Simulating changing traffic flow caused by new bus route in Augsburg

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Abstract

Public transportation in cities is less popular than the private car due to lower personal flexibility, perceived comfort or the unavailability of infrastructure. The latter one is an issue in Augsburg with regard to outer districts since the existing star-shaped network layout requires a route through the inner city. A recent proposal called "Verkehr4.0" aims to extend the layout of the existing infrastructure by adding new express bus lines to connect outer city districts. This research paper investigates the direct traffic flow between the outer districts Stadtbergen and Göggingen in contrast to the existing flow via the central hub "Königsplatz". We implement an agent-based simulation comparing waiting times, travel times and total times spent on trips in the two scenarios. Furthermore, we model a measure dubbed "happiness" of the people as well as their willingness to change their mode of transport. The preliminary results of our simulation show that waiting time for public transport users decreases, while total time, travel time and happiness reveal no statistical difference through the introduction of an express bus line.

1 Introduction and Motivation

Traffic nowadays is an integral part of urban society since an effective way of transporting goods and travelling is necessary in urban areas [15]. However, the current dominance of cars leads to essential problems such as congestion, high fuel consumption, traffic noise, and air pollution, among others [11]. Many governments are investing time and funds to further improve the existing infrastructure and develop traffic-control strategies that are carefully examined due to the immense costs of large scale traffic projects [4].

In the mobility project "Verkehr4.0" in Augsburg [14] express buses are proposed as extensions to the current network in order to better connect outlying districts such as Lechhausen, Stadtbergen and Göggingen without the need to pass through the city centre.

This research paper aims at introducing a baseline simulation with and without the introduction of a direct bus line using an agent-based modeling (ABM) paradigm. Three key questions are to be answered in this research study: First, how and in what scope does the introduction of an express bus line influence both the waiting and overall travel time for public transport users? Second, can we detect a change in the overall happiness of both car and public transport users? Third, how are simulated people, who are willing to change their mode of transport, distributed spatially?

Section 2 presents the reasons for using agent-based modelling and simulation as well as an overview over related work in agent-based simulation of traffic. Section 3 introduces the

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model and simulation setup, subdivided into the subsections data preparation, conceptual model, and experimental setup. Section 4 presents the results of the simulations, which are analyzed and critically discussed in Section 5. Lastly, the paper closes with a conclusion and an outlook.

2 Related work in agent-based modelling and simulation of traffic

As suggested by reviewer 2, former sections 2 and 3 were united. Agent-based-models (ABM) are a relatively recent approach applied to understanding patterns in complex systems in which a traditional method with differential equations is not sufficient [13]. Unlike traditional approaches, ABM takes into account the behaviour and decision-making of the individuals and their interactions, which might fall into the category of qualitative data [3]. The individuals, so called agents, are characterized by the following properties: Autonomy in their behaviour, reactivity to their environment, pro-activeness by taking initiative and their social ability to interact [16]. One key advantage of agent-based simulation is its ability to capture emergent phenomena such as the development of congestion in traffic scenarios [2]. Furthermore, ABM are flexible in a multitude of dimensions: adding or removing agents is simple, their complexity can be adjusted and users have the possibility to inspect both single agents as well as aggregates [2]. However, complex systems are bound to be influenced by both known and unknown factors, often referred as "soft factors" [2] as well as requiring more computation power [10].

ABM is especially useful for simulations at the micro scale due to the ability to differentiate the entities in terms of rules [2, 4], even though this presents a challenge in urban environments [8]. Traffic flow is influenced by many factors such as different traffic participants such as pedestrians, cyclists and public transport as well as intersections, traffic lights, one way streets and roundabouts. While it is computationally expensive to run detailed microscopic simulations, several research studies [17] utilize techniques such as parallelization to handle the massive amount of computations.

Simulating traffic flow in order to find patterns using either agent-based modelling or other methods has been extensively used in a wide variety of research studies. Martins-Turner et al utilize the software Jsprit, a separate tool from MATSim to model freight traffic in Berlin [9]. A macroscopic simulation of San Francisco traffic flow by Zhao et al [17] employs OpenStreetMap data as well as a Dijkstra-algorithm. Quantifying the impact of equalizing the ratio between the percentage of people using public transport and those using private cars has been reported in a study by Rahman and Zhou for Dhaka City [12] showing an increase in average travel speed as well as a decline in delay times with slight modifications to the modal split. Fujii et al [5] demonstrate the effect of an extended tramway in terms of traffic flow and car-pedestrian distribution with the results pointing out that the extension of a tramway can impact distant locations.

3 Model Setup

3.1 Data preparation

In our model, the areas of interest are the regions of Pfersee, Göggingen, outer parts of the inner city, and Stadtbergen with an extent between 48°33'5"N and 48°37'5"N and 10°85'E and 10°90'E, resulting in an area of about 20km². We use OpenStreetMap road network data due to its availability as well as its good representation of the real world and validity in urban areas [1], especially in our study area. A more abstract and simplified network with roughly 300 road segments is created in order to reduce computation time [10]. We employ data about the modal split [7], traffic counts [14] and the frequency of existing tramlines, gathered from the schedules of the public transport authority SWA to model the current situation as accurately as possible. Travel time along streets is derived from the length of the road segment in combination with the speed limit.

3.2 Conceptual model of the traffic simulation

A conceptual depiction of the simulation is visualized in Figure 1.

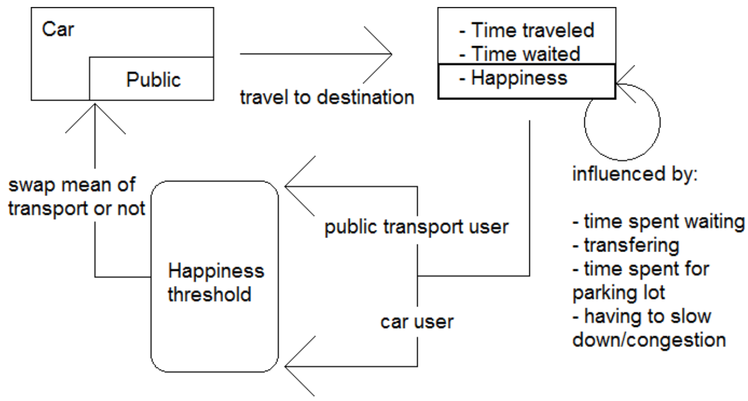

Figure 1 Conceptual view of the simulation.

People are randomly assigned to a node, which serves as their home. During the simulation, the car users drive towards their destination while public transport users wait for their bus or tram. Both car and public transport agents travel towards either Göggingen or Stadtbergen. After arriving and performing their activity such as work, they travel back home, which starts the cycle again. Happiness starts with a value of 100 units and decreases in two ways: An event occurring, such as cars slowing down or a transfer to another tram or bus, or diminishing over time due to traveling or waiting as a public transport user. Agents will consider changing their mode of transportation if the happiness value is below 50 units. Additionally, car agents search for the nearest bus or tram stop within 300m, since those are considered viable due to their walking distance [6].

Netlogo is chosen due to its ease of use, ability to integrate gis data and some experience with the application beforehand. A detailed documentation and explanation of the implemented model is provided in the Information tab of the Netlogo model, which will be published on the COMSES platform [2].

3.3 Experimental setup

The simulation uses 200 people, 100 filler vehicles and 4 trams as well as 2 buses for the hypothetical scenario. Transferring between trams or tram and bus deducts 10 units, slowing down 1.2 units, waiting 0.5 for each minute passed and 4 units for finding a parking space. This setup leads to around 10-20% of people considering to change their mode of transportation in order to inspect the spatial distribution. Both scenarios are run 15 times for 30'000 ticks in Netlogo (representing around 8,5 hours in the real world) and taking

[2] https://www.comses.net/

several minutes to compute in real time. The results, i.e. the states of the world when the simulation ends, are saved in .csv files as well as .png files. Using the white labels and the "car-to-public" attribute in Netlogo reveals people who changed their means of transportation, while the csv files analyzed with the software R present information about time attributes and happiness. An independent 2 group t-test in R is employed for the mean values with the null hypothesis stating that there is no difference between the two outcomes. This first requires a Shapiro-Wilk-Test to verify that the samples are distributed normally.

4 Results

Table 1 lists and presents the results of the experiment. The values display the minimum followed by the maximum and the average being marked with bold letters inside brackets. Forward slashes in the p-value column indicate that the normal distribution requirement of at least one sample has not been met. The rows show the attributes with the brackets indicating the agent class. Including the express bus route reduces the average total time for

Table 1 Comparison of the results of the two scenarios

	Current situation	**With bus route**	**p-value**
Total Time (cars) [min]	0.71 - 11.15 (**5.75**)	0.65 - 11.2 (**5.7**)	0.57
Total Time (public) [min]	5.6 - 42.27 (**21.03**)	5.57 - 43.18 (**19.25**)	/
Time Waited (public) [min]	0.11 - 32.16 (**8.96**)	0.11 - 28.60 (**8.51**)	0.007
Time Traveled (cars) [min]	0.1 - 5.74 (**3.03**)	0.08 - 5.7 (**2.98**)	0.42
Time Traveled (public) [min]	0.92 - 39.42 (**11.76**)	0.93 - 37.29 (**9.80**)	/
Happiness (cars)	0 - 96 (**88.44**)	0 - 96 (**88.53**)	0.76
Happiness (public)	36.41 - 95.79 (**79.54**)	38.08 - 95.82 (**79.63**)	0.82

public transport agents from 21.03 to 19.25 minutes. Both scenarios show a wide range of total time taken between 5 and 43 minutes. Additionally, examining both waiting and travel time reveals an overall decrease of the average values. Public transport users spend roughly 8 to 9 minutes waiting, while 10 to 12 minutes is spent travelling. However, car agents show no noticeable difference for each attribute. Furthermore, the recorded happiness at the final destination shows no signs of being different. Using a significance level of 0.05, the only attribute that rejects the null hypothesis is the time spent waiting for public transport users.

Figure 2 illustrates the spatial distribution of people who are willing to change their mode of transportation.

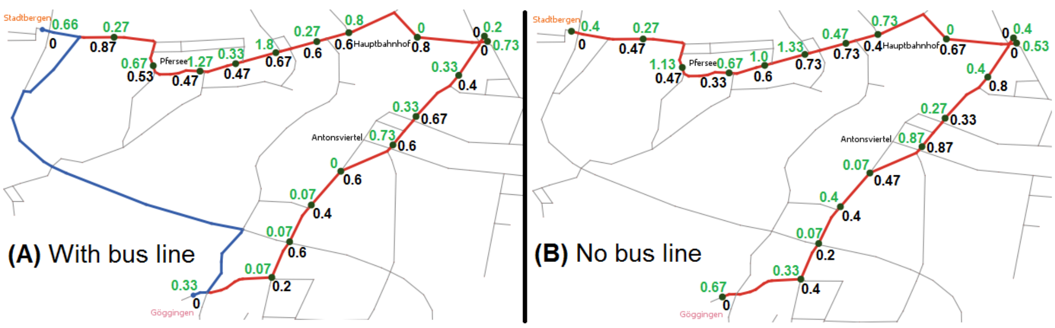

Figure 2 Spatial distribution of the willingness to change the mode of transport.

Black number indicates the amount of people, who are willing to change from public transport to cars while green numbers state the opposite case. Furthermore, only car agents within 300m are considered in this analysis. Figure 2 doesn't show any gradient or pattern. However, along the northern red line between Stadtbergen and Königsplatz more people change than along the southern line towards Göggingen. Car agents mostly change to public transport near tram stops in Pfersee, Königsplatz, Antonsviertel and both Göggingen and Stadtbergen while public transport agents scatter more evenly around the tram routes.

The model does show a difference between public transport agents in regards to their time attributes when the bus line is included or not. However, the happiness doesn't vary between the two scenarios.

5 Discussion of the results

The difference of the average times is small and suggests that the simulation has room for optimization. This is supported by the p-values rejecting the null hypothesis in one case as well as the normal distribution not applying for both total time and travel time. Long waiting times could be caused due to agents waiting at a tram or bus stop right from the beginning when the simulation starts as well as unfavorable placements of the trams and buses. One possible improvement could be the integration of information about the tram/bus schedule for public transport agents. The spatial distribution of people doesn't show any gradient or pattern. However, the region around Pfersee generally has a larger amount of car drivers who are willing to change to public transport. This could be caused by the overall higher density of car agents leading to the happiness decreasing due to congestion or heavy traffic. Moreover, the randomness of placement as well as the distribution of nodes leads to a bias. This can be seen when looking at the Gögginger Straße just south of the Antonsviertel tag, consisting of values equal or a bit higher than zero due to few nodes being within the tram stops.

6 Conclusion and outlook

This research paper applied a simplified traffic flow model to try to anticipate one scenario from a recently proposed project in Augsburg called "Verkehr4.0". The main questions to be answered were the differences in terms of travel, waiting and total time taken for public transport users, the spatial distribution of the locations and where people are considering to change their means of transportation. While the simulation reveals an overall decline in time taken for public transport users with the introduction of the express bus line, both the tests for total time and time traveled do not reject the null hypothesis and therefore show no statistical differences. As pointed out in the introduction, the costs for large scale infrastructure projects such as the one referred to here can be immense, which is the reason accurate predictions of the scenario and its impacts are crucial. Further work on this model include a more detailed and precise environment with the introduction of elements such as traffic lights, more traffic participants and extending the simulation to run over a longer period of modelled time to capture emergent phenomena. However, by implementing greater detail for various aspects of the model, the performance limits need to be taken into account. Possible improvements could be to limit the study area, introduce more cost-effective procedures for path finding and moving as well as reducing the randomness aspect of the original agent placement.

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