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Modeling the Transportation Impact of Cycle Highways: A Case Study for Leipzig, Germany

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Abstract

The presented study implements five cycle highways into a transport model for the city of Leipzig, Germany. For the model, the open-source framework Multi-Agent Transport Simulation (MATSim) is used. Additionally to a base case without cycle highways, the five cycle highways are simulated with three different cycling speed setups: 15 km/h, 25 km/h and 1500 km/h (as a potential analysis). With increasing cycling speed, an increased modal share of transport mode bike is observed (max. increase: 12%). Compared to their respective trips in the base case, agents achieve travel time gains of up to five minutes. The trips, which use the cycle highways mainly are trips with origin/destination rather close to the cycle highways. This euclidean distance also increases with increasing cycling speed on the cycle highways. This study predicts traffic volumes in the same range as those predicted by a feasibility study for one of the cycle highways, specifically within the inner-city area.

Keywords: cycle highways; bicycle traffic; sustainable transport; Agent-based Transport Simulation

1. Introduction

In the recent past, the improvement of cycling infrastructure has been a publicly agreeable pull-measure, while push-measures as roadpricing, car-free cities or increased parking fees often are controversially discussed. Several concepts for cycle highways in different german regions have emerged [2, 14, 13, 10]. In the case of the cycle highway Halle–Leipzig, a feasibility study provides information on general feasibility and predictions of traffic volumes, but the calculation of potential traffic volumes is not calculated based on a transport model, but on commuter data between different regions [2]. Simulation studies like [5] or [1] on the other hand, discover high potentials of transport mode change and/or travel time gains, but cannot be compared to parallel feasibility or potential analysis because such potential analysis do not exist.

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This study aims to provide a projection of potential traffic volumes for five different cycle highways, which are derived from [14]. The cycle highways are implemented into the Multi-Agent Transport Simulation (MATSim) Open Leipzig Scenario. MATSim is an open-source tool for modeling large-scale agent-based transport simulations [7]. The simulated scenarios are then investigated in terms of modal shift behavior and compared to the existing feasibility/potential study for the cycle highway Halle-Leipzig [2].

This work is structured as follows: Section 2 describes the applied methods to implement the transport model of Leipzig, Germany. Section 3 specifies the simulation setup. Finally, Section 4 presents the results of the simulation runs, which are discussed in Section 5 and concluded in Section 6.

2. Methodology

This study uses MATSim[1], an open-source framework for large-scale agent-based transport simulations. MATSim scenarios are applied for several cities/regions around the globe like Berlin [15], Leipzig [12], Mexico-City[2] or Patna [1]. In MATSim, initial transport demand and supply are used to simulate daily activity–leg chains (plans) for a synthetic population in the so-called mobility simulation (mobsim). Each executed plan is then scored and some agents are allowed to change or modify their plans (co-evolutionary algorithm). This MATSim-circle is repeated until a user-equilibrium or a predefined number of iterations is reached [6].

The scoring of daily plans in MATSim is done by the so-called Charypar-Nagel Utility Function, where all single scores per activity and leg are accumulated to a plan score. Typically, activity scores/utilities are positive while leg scores/activities are negative [11]. In this study, for the calculation of leg (dis)utilities an (agent-specific) income-dependent scoring term replaces the general marginal utility of money β_m:

$$\beta_{m,person} = \beta_m \cdot \frac{averageIncome}{income_{person}} \tag{1}$$

The modification of the leg (dis)utility function is deducted and enhanced based on [4]. The mathematical form is based on the Taylor-expansion of the assumption of logarithmic relation of overall utility on income: $U_{overall}(income) = \ln(income)$.

In addition to the above characteristics of MATSim, this study uses the MATSim bicycle contrib[3]. Introduced by [16] and [17], it adds the possibility to integrate different surface types, slopes, interaction with motorized traffic and infrastructure factors into the leg (by bike) scoring term. For this work, only the infrastructure factor attribute is used to simulate faster cycling speeds on cycle highways (see Section 3). The infrastructure factor of a network link is multiplied by the maximum cycle velocity to compute an adapted speed of a given infrastructure segment. Thus, an infrastructure factor of < 1.0 reduces the cycle speed on a network link and an infrastructure factor of > 1.0 increases it. The calculated speed can never be higher than the maximum allowed speed on a given infrastructure segment.

3. Study setup

The presented study is realized with version 1.1 of the MATSim Open Leipzig Scenario[4], which is an earlier version of the model described in [12]. The reason for using an earlier version is that the newer versions do not use the so-called bicycle contrib, since that was not needed for the envisaged studies of the associated project. It is, however, needed for the present study. Since the two versions are calibrated independently, their scoring parameters are different. The parameters per transport mode of the model used in this study are displayed in Table 1. Additionally to the mode parameters in Table 1, the marginal utility of performing an activity is set to 6.0. The model includes the

[1] https://matsim.org/
[2] unpublished, see https://github.com/matsim-scenarios/matsim-mexico-city
[3] https://github.com/matsim-org/matsim-libs/tree/master/contribs/bicycle
[4] https://github.com/matsim-scenarios/matsim-leipzig/releases/tag/v1.1

transport modes car (as a driver), bike, public transport (pt), ride (car as a passenger) and walk. The model scale is 25% which means that one person in the simulation represents four persons in reality. This is done out of computational reasons.

Table 1: Mode parameters of the MATSim Open Leipzig Scenario v1.1.

transport mode	bike	car	pt	ride	walk
constant	−0.56	−0.80	0.01	−5.31	0.00
daily monetary constant	0.00	−5.30	0.00	0.00	0.00
marginal utility of traveling [util/h]	−10.00	−0.50	−2.00	−0.50	-1.50
monetary distance rate [€/km]	0.00	−0.20	0.00	−0.20	0.00

For this study, three policy cases plus a base case are simulated. The base case depicts the traffic situation as described in [12] with mode parameters of Table 1 and without cycle highway infrastructure. In each policy case, five radial cycle highways, which connect cities in the surroundings of Leipzig and the city itself, are implemented: Cycle highway Halle–Leipzig (northwest–city center), cycle highway Taucha–Leipzig (northeast–city center), cycle highway Naunhof–Leipzig (southeast–city center), cycle highway Markkleeberg–Leipzig (south–city center) and cycle highway Markranstädt–Leipzig (west–city center). The cycle highways, which are derived from [14] and [2], are displayed in Figure 1.

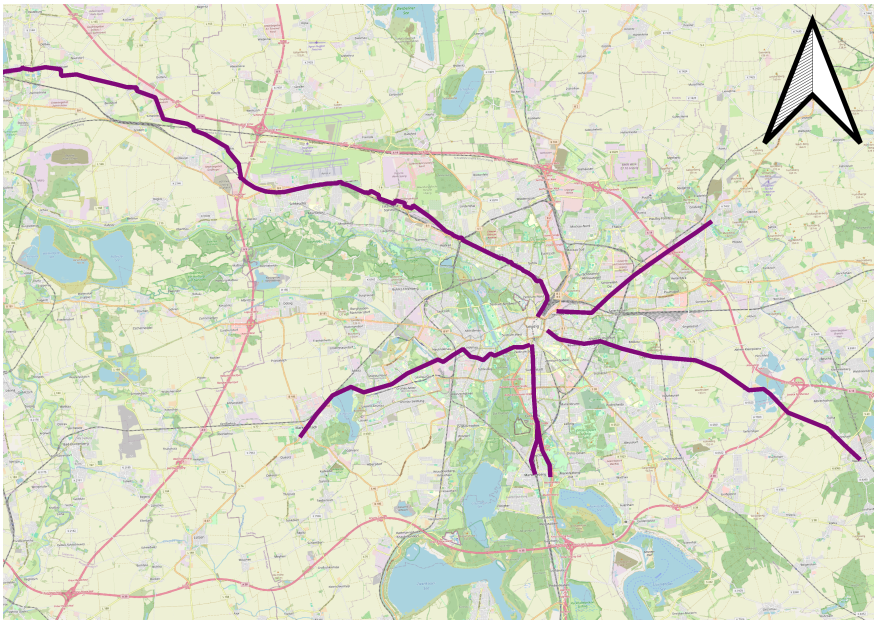


Fig. 1: The five different radial cycle highways (purple).

While all three policy cases simulate the same cycle highways, they differ in their so-called infrastructure factors (see Section 2). The infrastructure factor is applied on each cycle highway link such that an adjusted cycling speed is achieved. Policy case $speed_{15}$ implements the cycle highways with an infrastructure factor of 1.0, resulting in a cycling velocity of 15 km/h (as in the rest of the network). Policy case $speed_{25}$ applies an infrastructure factor of 1.67, resulting in a cycling velocity of 25 km/h on the cycle highways. Finally, policy case $speed_{1500}$ applies an infrastructure factor of 100, resulting in a corner case with agents being able to move at a speed of 1500 km/h on the cycle highways.

4. Results

A comparison of modal shares between base case and policy cases (for the city of Leipzig, see Figure 2) reveals that a simple implementation of cycle highways for Leipzig while maintaining a cycling speed of 15 km/h on the implemented highways does not draw many agents from other transport modes. Compared to the base case, the modal share of bike remains on the same level. An additional speed increase by factor 1.67 results in a modal share increase of bike by 6% (from 20% in the base case to 26% in case $speed_{25}$). The corner case with speed increase to 1500 km/h results in an even bigger bike share of 32%. Thus, Figure 2 indicates an increase of bike usage with increasing cycling speed on the implemented cycle highway infrastructure. In the two policy cases with significant modal shift behavior ($speed_{25}$ and $speed_{1500}$) **towards** bike, a parallel modal shift **from** car, ride and pt is observable, which is confirmed by Figure 3 (modal shift from base to case $speed_{1500}$). Policy case $speed_{25}$ shows a similar modal shift behavior to case $speed_{1500}$.

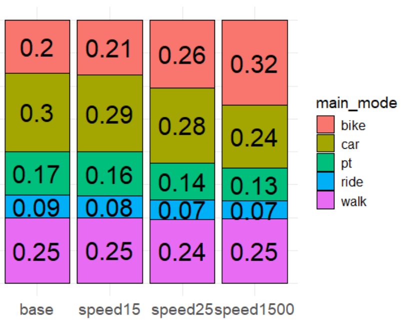


Fig. 2: Modal shares over base case and policy cases (Leipzig residents).

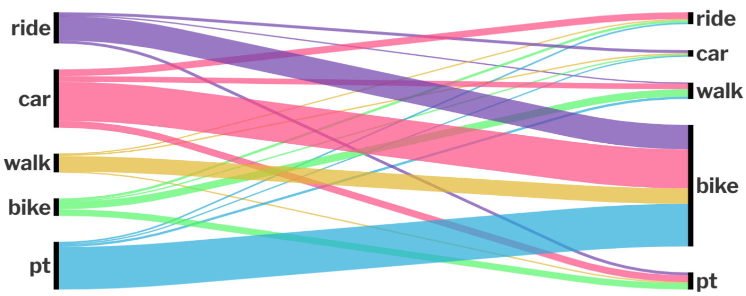


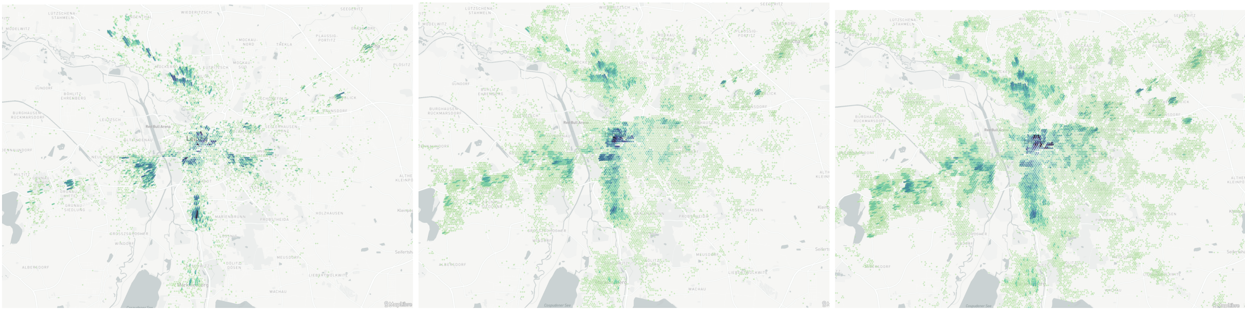
Fig. 3: Modal shift from base case (left side) to policy case $speed_{1500}$ (right side).

The mean travel times in Table 2 show that agents using the implemented cycle highways save up to five minutes (case $speed_{1500}$) of travel time (compared to the respective trips in the base case). For the two policy cases with more realistic cycling speed on the cycle highways ($speed_{15}$ and $speed_{25}$), the travel time savings compared to the base case lie around two minutes.

Table 2: Mean travel distances and times for trips using cycle highways and their respective trips in the base case.

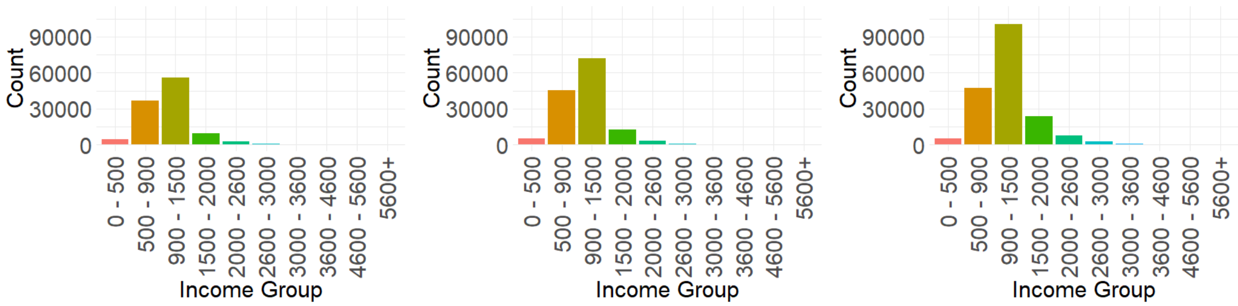
case	mean travel distance [km]		mean travel time [min]	
	base	policy	base	policy
speed15	5.0	4.9	25	23
speed25	5.3	5.5	23	21
speed1500	7.4	8.9	22	17

In terms of mean traveled distances the cycle highways in policy cases $speed_{25}$ and $speed_{1500}$ end up in longer mean trip distances than the mean distances of the respective trips in the base case (+0.2km for $speed_{25}$ and +1.5km for $speed_{1500}$). Here, the higher travel speeds on the cycle highway infrastructure attract agents with trip origins/destinations with greater euclidean distance to the cycle highway infrastructure (increasing euclidean distance of trip origins/destinations to cycle highways with increasing cycling speed on cycle highways). This is confirmed by a comparison between Figure 4 and Figure 1, which shows that origins of trips which use the cycle highways are clustered around the routes of each cycle highway. The above findings on trip origins are also valid for destinations of trips which use the cycle highway infrastructure (not displayed). For policy case $speed_{15}$ no increase in mean traveled trip distance (base case vs. $speed_{15}$) is observable. This is caused by two reasons: 1) Due to the low cycle speed (compared to the other policy cases) only trips with origins and destinations rather close to the cycle highways are attracted (see Figure 4a). 2) As the routes of all cycle highways **mainly** run along already existing street infrastructure, the difference of average traveled distance (compared to the respective trips in the base case) is not as high as for the other



(a) $speed_{15}$ (b) $speed_{25}$ (c) $speed_{1500}$

Fig. 4: Trip origins for trips which use the cycle highways over the policy cases. The darker the hexagon color, the more trips depart from there.

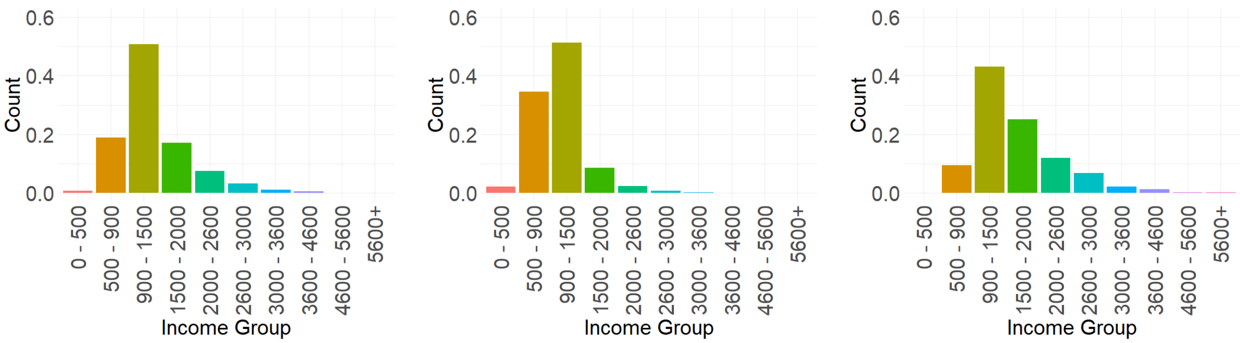


(a) base (b) $speed_{25}$ (c) $speed_{1500}$

Fig. 5: Income distribution of bike users over all simulated cases. Income group bins from [8]. Case $speed_{15}$ is not displayed because its income distribution is similar to the base case.

policy cases, which means that the access and egress legs to/from the cycle highways are not as long as in the other policy cases. In general, the implementation of cycling highways in Leipzig causes (with increasing cycling speed) longer trip distances (due to longer access and egress legs to/from the cycle highways), which are covered by less time than in the respective trips in the base case.

Figure 5 shows that the implementation of cycle highways does not change the income distribution of bike users by much. The most extreme policy case (Figure 5c) pushes the income distribution of cyclists towards the overall income distribution for Leipzig residents in Figure 6a, which means that the achieved travel time gains draw more affluent agents to cycling.



(a) overall (b) bike (c) car

Fig. 6: Base Case income distribution for Leipzig residents over different transport modes. Income group bins from [8]. The income distributions for transport modes ride, pt and walk are not displayed bcause they are similar to the overall model income distribution.

Figure 6, which displays the overall income distribution and income distributions per transport mode in the base case, shows that over all transport modes the majority of Leipzig residents (share of around 50%) belong to the income group of 900 – 1500 €/month. For car users, significantly fewer agents are members of the two income groups from 500 – 1500 €/month, but more agents possess a monthly income of more than 1500 €/month, which indicates that (in the model) the usage of a private car is affordable only for more affluent agents (see Figure 6c). On the contrary, the income distribution of bike users suggests a significantly bigger share of agents from the second lowest income group (500 – 900 €/month, compared to the overall income distribution), while less modeled bike users belong to income groups with a monthly income of 1500 € or more (see Figure 6b). The findings on income groups for bike and car users are caused by the usage of income-dependent scoring in MATSim (see Section 2).

5. Discussion

In general, the above results indicate that (depending on the cycling speed), cyclist could achieve lower travel times when using cycle highways. Other simulation studies with similar implementations obtain similar results: In a microscopic traffic simulation of a cycle highway in Munich, Germany [5] the authors find that cycling travel times could be reduced by up to 17% (in our study, the potential travel time savings are 23% in policy case $speed_{1500}$). The authors also find that travel times of motorized modes could increase if the cycle highways are not implemented on intersection-free infrastructure. In a simulation study for Patna, India using MATSim [1] discover a potential bike modal share increase of 16% when implementing a bicycle superhighway. The increase is achieved with a cycling speed of 15 km/h, but may not be comparable to the modal share increases of this study (max. 12%), as the general conditions in India and Germany are very different from each other. Another study which concentrates on the effect of London cycle superhighways on cycle hire [9] analyzes real-world cycle hire data. The study suggests that the cycle superhighway increases the overall cycle hire usage by 27%. In an area within a radius of 300m around the new cycle infrastructure, the cycle hire usage even increases by 73%. Those findings support the results of this study in Figure 4. Moreover, [9] observe travel time savings of 11%, which is in the same order of magnitude as the travel time savings of cyclists as in policy case $speed_{15}$ (–8%).

Figure 7 displays the traffic volumes (of bike users) for the cycle highways with a cycling speed of 25 km/h (case $speed_{25}$). Along the route of all the cycle highways, points with different colors can be observed. The points are connection links, which connect the cycle highways with the existing street network and can therefore be ignored. For all five cycle highways, the traffic volumes are the biggest near the city center with traffic volumes of > 5000 $cyclists/day$ (dark red color). The traffic volumes decrease with increasing euclidean distance from the city center. For the south-eastern arm of cycle highway Markkleeberg-Leipzig and a section of cycle highway Halle-Leipzig from Halle to Schkeuditz, the traffic volumes even drop below 1000 cyclists/day. The drop-off of traffic volumes in the starting points of four of the five cycle highways can be justified by the fact that the outskirts of Leipzig (or cities in general) typically are populated less densely. However, the drop-off for cycle highway Halle–Leipzig is caused by the model's scope, which ends exactly between Halle and Leipzig (see Figure 1 of [12]). Thus, there are less agents from Halle in the model, as agents from outside the spatial mode scope are only integrated to assure accuracy of incoming, outcoming or crossing traffic flows, but not accuracy of traffic flows in that certain area (if not included in the model's scope).

In a guideline on the usage and design of high-speed cycle connections in Germany [3], the authors define quality standards for cycle highways as follows: Safe usability at cycling speeds up to 30 km/h, direct and largely detour-free routing, separation/low number of intersections with other transport modes, sufficient lane width, high-quality surfaces and more. The policy case with the highest comparability to the above criteria is policy case $speed_{25}$, where the cycling speed is at the same level as the mentioned 30 km/h and all other parameters implicitly match the above quality standards. Therefore, it is interesting to compare the traffic volumes of Figure 7 to the feasibility study of the cycle highway Halle-Leipzig by [2]. The authors calculate projected traffic flows of > 2000 $cyclists/day$ for the sections between Leipzig's city center and Schkeuditz and in the city of Halle. Between Halle and Schkeuditz, cycle flows of mostly 1000 – 1500 cyclists/day are predicted. Thus, Figure 7 and the feasibility study match in the city center of Leipzig, but the simulation study achieves lower traffic volumes (Δ of around 1000 cyclists/day) in the section between Wahren and Schkeuditz. Those differences could be caused by the difference of assumed cycling speed (25 km/h vs. up to 30 km/h) and/or potential shortcomings due to implicitly setting the quality standards from

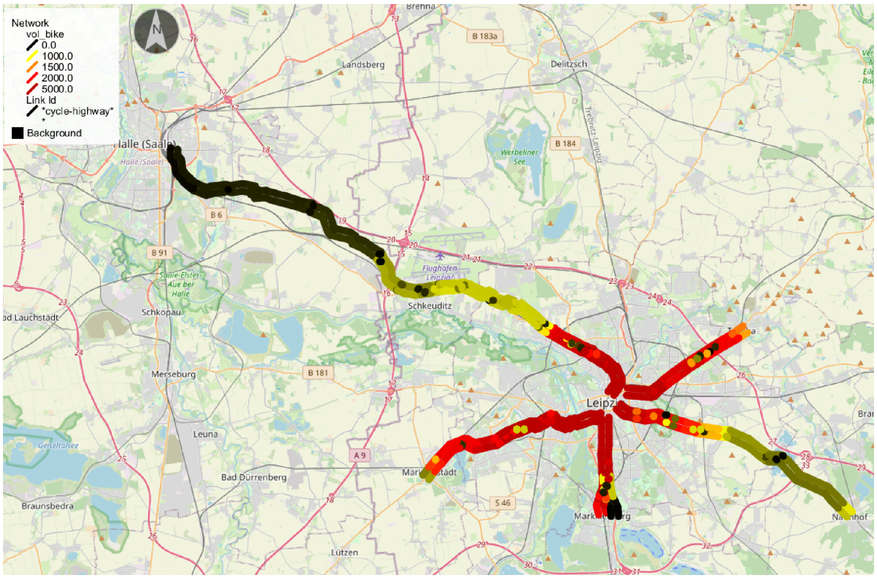


Fig. 7: Cycle volumes on the cycle highways of case $speed_{25}$.

[3] through the cycling speed. Here, additional simulation studies with exactly matching criteria could be useful. The big differences in traffic volumes (Δ of around 2000 cyclists/day) between Schkeuditz and Halle can be justified with the spatial scope of the MATSim Open Leipzig Scenario (see above and [12]).

The findings on modal shift behavior and income group distribution per policy case indicate that the number of attracted agents with higher monthly incomes – and therefore car users – increases with increasing cycling speed on cycle highways. Thus, the increased cycling speed offers potential travel time savings which cannot be achieved by the usage of a private car. Moreover, the potential travel time saving by using cycle highways pushes the income distribution into the direction of the general income distribution for Leipzig (Figure 6a) by attracting more car users.

Evidently, the policy case with a cycling speed of 1500 km/h on the cycle highways is not realistic. It rather acts as a reference case as to potentially how many agents could be drawn from other transport modes, how much time savings could be achieved or how much capacity might be needed.

The two policy cases with more realistic cycling speeds of 15 km/h and 25 km/h draw fewer agents from other transport modes and offer less travel time savings, but could be implemented as a kickstart of transitioning to more cyclable and sustainable cities. However, the implementation could have negative effects on other sustainable transport modes, as the new bike users are mainly drawn from modes like pt. Additionally, it seems odd that for case $speed_{15}$ there are travel time gains without significant decrease of mean travel distance or increase of modal share for bike. In the transport model, cyclists travel on the same network links as cars. They are obliged to follow the german traffic laws, so they are not allowed to overtake car queues on the right side. Future research should model bicycles on separate cycle lanes (if they exist on a given link), which could end up in more realistic results for policy case $speed_{15}$ (no travel time gains, which would be in line with the (compared to the base case) unchanged mean travel distance and modal share for transport mode bike).

6. Conclusion

The presented study uses the MATSim Open Leipzig Scenario and implements three setups of cycle highways. The highways are derived from plans of the saxon ministry of economy and a feasibility study for one of the cycle highways [14, 2]. In the most favorable setup, the five cycle highways lead to modal share increase for bike of 12% and a decrease of the mean travel time by bike of five minutes. Those results are in a similar range of comparable studies (see Section 5). However, the results also show that private car users are only drawn to bike if the travel time gains (achieved through cycle highways with high quality standards) are rather high. The better the cycling infrastructure the higher the number of agents with trip origins/destinations of higher distance to the cycle highways and the higher the number of more affluent agents drawn to bike. The traffic volumes of policy case $speed_{25}$ are in a similar range as the predicted cycle volumes of the feasibility study for the cycle highway Halle-Leipzig [2].

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