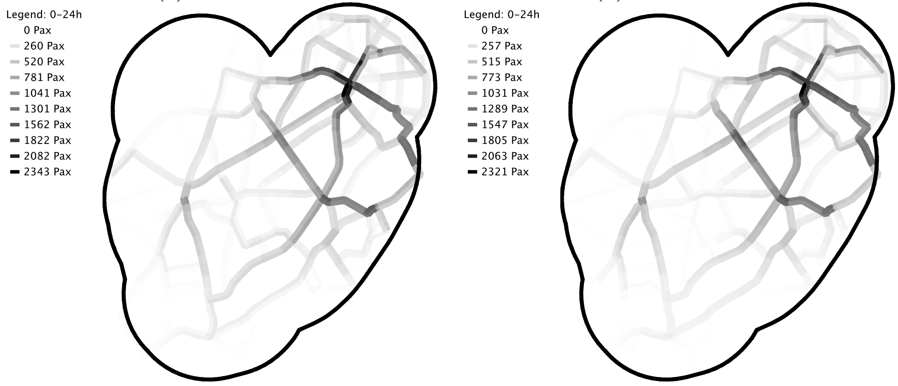
The resulting transit services of all three setups and the *Reference* are depicted in Figure 8. The comparison with the *Reference* in Figure 8a reveals a close match in terms of street sections served and number of passengers served. Basically, the same amount of passengers is served along the same street sections for all three setups. Note that the lower number of passengers served in Figures 8c and 8d derives from the smaller population sample. For the setups using standard buses, namely *Standard Bus* and *Combination*, slight differences occur in the secondary network. The higher capital costs of full-sized standard buses do not allow for a ramified network. Thus, there is a tendency to concentrate services on high-demand corridors and to reduce capacity on low-demand street sections.

The more detailed figures of Table 1 indicate a considerably higher number of transfers for all three setups when compared to the *Reference*. However, the average total door-to-door travel time of the agents decreases by at least 2 minutes. This means, agents need to transfer more often, but can nevertheless travel faster than in the *Reference* setup. Furthermore, the longer access and egress walking time for the two standard bus setups (*Standard Bus* and *Combination*) indicate that agents need to walk a longer distance to and from the stop. This supports the findings of the aforementioned analysis of the resulting networks. The larger vehicle size used in the standard bus setups forces the operators to concentrate their capacities on corridors. As a result, the service coverage in low-demand areas decreases. The agents need to walk longer distances to those bus corridors. However, passengers gain by waiting less at the stops. Overall, the average score per agent increases. Also the number of agents that never reach their destination, e.g. due to insufficient provided capacities and thus denied boardings, decrease as well. In summary, the agents gain by having a more reliable service.

The comparison of the *Reduced Population* setup with the *Reference* reveals that passengers wait less at the stop and benefit from a shorter walk time. This



(a) Reference (b) Standard bus



(c) Reduced population (d) Combination

Fig. 8: Resulting minibus services showing the average number of passengers served per street section

is mainly, due to the limitations of the model. The vehicle capacity of one single passenger increases the impact of each single passenger. As a consequence, operators tailor their supply to the requests of individual passengers. The resulting supply resembles a taxi-like door-to-door service. This is only later compensated in the *Combination* setup when the capacity of the vehicles is increased to 7 pax. Then operators again need to find a solution that suits several requests.

3.4 Discussion

The results support the thesis that passengers gain when operators concentrate their bus services on high-frequency corridors. This is a strategy that the transit authority of Berlin BVG has implemented in 2004 with the introduction of the Metrobus system. However, it should be noted that the current implemen-

Table 1: Passenger performance figures

	Reference				Standard Bus			
	Mean	SD σ	Min	Max	Mean	SD σ	Min	Max
Figures represent trips starting and ending within the scenario area only								
Avg. number of transfers	0.764	0.046	0.708	0.854	0.795	0.025	0.769	0.854
Avg. door-to-door travel time	30.4 min	1.1 min	28.7 min	32.6 min	28.3 min	0.5 min	27.6 min	29.4 min
Avg. access walk time	5.9 min	0.1 min	5.8 min	6.1 min	6.6 min	0.1 min	6.5 min	6.7 min
Avg. transfer walk time	0.0 min	0.0 min	0.0 min	0.1 min	0.1 min	0.0 min	0.0 min	0.1 min
Avg. egress walk time	5.8 min	0.1 min	5.7 min	5.9 min	6.3 min	0.1 min	6.2 min	6.5 min
Avg. waiting time at first stop	5.2 min	0.6 min	4.3 min	6.3 min	3.0 min	0.2 min	2.6 min	3.4 min
Avg. waiting time at transfers	5.0 min	0.7 min	4.0 min	6.1 min	3.2 min	0.2 min	2.9 min	3.8 min
The following figures include all trips of the population								
Avg. score per agent	87.146	0.528	86.303	87.731	88.038	0.392	87.076	88.424
Avg. score per non-stuck agent[1]	88.956	0.089	88.796	89.058	89.472	0.059	89.389	89.556
Avg. number of agents stuck	1806.300	588.555	1157.000	2819.000	1395.600	450.374	953.000	2500.000
Percentage of stuck agents	0.304 %	0.099 %	0.195 %	0.475 %	0.235 %	0.076 %	0.161 %	0.421 %
Circuity[2] of transit trips	1.353	0.002	1.349	1.355	1.354	0.001	1.353	1.356

	Reduced Population				Combination			
	Mean	SD σ	Min	Max	Mean	SD σ	Min	Max
Figures represent trips starting and ending within the scenario area only								
Avg. number of transfers	0.809	0.039	0.743	0.852	0.854	0.022	0.816	0.886
Avg. door-to-door travel time	26.0 min	0.9 min	24.5 min	27.9 min	25.8 min	0.8 min	24.9 min	27.3 min
Avg. access walk time	5.7 min	0.1 min	5.5 min	5.8 min	6.2 min	0.2 min	6.0 min	6.5 min
Avg. transfer walk time	0.0 min	0.0 min	0.0 min	0.1 min	0.0 min	0.0 min	0.0 min	0.1 min
Avg. egress walk time	5.4 min	0.1 min	5.2 min	5.5 min	6.0 min	0.2 min	5.8 min	6.2 min
Avg. waiting time at first stop	3.1 min	0.6 min	2.4 min	4.4 min	2.1 min	0.3 min	1.8 min	2.8 min
Avg. waiting time at transfers	2.8 min	0.3 min	2.2 min	3.2 min	2.2 min	0.3 min	2.0 min	2.8 min
The following figures include all trips of the population								
Avg. score per agent	90.229	0.281	89.596	90.525	90.610	0.449	89.420	91.005
Avg. score per non-stuck agent[1]	91.441	0.094	91.221	91.548	91.668	0.082	91.496	91.756
Avg. number of agents stuck	124.700	25.730	85.000	175.000	107.700	48.822	68.000	238.000
Percentage of stuck agents	0.214 %	0.044 %	0.146 %	0.300 %	0.185 %	0.084 %	0.117 %	0.409 %
Circuity[2] of transit trips	1.321	0.002	1.318	1.324	1.326	0.003	1.320	1.331

[1] An agent is excluded if it is stuck in at least one of the ten runs of the ensemble run of one of the setups.
[2] Circuity is defined as the ratio of network to Euclidean distance. Its reciprocal is Directness.

tation of the model does not respect the different walking speeds passengers have. For instance, mobility impaired people may find it cumbersome to bear an increased access or egress walking distance. Instead, they may still favor a low-frequency direct connection over a high-frequency service with more transfers. The underlying multi-agent simulation MATSim can be extended to include per-person attributes as walking speed into the optimization.

In this paper, the passenger agents were not allowed to alter their departure time, i.e. the time when they leave their last activity and start heading to their first stop. It is a well-known fact that passengers start to arrive in a coordinated way for low-frequency services, see e.g. Neumann et al (2013) and the references therein. Thus, the figures for the average waiting time at the first stop may differ. However, for inner-city transit, the service frequency is rather high and passengers tend to arrive randomly at the stop. This is especially the case for high-frequency bus corridors with a headway of 5 minutes or less.

Fig. 9: Distribution of activities. There is no single CBD. Note that this is a 10 % sample of the full population

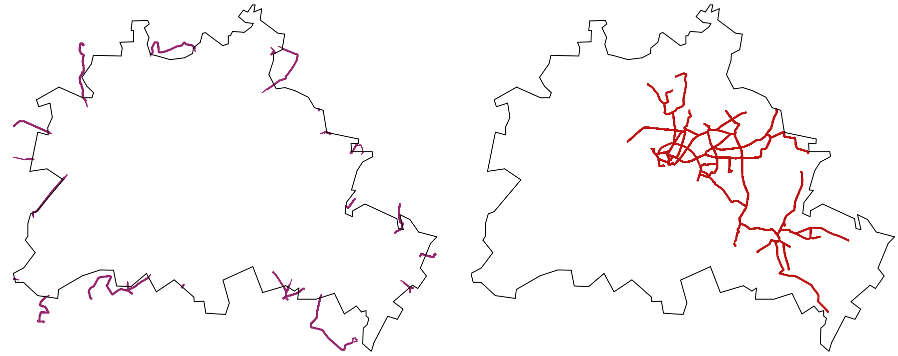
4 Going small – Towards a large-scale application

This application uses the same relaxed model of the actual state of 2008 from (Neumann et al, 2014) as described in section 3. The population is reduced to a 10 % sample. The resulting activity distribution shown in Figure 9 illustrates the decentralized structure of Berlin. Contrary to other large cities, Berlin features not a single central business district but rather features a several sub-centers.

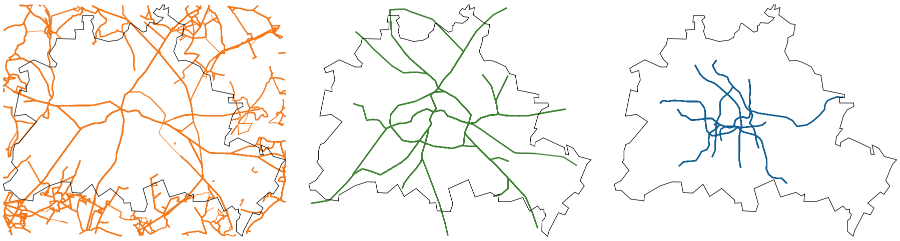
4.1 Scenario description

As in the other applications, buses operated by BVG are removed from the scenario area. The remaining bus services of BVG are depicted in Figure 10a. One of the legacies of the former division of the city of Berlin still evident today is the missing tram network in the western part of the city. This is to some part compensated by the more dense U-Bahn services in the western districts as the comparison of Figures 10b and 10e reveals.

The minibus model is set up in the same way as in the *Combination* setup of the application in section 3. That is, the minibuses are replaced with regular standard buses used by BVG. The capacity of the standard bus is reduced to 7 pax to match the reduced sample size of the population of 10 %. The cost figures of BVG decrease as well by a factor of 10. The minibus model fills in the market niche left by the removed BVG bus services. Potential bus stops



(a) Remaining BVG bus services (b) BVG tram services



(c) Other services (d) S-Bahn services (e) U-Bahn services

Fig. 10: BVG bus services are removed from the city area. The other transit modes remain unchanged. Note that BVG tram services are only available in the eastern part of the city

for new services are drawn from existing bus and tram stops. The resulting distribution of potential minibus stops is shown in Figure 11. As a result, the stops are equally distributed over the city and not biased, i.e. omitting the tram stops would significantly reduce the number of potential stops in the eastern part of the city.

4.2 Preliminary results

Although the minibus model creates a bus network for the whole area of the city, at this stage, only results for the district of Steglitz-Zehlendorf can be shown. As a reference, the resulting bus network is compared with the transit supply of the unaltered BVG bus services as encoded in the model of the actual state of 2008 (Neumann et al, 2014). That is, Figure 12a shows the number of passengers served by BVG buses per street section. Since the real figures cannot be disclosed the legend is omitted. As an estimate, the maximum value of the *Combination* is about twice as high as in the *Reference*. In consequence, the same number of passengers served in the *Combination* has only about half the intensity of the color than in the *Reference*. Note that the difference in the

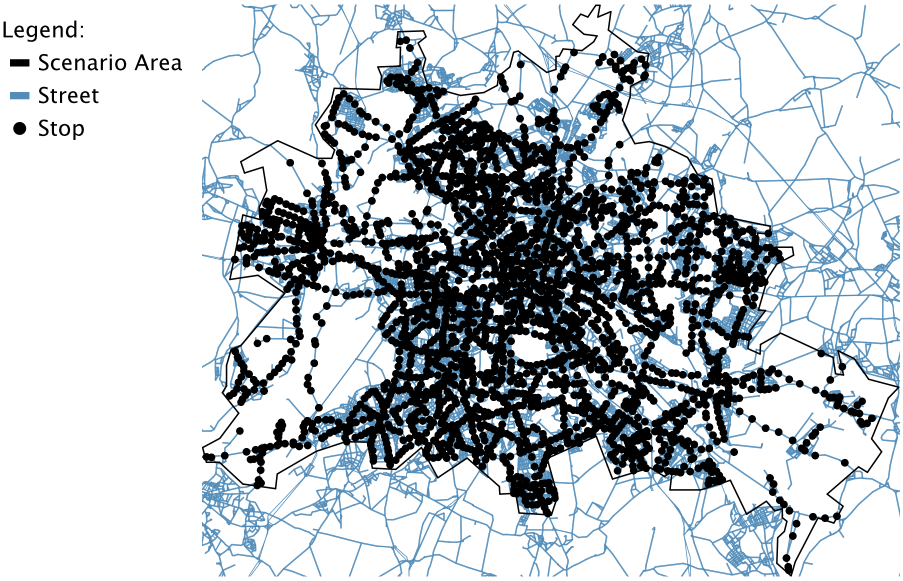


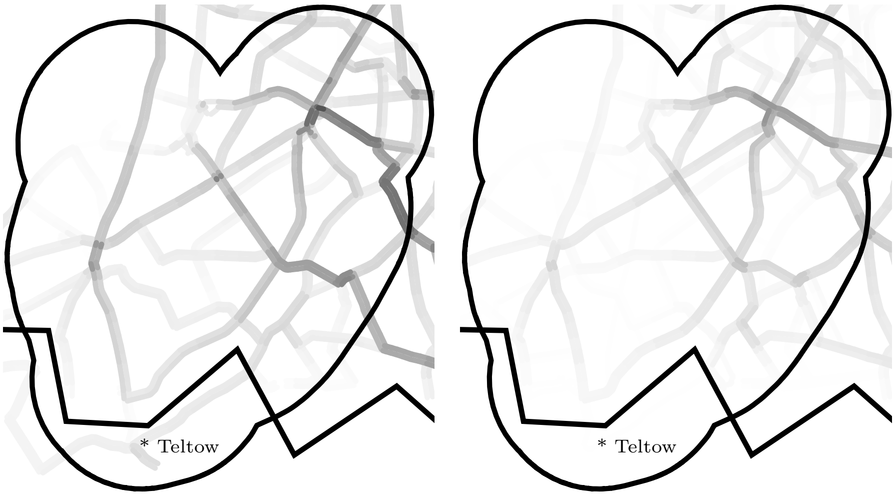
Fig. 11: Potential bus stops are equally distributed within the city

maximum value and thus in the gray-scale derives from the direct competition between the transit modes in areas not shown in this figure.

The detail of Steglitz-Zehlendorf in Figure 12 demonstrates that both the *Reference* network of BVG and the bus network proposed by the minibus model (*Combination*) are quite similar in terms of street sections served and number of passengers served. Note again that the difference in the scaling derives from the competition of services in other areas.

Also the comparison of Figure 8d with Figure 12b shows that the minibus model creates similar networks independent of the size of the scenario area. As a reference, the maximum value at the mayor house of Steglitz is about the same in both figures. Recall that the bus operators are not allowed to operate outside the scenario area. Since the scenario area of section 3 is not congruent with the city area of Berlin some areas are exclusive to one of the scenarios. In consequence, the town of Teltow can only be served in section 3 whereas operators in the scenario of this section can also offer direct services to other districts of Berlin.

In summary, the model can be applied to large metropolitan areas. The resulting bus networks are similar to those of the locally-confined scenario of section 3. The removal of the locally-confined scenario area allows the model to propose transit services that link different districts of the city. Thus passenger flows between different parts of the city become apparent and can be incorporated into the transit network planning process.



(a) Reference (b) Combination

Fig. 12: Detail of the resulting minibus services showing the average number of passengers served per street section. In addition to the city boundary of Berlin, the figure also shows the scenario area used in section 3

5 Outlook on further research

The individual route choices of passengers can be improved by using a taste-variation router (e.g. Graf, 2013). Passengers can then have individual sets of parameters and thus may choose different routes for the same pair of origin and destination, e.g. avoiding transfers or certain types of services. In conjunction with a fare-dependent transit router this may even allow for a diversification of transit services. Agents can then react to changes in the transit system based on intrinsic motivation and personal income, e.g. to bear longer access/egress walking distances in order to pay a lower fare.

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