Accessibility in an E-Bike City

Working Paper

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ABSTRACT

Decades of investments in transport infrastructure have created large welfare gains through increased accessibility. However, the current traffic patterns necessary for maintaining these accessibility levels are in conflict with the need for a rapid decarbonization of the transport system. In this paper, we evaluate the accessibility effects of an E-Bike City in Zurich, Switzerland and test whether an urban transportation system based heavily on sustainable modes modes like bicycles and public transit could still deliver the current accessibility levels. We generate an alternative transportation network within the existing road space using SNMan, a network design tool developed as part of the E-Bike City Project. Second, we use MATSim to simulate the traffic loads of the modified network and finally, calculate a gravity-based accessibility measure for every resident in the city. This paper reports on the current state of work, especially the literature, methodology and the data used, while the results are planned in a later version.

KEYWORDS

E-Bike City; Micromobility; Road Space Allocation; Cycling Network; MATSim

1 INTRODUCTION

Decades of transport infrastructure investments have delivered massive improvements in accessibility (Axhausen et al., 2011). Increasing speeds and decreasing real travel cost have created economic benefits in consumer choice, specialization, and residential options. More travel has allowed reaching more destinations or developing settlements with lower density. However, it remains unclear how it can be reconciled with the need to decarbonize (IPCC, 2022) the transport sector within the next decades (Axhausen, 2022). Commonly discussed technical developments such as battery-electric vehicles (BEV) will not be sufficient and fast enough (de Blas et al., 2020; Gebler et al., 2020; Cox et al., 2018) to reach this goal. Other approaches like mobility pricing, or massive transit investments are either politically infeasible (Lichtin et al., 2024), or will take a very long time, with uncertain effects. As an example, in Switzerland, despite exceptionally high transit and rail investments, the mode share of transit is stagnating around only 20% (BFS and ARE, 2023).

E-Bike City (Ballo et al., 2023) is an alternative approach to reducing transport emissions within the next two to three decades. Building on top of similar visions like 15-minute cities (Moreno et al., 2021) or Superblocks (Rueda, 2019; Eggimann, 2022), it presents a possible model for changing urban transport systems in favor of sustainable and equitable modes. Its core hypothesis is that current levels of accessibility can be produced sustainably if future transport systems in cities will be centered on public transit and bicycles. This should be achieved by allocating approximately 50% of road space to dedicated cycling infrastructure and prioritizing public transit, while still providing basic access for regular motorized traffic.

In past work, we have presented the overall concept of an E-Bike City (Ballo et al., 2023), as well as an algorithm for allocating the road space (Ballo and Axhausen, 2024) but so far, little is known about the effects of such transformation on performance of the transport system. In this paper, we test the core hypothesis of maintaining today's accessibility levels in Zurich, Switzerland. We use potential-based accessibility (Hansen, 1959), extended with mode choice probabilities (Ben-Akiva and Lerman, 1979) to represent the changes experienced by people with different residential locations and demographic attributes. Further, we elaborate on the expected equity implications based on how these changes affect exemplary groups in the population.

Chapter 2 reports the current mobility choices in Zurich. Chapter 3 shows and overview of previous work. Chapter 4 explains the methods used and chapter 5 shows the results. Chapters 6 and 7 close the paper with a discussion and conclusions.

2 MOBILITY IN ZURICH

As of 2024, the municipality of Zurich has a population of 443'037 inhabitants, an area of 91.9 km2, and roughly 1.9 Million inhabitants living within its entire metropolitan region (City of Zurich, 2024). Based on data from the Swiss travel survey (BFS and ARE, 2023), the mode share of private cars is 28.4% for trips within the city and 44.4% for cross-border trips. However, private cars dominate the streets by accounting for 84.4% of the total vehicle kilometers. Table 1 gives an overview.

Table 1: Mobility in Zurich in 2024

		Other	E-bike	Private Cars	Public Transit	Bicycle	Walking	All	All excl. walking
	avg. occupancy	1	1	1.2	20	1			
Within the City of Zurich	pkm	202	793	13030	14360	6886	10549	45820	35271
	vkm	202	793	10858	718	6886			19457
	% pkm	0.4%	1.7%	28.4%	31.3%	15.0%	23.0%	100.0%	77.0%
Cross-Border trips	pkm	1189	416	113723	137841	2488	631	256288	255657
	vkm	1189	416	94769	6892	2488			105754
	% pkm	0.5%	0.2%	44.4%	53.8%	1.0%	0.2%	100.0%	99.8%
Total	pkm	1391	1209	126753	152201	9374	11180	302108	290928
	% pkm	0.5%	0.4%	42.0%	50.4%	3.1%	3.7%	100.0%	96.3%
	vkm	1391	1209	105628	7610	9374			125211
	% vkm	1.1%	1.0%	84.4%	6.1%	7.5%			100.0%

3 PREVIOUS WORK

3.1 Accessibility

Many different definitions of accessibility exist to represent the performance of transport systems. Geurs and van Wee (2004) criticize that the measures often used are insufficient and propose a systematic framework of different accessibility types. The possibilities of different people to interact with others is commonly expressed using place-based LogSum of potentials, weighted by a function of generalized cost to reach them, originally defined by Hansen (1959). Ben-Akiva and Lerman (1979) extend this definition by adding behavioral components such as mode choice, consistent with the random-utility theory. A combination of these two allows the expression of place-based accessibility based on all available destinations and modes to reach them.

3.2 Street network redesign

Multiple pieces of work have proposed algorithms for automatically generating optimal cycling networks, e.g., Szell et al. (2022), Steinacker et al. (2022), Paulsen and Rich (2023). However, they ignore the tradeoffs where adding cycling infrastructure is only possible by removing lanes originally assigned to other modes. In our previous work, we have introduced a process for network-wide reallocation of road space while maintaining a set of connectivity and accessibility criteria for all modes, implemented in Python as `snman`[1] (Ballo and Axhausen, 2024). A notable part of the process is a heavy simplification of the street network, abstracting even complex intersections into single nodes and all streets into single edges. The reallocation then considers the entire available road space on every street, regardless of its representation in the original data.

[1] https://github.com/lukasballo/snman/

3.3 Agent-based simulations in MATSim

MATSim (Horni et al., 2016) is a multi-agent transport simulation toolkit, aimed at representing complex travel behaviors. Sonnak (2024) has used it to perform first simulations of the rebuilt networks generated using `snman`. Her work is based on an earlier MATSim scenario of Switzerland described in Tchervenkov et al. (2022). She demonstrated that the heavy network simplification does not have a substantial effect on the results, except where the capacity of minor roads is artificially increased by merging them with parallel major roads.

3.4 Route choice modeling

The effects of cycling infrastructure include not only travel time but also most importantly safety and comfort. Route choice studies such as Meister et al. (2023), Scott et al. (2021), Jensen (2019), Hood et al. (2011), Broach et al. (2012) have developed robust estimates of these effects on perceived utility. Converting them to Value of Distance (VoD) indicators allows representing these effects as added or reduced distance or travel time.

3.5 Mode choice modeling

The behavioral mode choice component of accessibility (Ben-Akiva and Lerman, 1979) introduced above requires a model to provide the choice probability of each mode. Hörl et al. (2019) present a discrete mode choice model for Switzerland that is paired with the MATSim scenario described above. However, the empirical evidence is limited for predicting such choices after a large change like in the E-Bike City, especially once secondary effects, such as those of an emerging cycling culture (te Brömmelstroet et al., 2020) are present.

4 METHODS

4.1 Perimeter

The perimeter covers the larger Zurich area which we define as all municipalities with at least 15% of population commuting to Zurich. The synthetic population generating traffic includes a buffer of 5km and traffic generated by trips beyond that buffer is represented by fixed trips cut out of the national model. The network includes an additional buffer of 5km, with small extensions for adjacent highway interchanges to avoid long disconnected highway sections. The process of generating the synthetic population in the MATSim scenario and its adaptation to the chosen perimeter, see Tchervenkov et al. (2022) and Sonnak (2024). Figure 1 shows an overview of the perimeter geometries.

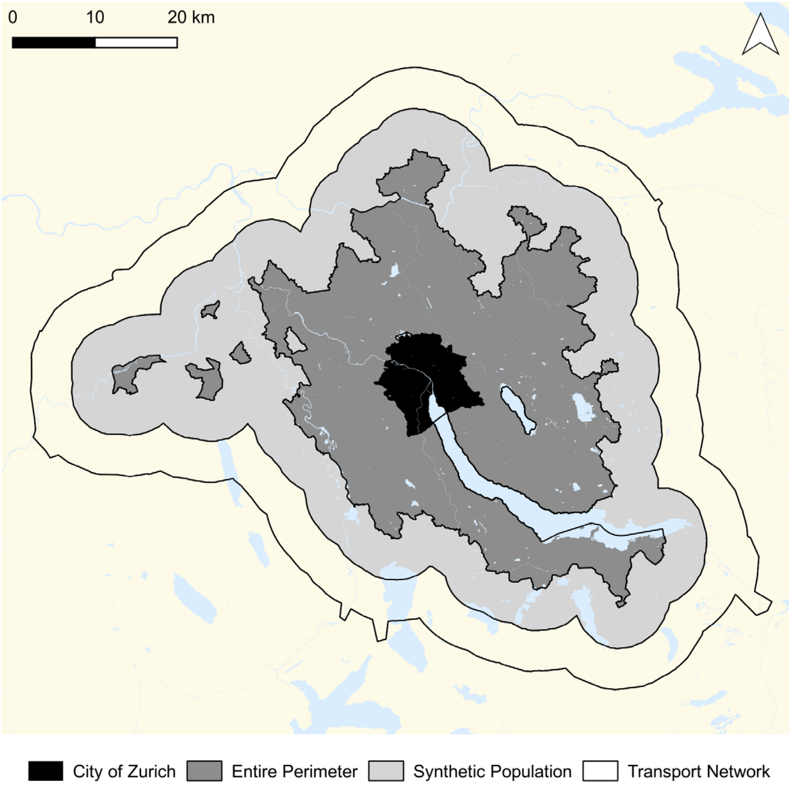

Figure 1: Perimeter geometries

4.2 Population data

The population data is provided by the 2017 Statpop dataset of Switzerland[2], representing each registered resident, with attributes including age, sex, and residence permit. A spatial analysis of residential locations based on these attributes in Figure 2 shows clear spatial disparities: While central locations have a higher proportion of foreigners with residence permits, people under 65 years of age, and slightly more males, the periphery is more strongly occupied by the Swiss, elderly, and females. The effects of these spatial disparities on the accessibility changes experienced by each group will be studied in the results section.

[2] https://www.bfs.admin.ch/bfs/de/home/statistiken/kataloge-datenbanken.assetdetail.27965868.html

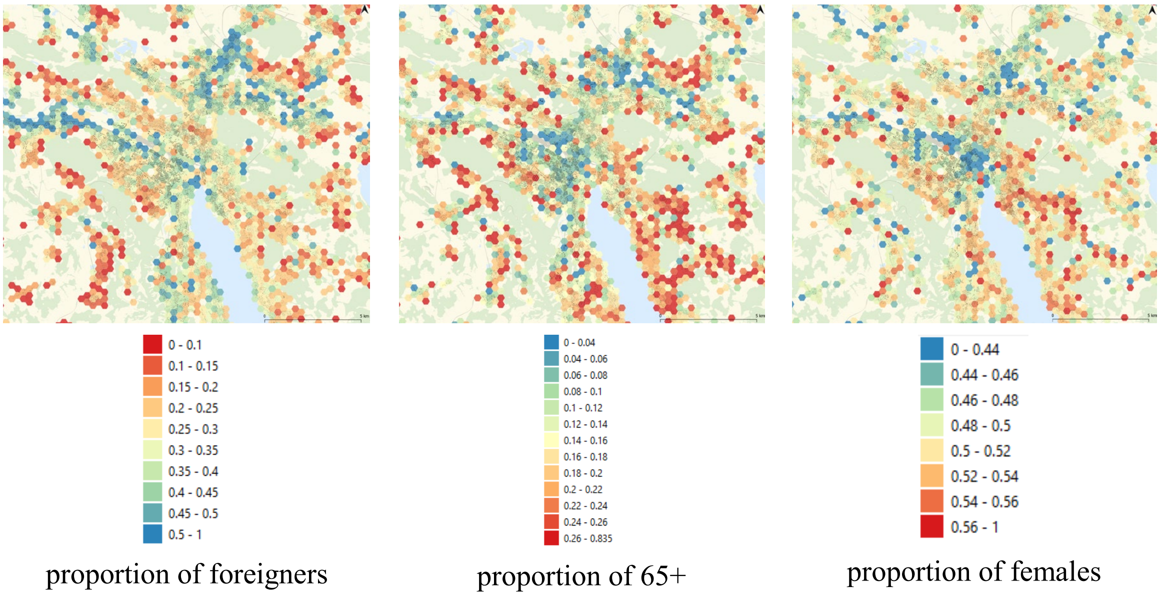

Figure 2: Residential locations of different demographic groups

4.3 Network data

The road network used is generated using `snman`, based on OpenStreetMap (OSM) data, enriched with a parking dataset of the City of Zurich[3], matched street widths from official land survey data of Canton Zurich[4], public transit routes[5], and manual corrections of wrongly simplified complex intersections. See Ballo and Axhausen (2024) for details. In contrast to the previous networks used by Sonnak (2024), the simplification algorithm has been modified to avoid the issues described in section 3.3. The rebuilt network is generated with a preference for cycling infrastructure, while maintaining the existing transit network, ensuring reachability of every intersection by motorized traffic, and providing space for one parking space/loading zone for every ten residents within a radius of 100 meters.

Every link has a length attribute for each mode and direction. For cycling, the length is adjusted using the VoD indicators explained in section 3.4:

$$l_{uvk,cycling} = l_{uvk} * [1 + VoD_{infra}(infra) + VoD_{grade}(grade)]$$

For VoD_{infra}, we assume -0.5 if dedicated cycling infrastructure is present and 0 otherwise. VoD_{grade} is 0.55 for $2\% < grade \leq 6\%$, 3.11 for $6\% < grade \leq 10\%$ and 4.33 for $10\% < grade$. Table 2 shows descriptive statistics of the original, simplified, as well as rebuilt network.

[3] https://data.stadt-zuerich.ch/dataset/geo_oeffentlich_zugaengliche_strassenparkplaetze_ogd
[4] https://www.stadt-zuerich.ch/geodaten/download/10016
[5] https://data.stadt-zuerich.ch/dataset/ktzh_linien_des_oeffentlichen_verkehrs__ogd_

Table 2: Descriptive statistics of the network

Metric	Original OSM network	Simplified	Simplified and Rebuilt	
N edges	61’250	25’660	25’660	
N nodes	49’398	20’180	20’180	
avg shortest path for motorized traffic	-	5.251	6.577	[km]
avg shortest path for cycling with VoD indicators	-	4.449	3.610	[km]
% road space for motorized traffic	-	72.2	46.1	[%]
% road space parking	-	15.8	15.5	[%]
% road space transit lanes	-	6.5	6.5	[%]
% road space cycling infra	-	5.5	30.8	[%]
% road space other	-	0	1.1	[%]

4.4 MATSim simulation

The distances calculated in previous step can be converted to travel times using assumptions about average speeds. However, they do not account for differences due to traffic loads in motorized traffic. To calculate realistic travel times, we use an agent-based traffic simulation in MATSim. The new travel times for motorized traffic (accounting for congestion) are then mapped back into the `snman` network.

4.5 Mode choice model

We use the mode choice model in (Hörl et al., 2019):

$$\begin{aligned} u_{car}(x) = \alpha_{car} &+ \beta_{travelTime,car} * x_{travelTime,car} \\ &+ \beta_{travelTime,car} * \theta_{travelTime,car} \\ &+ \beta_{travelTime,car} * \theta_{parkingSearchPenalty} \\ &+ \beta_{travelTime,walk} * \theta_{accessEgressWalkTime} \\ &+ \beta_{cost*} * \left(\frac{x_{crowflyDistance}}{\theta_{averageDistance}}\right)^{\lambda} * x_{cost,car} \end{aligned}$$

$$\begin{aligned} u_{pt}(x) = \alpha_{pt} &+ \beta_{numberOfTransfers} * x_{numberOfTransfers} \\ &+ \beta_{inVehicleTime} * x_{inVehicleTime} \\ &+ \beta_{transferTime} * x_{transferTime} \\ &+ \beta_{accessEgressTime} * x_{accessEgressTime} \\ &+ \beta_{cost*} * \left(\frac{x_{crowflyDistance}}{\theta_{averageDistance}}\right)^{\lambda} * x_{cost,car} \end{aligned}$$

$$u_{bike}(x) = \alpha_{bike} + \beta_{travelTime,bike} * x_{travelTime,bike} + \beta_{age,bike} * \max(0, \alpha_{age} - 18)$$

$$u_{walk}(x) = \alpha_{walk} + \beta_{travelTime,walk} * x_{travelTime,walk}$$

To represent the uncertainties related to the large changes created by the E-Bike City transformation, we use the default parameters, as well as two modifications where the cycling-related parameters have been adjusted to achieve higher bicycle mode shares.

The default parameters, as well as the modifications are shown in Table 3.

Table 3: Mode choice model parameters

		Default scenario	+50% cycling	+100% cycling	
Car	α_{car}	0.827	0.827	0.827	
	$\beta_{travelTime,car}$	-0.0667	-0.0667	-0.0667	[min^{-1}]
Public Transport	α_{pt}	0.0	0.0	0.0	
	$\beta_{numberOfTransfers}$	-0.17	-0.17	-0.17	
	$\beta_{inVehicleTime}$	-0.0192	-0.0192	-0.0192	[min^{-1}]
	$\beta_{transferTime}$	-0.0384	-0.0384	-0.0384	[min^{-1}]
	$\beta_{accessEgressTime}$	-0.0804	-0.0804	-0.0804	[min^{-1}]
Bike	α_{bike}	-0.1	*	*	
	$\beta_{travelTime,bike}$	-0.0805	*	*	[min^{-1}]
	$\beta_{age,bike}$	-0.0496	*	*	[a]
Walking	α_{walk}	0.63	0.63	0.63	
	$\beta_{travelTime,walk}$	-0.141	-0.141	-0.141	[min^{-1}]
Others	β_{cost}	-0.126	-0.126	-0.126	[CHF^{-1}]
	λ	-0.4	-0.4	-0.4	
	$\theta_{averageCrowflyDistance}$	40	40	40	[km]
Calibration	$\theta_{parkingSearchPenalty}$	6	6	6	[min]
	$\theta_{accessEgressWalkTime}$	5	5	5	[min]

* to be adjusted based on the simulation results, such that the desired mode shift is achieved

4.6 Accessibility analysis

We calculate the accessibility for every residential location, considering all residents as possible destinations and all possible modes (private car, bicycle, transit, other) with their respective choice probabilities according to the mode choice model. The shortest path for each destination by car and bicycle is calculated using the `networkx` package (Hagberg et al., 2008). For public transit, we use the `R5` package (Conway et al., 2018), both allowing for fast n-to-n shortest-path search. As a result, the cost c_{ij} for reaching the destination j from an origin i is a weighted average of the different modes m, using the choice probability P_{ijm} as the weight:

$$c_{ij} = \sum_{m} P_{ijm} * c_{ijm}$$

The resulting cost c_{ij} is then used for calculating the accessibility a_i for each location i, while considering all residents as possible destinations j. The utility u_j of each destination is equal to the number of residents living there:

$$a_i = \sum_j f(c_{ij}) * u_j$$

5 RESULTS

Note: The results are under development and will be added in a later draft of this paper. The data reported below represents the current state of work.

Figure 3 shows the relative bicycle accessibility in comparison to car accessibility – both, in the current, and rebuilt network, assuming the present mode choice model (default scenario).

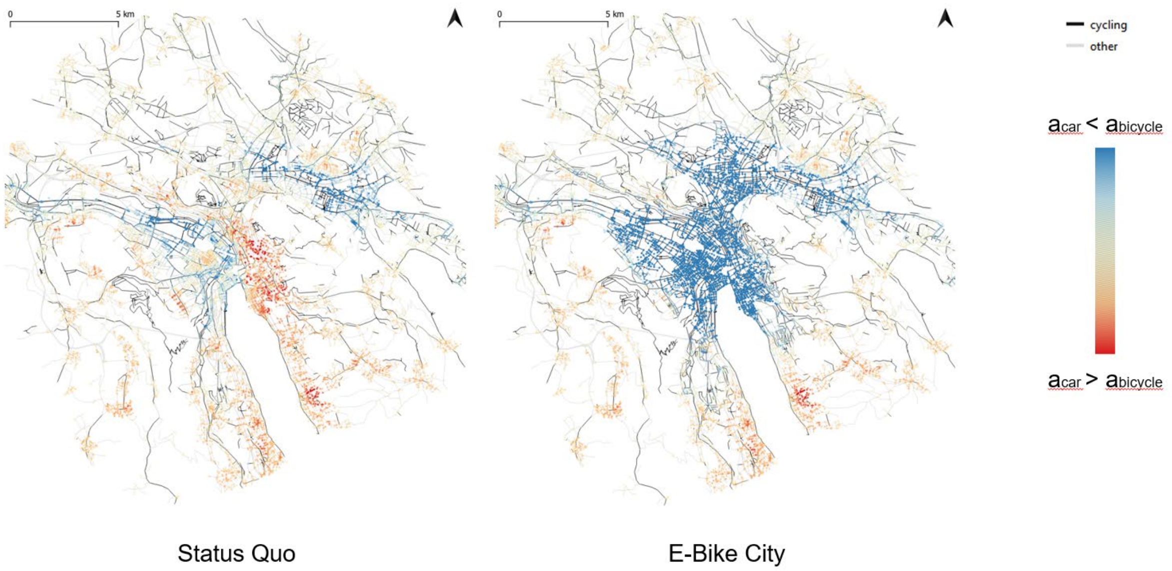

Figure 3: Accessibility changes assuming the present mode choice model

Table 4 shows the resulting accessibility for the entire population, as well as for a number of population groups. The results are shown for the current state, and the E-Bike City, using the three mode choice models described in 4.5.

Table 4: Accessibility for different demographic groups (to be completed later)

Group	Accessibility in status quo (avg, median, std)	Change in default scenario (avg, median, std, sig.)	Change with +50% cycling (avg, median, std, sig.)	Change with +100% cycling (avg, median, std, sig.)
Entire population				
City of Zurich				
Other Municipalities				
Young <25 yrs				
Elderly >65 yrs				
Male				
Female				
Swiss, born in CH				
Immigrants				

6 DISCUSSION

The discussion will be added later.

7 CONCLUSIONS

We have presented the first steps toward assessing whether a car-reduced urban mobility future can maintain today's levels of accessibility. The code used in this paper is published as part of the open-source Python project `snman`: https://github.com/lukasballo/snman

AUTHOR CONTRIBUTIONS

Lukas Ballo: Conceptualization, Data Curation, Investigation, Writing - Original Draft,
Aurore Sallard: MATSim simulations, Writing – Review & Editing
Lucas Meyer de Freitas: Data Curation, Writing – Review & Editing
Kay Axhausen: Conceptualization, Writing – Review & Editing

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CONFLICTS OF INTEREST

None.

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