Sensitivity tests with high resolution accessibility computations

Thomas W. Nicolai *
Transport Systems Planning and Transport Telematics Group,
Berlin Institute of Technology (TU Berlin), Berlin, Germany

Kai Nagel
Transport Systems Planning and Transport Telematics Group,
Berlin Institute of Technology (TU Berlin), Berlin, Germany

*Email: nicolai@vsp.tu-berlin.de

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Abstract

In Integrated Land-use and Transport (ILUT) accessibilities are typically computed for zones. This implies that accessibilities are constant within a zone. Besides, the size of a zone is fixed, and has an impact on the measured values. However, accessibility is continuous in space, it is not limited by administrative boarders. This paper presents an approach to measure accessibilities at high resolutions that is also computationally feasible. The approach is applied to a real-world scenario, the city of Zurich (Switzerland). For the present study an utility-based accessibility measure is selected that is also known as the logsum term. Furthermore, this study investigates the (i) sensitivity to different transport modes, such as car, bicycle and walk, and (ii) the sensitivity to a modification in the transport system.

Keywords: high resolution accessibility, utility-based accessibility, sensitivity test

1 Introduction

Persons' choice of their residential location is influenced by how well they can access their activities from there. It is clear that there has to be *some* influence, however weak, since, say, commuting plus working plus sleeping needs to fit into the 24 hours of a day. Similarly, the location choice of firms is influenced by how well they can access their customers from there, or how well suppliers and customers can access them at the location.

In consequence, the suitability of a location for a specific person depends on that person's activity pattern. Similarly, the location for a specific household depends on the activity patterns of all household members, and the location for a specific firm depends on the location of its suppliers and customers. If all these were known, one could compute individual values of every location for persons, households or firms that search for locations.

For many purposes, however, one is interested in a more general value of a given location. For example, a developer might be interested in developing a certain location without knowing the person, household or firm that might eventually occupy it. A family might search for a residence before knowing where, say, the spouse will work. This is where the concept of accessibility comes in: it describes how well a given location can be reached, or how well other locations can be reached from this location.

Researchers assert that accessibility has a measurable impact in the real world: Hansen [1] shows that areas which have more access to opportunities have a greater growth potential in residential development. Moeckel [2] asserts that the principal idea of Hansen's approach is also true for businesses. In other words: Locations with easier access to other locations are more attractive compared with otherwise similar locations with less access.

Many quantitative indicators can be used for accessibility. Some examples are

- distance to next shopping area
- travel time (e.g. [3]) or distance (e.g. [4]) to next central business district
- travel time (e.g. [3]) or distance (e.g. [4]) to next railway station
- number of opportunities (e.g. workplaces, places to shop) within, say, 1 kilometer .

A comprehensive review of accessibility measures can be found in [5, 6]. Accessibility measures can be broadly classified into three categories [5]:

1. The **infrastructure-based** approach is based on the performance of the transport system.
2. The **activity-based** measure deals with the distribution of activities in space and time.
3. A **utility-based** measure of accessibility reflects the (economic) benefits, as the maximum expected utility, that someone gains from access to spatially distributed opportunities [5, 7].

Accessibility can be seen as the result of the following four independent components [5, 6]:

1. A **land-use** component that deals with the number and spatial distribution of opportunities.
2. A **transport** component, which describes the effort to travel from a given origin to a given destination.
3. A **temporal** component, which considers the availability of activities at different times-of-day, e.g. in the morning peak hours.
4. An **individual** component that addresses the different needs and opportunities of different socio-economic groups, e.g. different income groups.

For the present study, the utility-based measure from Ben-Akiva and Lerman [8] is selected, which is also known as the logsum. It is defined as

$$A_i := \frac{1}{\beta_{scale}} \ln \sum_k e^{\beta_{scale} V_{ik}} \ , \tag{1}$$

where V_{ik} is the (dis)utility of travel in order to get from location i to location k, and β_{scale} is the logit model scale parameter.[1] The logsum term includes a land-use component that considers the number and distribution of opportunities, and a transport component that determines the effort to get there.

There are two ways to interpret Eq. (1):

- $\sum_k e^{\beta_{scale} V_{ik}}$ is a weighted sum over possible destinations for a given origin i, where opportunities k which are more difficult to reach obtain a smaller weight. This will always be a positive number.

  The logarithm in front of the weighted sum is not necessary in this interpretation, but it is useful to be consistent with the econometric interpretation given next. Since the logarithm is a monotonic transformation, it will not change the order of the accessibilities. Note, however, that the result may be negative.

- Eq. (1) can also be interpreted as an expected maximum utility. If one traces the expected maximum utility derivation from the logit model (e.g.[8]), one finds that V_{ik} should actually be replaced by $V_{typ} + V_{ik}$, where V_{typ} is the typical systematic utility at the destination. If it is assumed that this is the same for every person at every opportunity, then this can be factored out, and in the end just becomes a constant addend to the accessibility. That is, A_i does *not* include the intrinsic systematic utility of the activity at the destination. It *does*, however, include the averaged effect of the ϵ_k that describe the fluctuations around the systematic utility.

  In this interpretation, the expected utility is $A_i + V_{typ}$. It is maybe easiest to imagine, for a moment, to have this utility realized at location k. One would then have $A_i = V_{ik} + \epsilon_k$. As stated earlier, A_i can become negative, which means that the fluctuation ϵ_k is not sufficient to compensate for the cost of getting to k. Under normal circumstances, this would be compensated for by the systematic utility at the destination, V_{typ}. One could, however, imagine circumstances in which even $A_i + V_{typ}$ would remain negative. In such circumstances, it is plausible to assume that no trip of this type would be made.

  The question how the values of A_i according to Eq. (1) could be converted into monetary units is addressed in Sec. 6.

Quite often, accessibilities are attached to spatial units i. These spatial units are typically relatively large zone, but one could equally calculate accessibilities for each parcel or building in the region of interest. In many cases, however, the computational effort for this would be rather large. In addition, it may not be necessary: Since accessibility is a spatially averaged quantity, it is plausible to assume that the accessibility of a building between two other buildings might be interpolated from the two neighboring accessibility values.

Taking this argument further, one could as well consider accessibility as a field, i.e. as continuously varying in space, $A(x, y)$, where x and y are the coordinates. As is common in many areas of science, such fields can be visualized by calculating the values on regular grid points, and then use an averaging plotting routine. A similar approach was also used by [4]. Going beyond that paper, however, we will compute accessibility not based on Euclidean distance, but using the network oriented performance of the transport system. Sec. 3 describes in detail how this accessibility measure is implemented.

[1] In this paper, sometimes the term "generalized cost of travel" is used instead of "(negative) utility of travel". Strictly speaking, "generalized cost" is often meant in monetary terms, while "utility" is not.

2 Motivation

The present paper is, in fact, motivated by an attempt to couple a land use simulation model, UrbanSim [9, 10, 11], with a transport simulation model, MATSim [12, 13, 14]. The transport model is to feed back information to the land use model. Since one of the UrbanSim submodels is, in fact, a developer model, it makes sense to feed this information back in the form it might be used by a developer who is considering to develop a certain lot. In practical terms, the developer model is obtained by defining multiple choice models, estimating their parameters based on real-world data (actual decisions by developers), and eventually settling on one of those models. In that sense, the best feedback from the transport model is simply the quantity that results in the best model. In that sense, Eq. (1) can be seen as a proxy for other possible accessibility indicators. From a computational performance perspective, it is a relatively difficult case since it averages over *all* opportunities. Indicators that consider only a subset of opportunities will at least be equally fast.

Readers who are interested in a more detailed description of the simulation and integration approach of MATSim with UrbanSim are referred to [15].

3 Methodology: high resolution accessibility

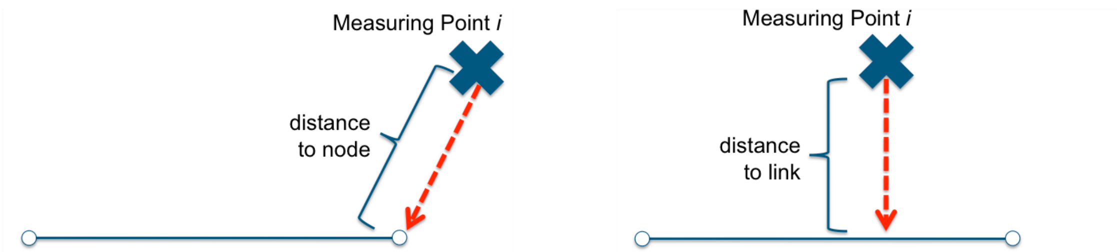
This section looks at the implementation of the econometric accessibility measure that is given by Eq. (1). This task is performed in MATSim. In this section it is assumed that MATSim completed the traffic flow simulation based on the land-use pattern provided by UrbanSim. As a result MATSim possesses a congested road network with time dependent travel times on which it calculates the accessibility indicators as feedback for UrbanSim. A comprehensive description of the simulation and integration approach of MATSim and UrbanSim is given in [15].

In order to calculate the accessibility A_i, origin locations i and opportunity locations k are assigned to the MATSim road network, see Sec. 3.1. For every given origin i a so-called "least cost path tree" runs through the network and determines the best route, and thus the least negative travel utility V_{ik}, to each opportunity location k by using the Dijkstra shortest path algorithm [16]. The best route from i to k depends on the given cost type such as link travel times or distances. Once the least cost path tree has explored all nodes, MATSim queries the resulting travel utilities V_{ik} for all opportunities and calculates the accessibility as stated in Eq. (1).

3.1 Network assignment

Origin and opportunity locations do not necessarily lie on the network; see also Fig. 1. Thus, the calculation of V_{ik} includes in addition the disutility of travel to overcome the gap between locations and the road network. The gap is determined by taking the shortest distance to the network. It is assumed that the distance is covered on foot with a constant speed of 5km/h.

For origin locations i the shortest distance to the network is either given by the Euclidean distance to the nearest node or the orthogonal distance to the nearest link on the network. If the mapping of location i is on a link, as in case of the orthogonal projection (Fig. 1(b)), V_{ik} further includes the travel disutility to overcome the distance to the nearest node. The travel costs are calculated by dividing the distance to the node by the



(a) Euclidean distance measure between the origin location i in accessibility calculation and the nearest network node.

(b) Orthogonal distance measure between the origin i in accessibility calculation and the nearest network link.

Figure 1: The calculation of V_{ik} includes the disutility of travel to overcome the gap between locations such as origins i (blue cross) and the network, which is based on the shortest distance. This is either given by the euclidean distance to the nearest node or the orthogonal distance to the nearest link on the network.

travel speed of the according transport mode, e.g. car (free speed or congested car travel times at a given time-of-day), bicycle (15km/h) or walk (5km/h).

For opportunity locations k the Euclidean distance to the nearest node is used to determine the shortest distance to the network.

3.2 Disutility of travel

As stated earlier (Eq. 1), the computation of the accessibility for a given origin location i contains a summation of the term $e^{\beta_{scale} V_{ik}}$ for all opportunity locations k. The determination of the disutility of travel, V_{ik}, consists of the following contributions:

1. The disutility of travel of reaching the transport network from origin i, as described in Sec. 3.1. It is assumed that opportunities can only be reached via the transport network.

2. The disutility of travel *on* the transport network towards k.

3. The disutility of travel of reaching the opportunity k from the transport network, as explained in Sec. 3.1.

As a result the disutility of travel is composed as follows:

$$V_{ik,tt_{mode}} \quad := \quad \beta_{tt_{wlk}} \cdot tt_{wlk,gap,i} \quad + \quad \beta_{tt_{mode}} \cdot tt_{mode} \quad + \quad \beta_{tt_{wlk}} \cdot tt_{wlk,gap,k} \tag{2}$$

where

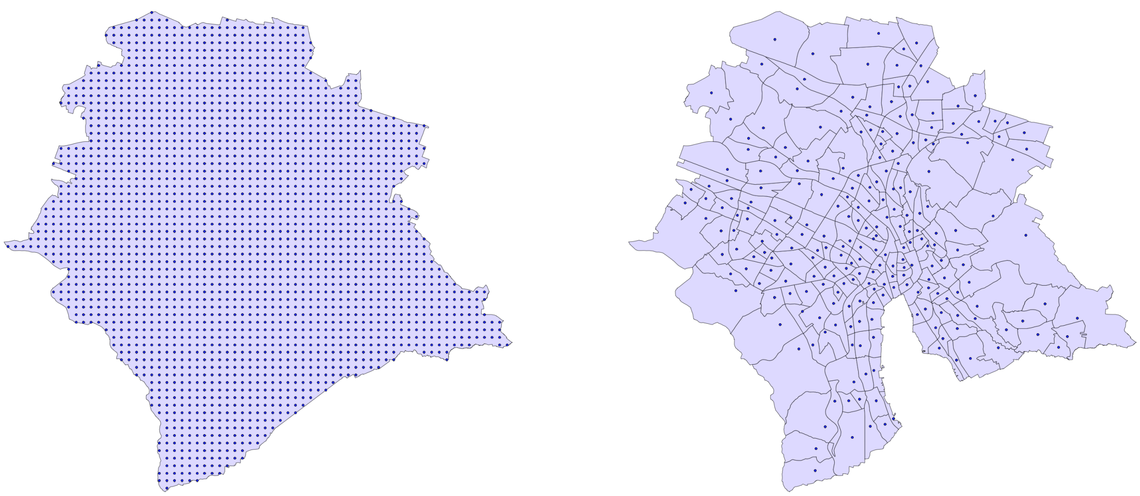
- tt_{wlk} is the travel time [in h] on foot.
- tt_{mode} is the travel time [in h] according to the given transport mode. Transport modes are either car (free speed or congested), bicycle or walk.
- $tt_{wlk,gap,i}$ is the travel time [in h] on foot to overcome the gap between the origin location i and the road network.
- $tt_{wlk,gap,k}$ is the travel time [in h] on foot to overcome the gap between the road network and the opportunity location k.

- $\beta_{tt_{mode}}$ and $\beta_{tt_{wlk}}$ are marginal utilities [in utils/h] that convert travel times into utils. By default all marginal utilites are set to -12 utils/h. In MATSim terms, this is the sum of the marginal opportunity cost of time (typically -6 utils/h) and the marginal additional disutility of travel (typically another -6 utils/h). In calibrated applications, a util is often worth roughly one Euro or one Dollar.

The travel times for traveling by bicycle or on foot are computed by taking the travel distance with a constant velocity of 15km/h (bicycle) or 5km/h (walk).

3.3 Spatial resolution

When looking at high-resolution accessibility calculations, there are, in fact, two resolutions to consider: One that defines for how many origins i the accessibility is to be computed. And a second one that defines to what level the opportunities k are to be resolved.



(a) Cell-based approach using a $200m \times 200m$ side length

(b) Zone-based approach

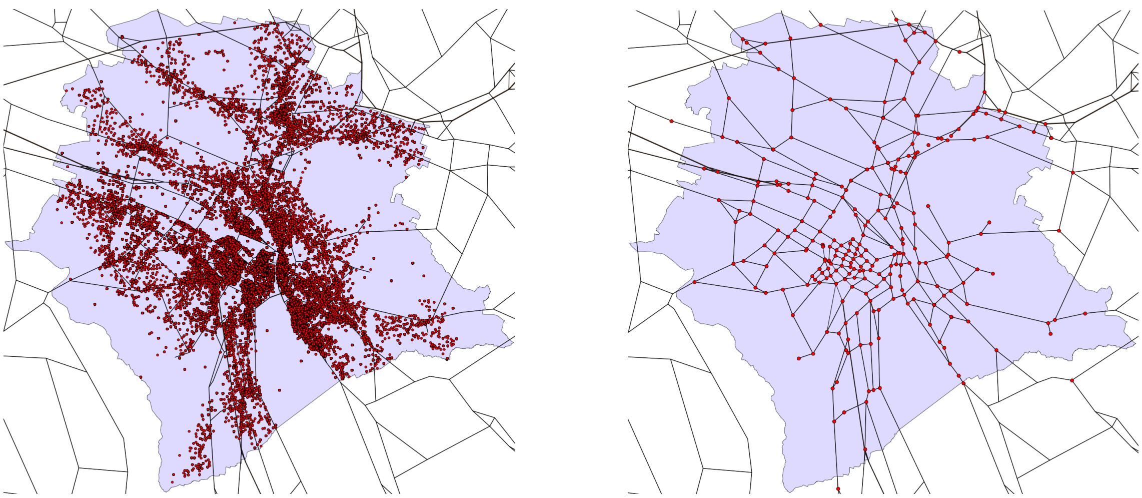
Figure 2: The figures visualize the cell- and zone-based approach in accessibility calculation at the example of the city of Zurich (blue area). The measuring points (origins) for accessibility calculation are determined as follows: The cell-based approach subdivides the study area in square cells of configurable size; here a side length of $200m \times 200m$ is used for visibility reasons. The cell centroids (blue dots) serve as origins. The zone-based approach is using zone centroids instead, which are determined by averaging all parcel coordinates that belong to a zone. The number of measuring points is given by the number of zones.

Spatial resolution of the origin: The origin side can be calculated for two spatial units, cells or zones. Their spatial resolutions determine the number of points for which the accessibility will be computed:

- **Cell-based Approach**: In this approach the study area is subdivided into square cells, where the resulting cell centroids serve as measuring points (origins) for the accessibility calculation; see Fig. 2a. The spatial resolution depends on the selected cell size, which is configurable.

- **Zone-based Approach**: This approach uses the zone centroids as measuring points, as shown in Fig. 2b. The centroid coordinates can be obtained from a variety of definitions. In this paper, they are determined by averaging all parcel coordinates that belong to a zone. This corresponds to weighting each parcel equally; this may not be justified when, say, the number of residents or households varies strongly between parcels.[2] The number of measuring points is defined by the number of zones.

Since the latter approach is on an aggregate zone level, the following paragraphs concentrate on the cell-based approach that is qualified for high resolution accessibility calculations. Nevertheless, the calculation procedure of the logsum term is the same for both approaches.



(a) Opportunities with parcel coordinates given by the land-use model

(b) Opportunities, aggregated on the nearest node on the road network

Figure 3: Opportunity locations (red dots) are provided from the land-use model on a disaggregated parcel level. The spatial resolution inside MATSim depends on the resolution of the road network, i.e. on the number of nodes and link lengths. Thus, opportunities are directly aggregated to their nearest node on the given road network.

Spatial resolution of the destinations (= opportunities): Opportunity locations such as work places are given form the land-use side. Unlike origins, for the present paper such locations are directly aggregated to the nearest node on the road network as depicted in Fig. 3. The sum of travel disutility V_{jk} to get from a node j to opportunity k over all opportunities k that are aggregated on the same node are included. Assume the travel disutility from origin i to node j is V_{ij} and the disutility from node j to opportunity k is V_{jk}. Then $\sum_k e^{\beta_{scale} V_{ik}} = \sum_k e^{\beta_{scale} V_{ij}} e^{\beta_{scale} V_{jk}} = e^{\beta_{scale} V_{ij}} \sum_k e^{\beta_{scale} V_{jk}}$. Thus, there is in fact no approximation in accessibility computation on the opportunity side using the proposed aggregation approach.

Spatial resolution setting: In the present paper a resolution of $100m \times 100m$ is selected to perform cell-based accessibility measures. This is due to a previous observation in [15], where the same scenario with the same network is used. It shows a significant

[2] This is another example of an assumption that does not have to be made for the high resolution accessibility computation.

increase in the level of detail until a resolution of $100m \times 100m$. Whereas resolutions better than $100m \times 100m$ do not deliver noticeable gains. The reason for this is the spatial resolution inside MATSim, which is determined by the road network; see Sec. 4.2.

However, when looking at the computing times for the present scenario (Sec. 4) in Tab. 1, there is no reason to limit the accessibility measure to low resolutions. The fast computing times are due to a pre-processing step that reduces the execution of the "least cost path tree". This is achieved in two steps. (i) For all origin locations i their nearest node on the road network is identified. For origins that share the same node (ii) the "least cost path tree" is executed only once during the accessibility computation.

Resolution Cell-Based Approach	**Measuring Points**	**Aggregated Opportunities**	**Computing Time [minutes]**
$50m \times 50m$	36 748	272	2-3
$100m \times 100m$	9195	272	2
$200m \times 200m$	2292	272	≈ 2
$400m \times 400m$	577	272	≈ 1
$800m \times 800m$	142	272	< 1
Number of Zones Zone-Based Approach	**Measuring Points**	**Aggregated Opportunities**	**Computing Time [minutes]**
234	234	272	≈ 1

Table 1: This table summarizes the consumed computing times to measure accessibility at different resolutions and different spatial units, i.e. zones and cells. All measures are performed on a Mac Book Pro with an Intel Core 2 Duo 2.5GHz processor and 4 GB of memory, where 1 CPU core is used to execute the accessibility measures.

4 Scenario: Zurich, Switzerland

The present study is applied to a real-world scenario. This is the city of Zurich, a parcel-based UrbanSim application that will be briefly discussed here. A full description is given in [17, 18].

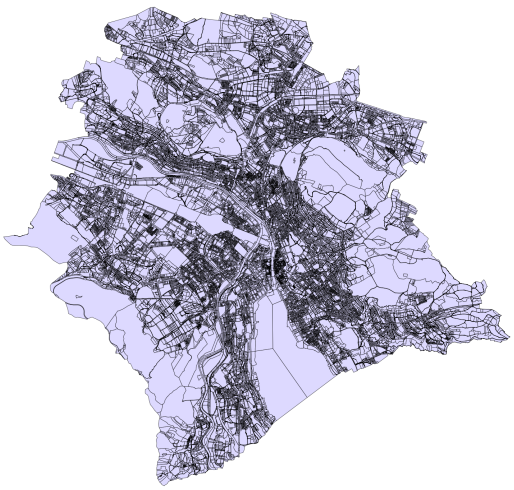
The Zurich case study uses the the year 2000 as the UrbanSim base year. It stores the initial state of the study area. The data that is needed to create the base year such as a population census, mobility census, enterprise census, etc., comes from several sources that can be divided into two main categories: governmental and private data. The sources for governmental data includes various Swiss federal, cantonal,[3] and municipal offices. The acquisition of private data includes private institutions, web-sites, and self created data. For more details on the base year data and data processing methods see [17, 18].

The Zurich application consists of 40'407 parcels and 234 zones; see Fig. 4. The synthetic population of Zurich counts 336'291 inhabitants. 316'703 jobs are provided in the study area. In this paper the UrbanSim base year is used to create the input for the MATSim runs. After that, UrbanSim is no longer needed for the present study.

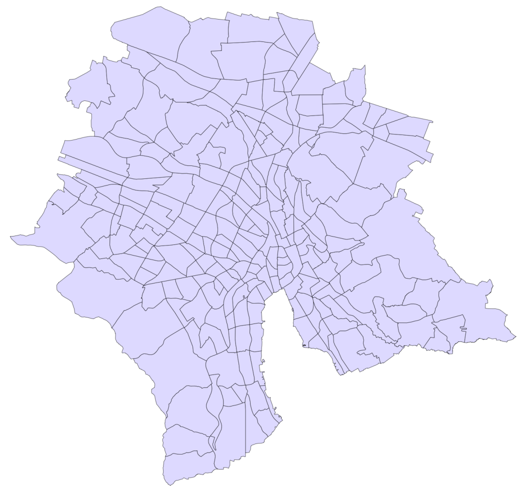
4.1 Population and Travel Demand

In order to speed up computation times, MATSim considers a 10% random sample of the synthetic UrbanSim population, consisting of 33'629 agents. All MATSim agents have

[3] A Swiss Canton corresponds to a federal state



(a) UrbanSim Parcels



(b) UrbanSim Zones

Figure 4: UrbansinSim provides different geographic units of analysis such as parcels (a) and zones (b) [11]. The blue area indicates the city of Zurich.

complete day plans with “home-to-work-to-home” activity chains. Work activities can be started between 7 and 9 o’clock with a typical duration of 8 hours. The home activity has a typical duration of 12 hours and no temporal restriction.

4.2 Network and Adjustments

A revised Swiss regional planning network [19] is used that includes major European transit corridors; see Fig. 5. The network consists of 24’180 nodes and 60’492 links, where each link is defined by an origin and a destination node, a length, a free speed car travel time, a flow capacity and a number of lanes. In addition each link obtains congested car travel times once the traffic flow simulation in MATSim is completed; see [15].

The following summarizes modifications to improve link capacities especially at the urban scale; a detailed description is given in [20] and [21]. All links within a radius of 4 kilometers around the Zurich city center were modified as follows:

- Links that correspond to so-called primary[4] roads in OpenStreetMap[5] (OSM) get a capacity of at least 2000 vehicles per hour. Links with higher capacities remain unchanged.
- Links that correspond to secondary roads in OSM keep their initial capacity (usually between 1000 and 2000 vehicles per hour).
- The remaining links get a capacity with a maximum of 600 vehicles per hour. If the original capacity is lower, it is not changed.
- Finally, a few individual links are adjusted manually based on local knowledge.

[4] an open street map road classification is given at `http://wiki.openstreetmap.org/wiki/Highway_tag_usage`

[5] see `http://www.openstreetmap.org`

The flow- and storage capacity of the road network are automatically adjusted based on the given population sampling rate used for the MATSim runs. This is done in order to preserve congestion effects when running MATSim at small samples. The flow capacity gives the maximum number of vehicles per time unit that can pass a link [22]. It is adjusted by a flow capacity factor, which is set to the same value as the given *Population Sampling Rate*. The storage capacity defines the maximum number of vehicles that can be on a link [22]. The corresponding storage capacity factor is defined by $\frac{Population\ Sampling\ Rate}{Heuristic\ Factor}$, where the $Heuristic\ Factor = \sqrt[4]{Population\ Sampling\ Rate}$. The *Heuristic Factor* is a fit function based on engineer heuristics. It aims to raise the storage capacity especially at low sampling rates to avoid network breakdowns caused by strong but spurious backlogs. This effect is explained in [23].

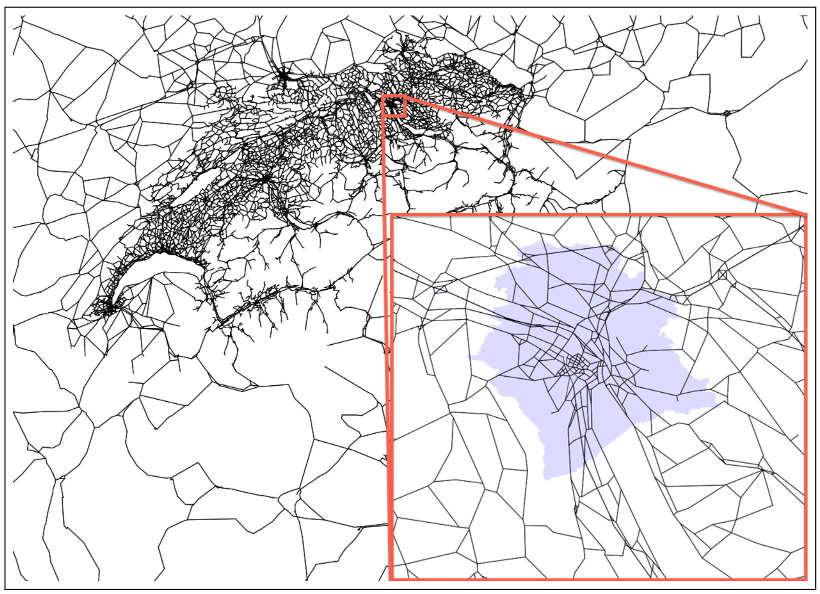


Figure 5: The Zurich case study network, area of Zurich (in blue) enlarged.

4.3 Simulation Run

First, a preparatory MATSim run is performed by running the simulation for 1000 iterations. During the first 800 iterations 10% of the agents perform "time adaptation", which changes the departure times of an agent, and 10% adapt their routes. The remaining agents switch between their plans. During the last 200 iterations time and route adaptations are switched off. Thus, agents only switch between existing plans. The output of this run is referred to as the **Base Case**.

5 Sensitivity testing

The present study looks at the proposed econometric accessibility measure using the example of work place accessibility. By aggregating the work places on the network nodes the number of opportunities is significantly reduced from 316'703 to 272 as described in Sec. 3. Two tests are performed to investigate the (i) sensitivity to different transport modes and (ii) the sensitivity to a modification in the transport system.

Both tests are applied for the cell-based approach with a resolution of $100m \times 100m$ as explained in Sec. 3.3. The scale parameter (β_{scale}) is set to 2, which is the MATSim default setting. The accessibility is measured for the morning peak hour at 8am, when most travellers are commuting to work.

5.1 Sensitivity to different transport modes

Three different travel modes in accessibility computation are compared, which are car, bicycle and walk. For car both, free speed and congested travel times are tested. The travel times for traveling by bicycle or on foot are computed by taking the travel distance with a constant velocity of 15km/h (bicycle) or 5km/h (walk). The marginal utilities for all modes, i.e. $\beta_{tt_{free}}$, $\beta_{tt_{car}}$, $\beta_{tt_{bic}}$ and $\beta_{tt_{wlk}}$, are set to -12utils/h as stated in Sec. 3.2. All measures are applied to the **Base Case** (Sec. 4.3).

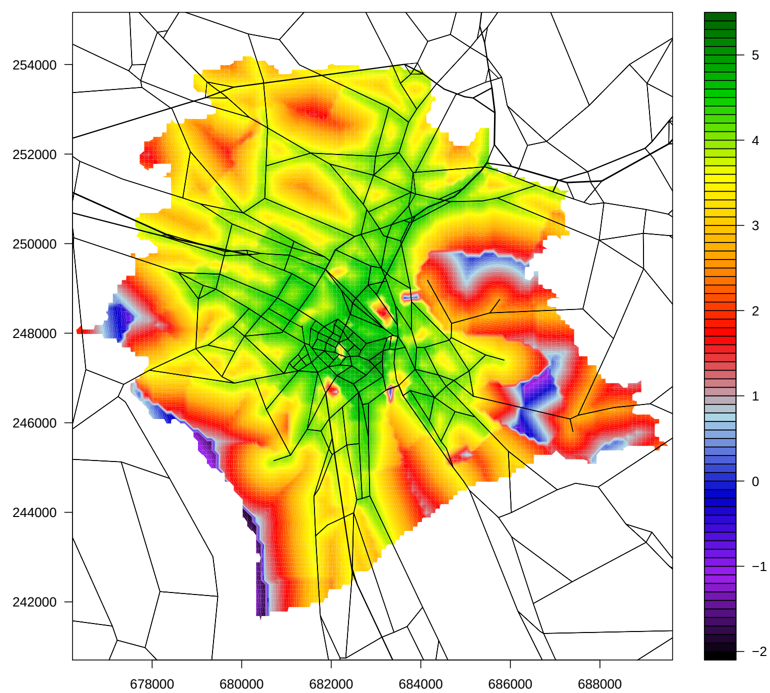
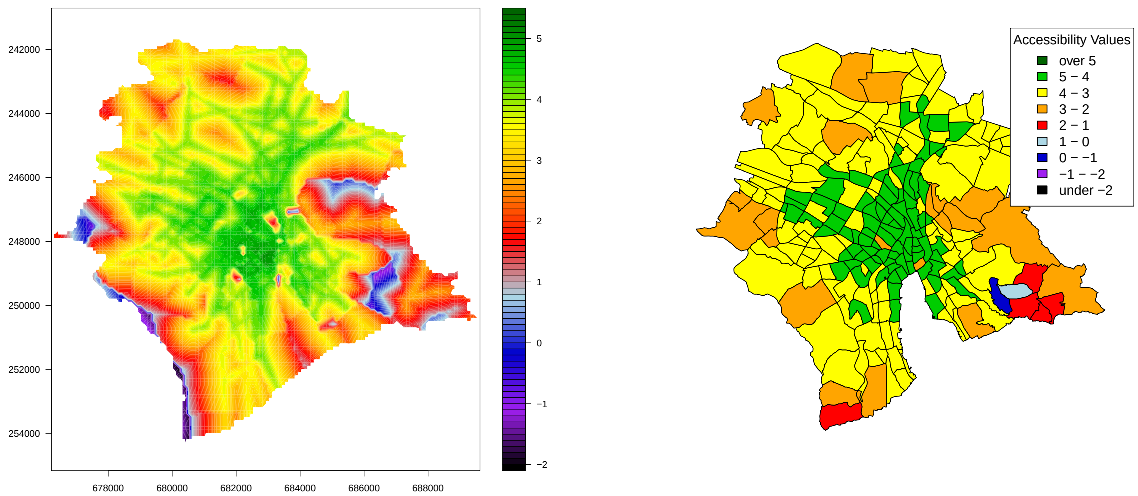


Figure 6: This shows the accessibility measure with the reference settings and the underlying road network.

Fig. 6 depicts the outcome of congested car travel times in accessibility computation, which can be seen as the MATSim default setting for accessibility calculations. To improve the interpretability, the road network is overlayed. The color bar on the right hand side indicates the accessibility level, where a good work place accessibility is indicated by green areas and poor accessibility is indicated by dark blue or black areas.

As might be expected, the plot exhibits a very good work place accessibility in areas that provide a high density of opportunities and a well developed road network. These characteristics apply for the inner city, where the highest utility values are measured, and the areas along the major access roads from and to Zurich, visible as green or yellow



(a) The same as Fig. 6, but without showing the road network.

(b) The same as Fig. 6, but now based on zones as is traditionally done.

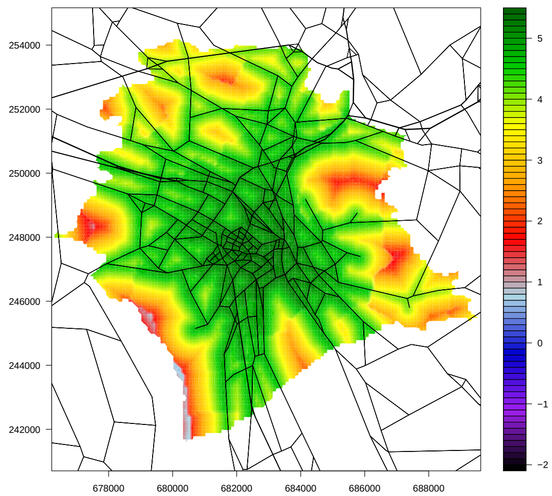
Figure 7: Alternative representations of the same data as Fig. 6.

lines. In contrast, less accessible areas with a low work place density have a color gradient from red to dark blue or black. This for instance applies for the "Zürichberg" and the "Uetliberg", which are two undeveloped wooden hills located in the east and south west part of Zurich. The several "islands of low accessibility" in the center of Zurich are due to localized congestion on those links: If there is strong congestion at the origin, then *all* opportunities k incur a strongly negative V_{ik} and thus make only a small contribution to the sum.

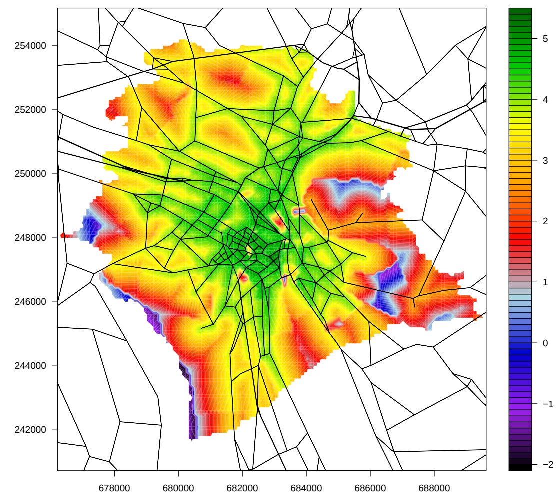
It should be noted how the accessibility is now smooth in space. This can be even more clearly seen in Fig. 7(a), which is the same as Fig. 6 but without the road network. One clearly sees how the highly accessible areas trace the road network. Compare this to Fig. 7(b), which is the same data aggregated into uniform zones. Clearly, all additional spatial resolution within the zones is now gone. Also, with the zones approach the question in how far the transport network becomes visible in the accessibility plot hinges entirely on the question if the zones reflect the structure of the transport network or not. All this arbitrariness is removed with an approach that does not rely on zones.

The results with different transport modes are shown in Fig. 8. The first two plots are illustrating how congestion significantly reduces accessibility. The third and fourth plot illustrate accessibility by bicycle and by walking, respectively. Congestion has no effect on these modes. Both plots show that spatial proximity to opportunities has a strong influence on the results. Locations away from the city center and the commercial areas in the northeast and western part of Zurich have a rapidly decreasing accessibility. As seems plausible, near the city center the bicycle provides similar accessibility as the car under congested conditions. Farther away from the center, the car gains ground, even under congested conditions.

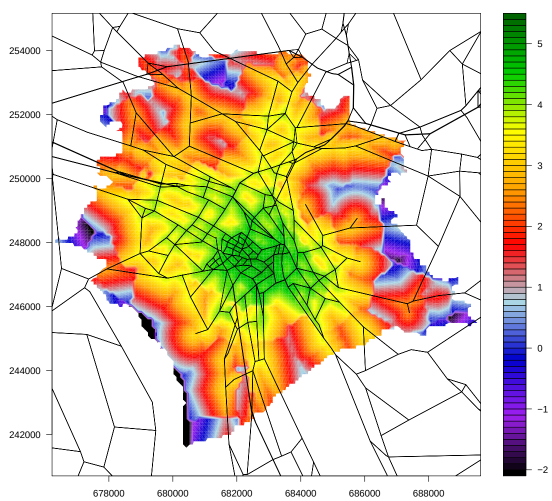
Overall, one might speculate that Fig. 8(a) is what people who plan to use a car expect, for example when selecting a residence, but Fig. 8(b) is what they actually get. And what they actually get is not much different from what one gets by using a bicycle (Fig. 8(c)).



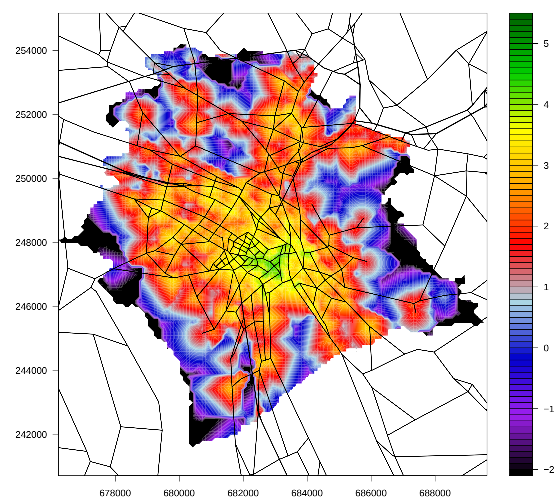
(a) Free speed car travel times in accessibility computation



(b) Congested car travel times in accessibility computation



(c) Bicycle travel times in accessibility computation



(d) Walk travel times in accessibility computation

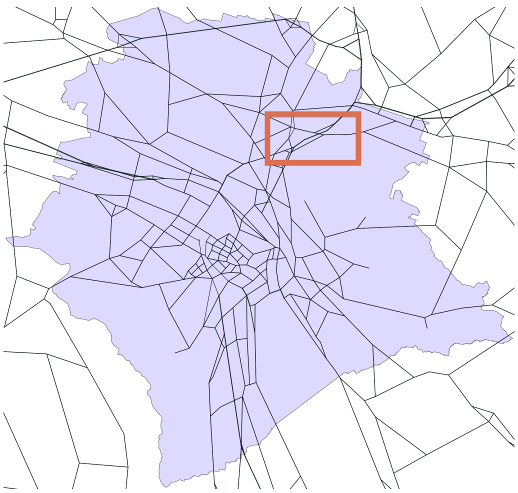
Figure 8: These plots visualize the influence of different transport modes on the accessibility computation.

In contrast, walk is truly much worse (Fig. 8(d)).

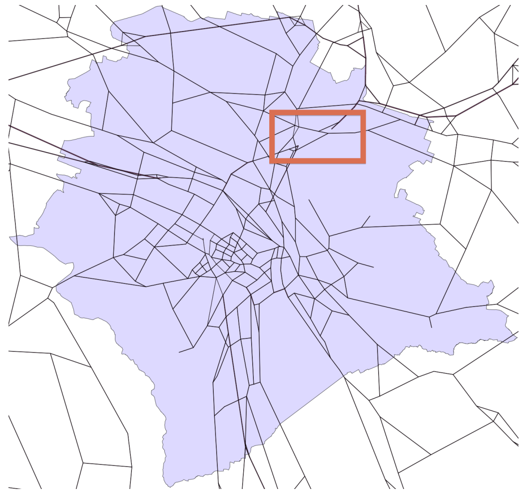
5.2 Sensitivity to a modification in the transport system

In this section, the accessibility consequences of a tunnel closure are considered. For this purpose two scenarios are created, which only differ in the network set-up:

1. **Base Scenario**: The base scenario leaves the road network as it is.



(a) Network used in the Base Scenario



(b) Network used in the Schöneichtunnel Scenario

Figure 9: In order to investigate the impact of changes in the transport system, the "Schöneichtunnel" is closed by removing links from the road network as illustrated in Figure (b). Figure (a) shows the default, unchanged network.

2. **Schöneichtunnel**: In this scenario the "Schöneichtunnel", an important intersection-free artery connection in the western part of Zurich is closed; see Fig. 9. It connects the north-easterly suburbs and the central business district with a capacity of 5'740 vehicles per h in each direction. In Fig. 10 it can be seen that there are no alternative roads that can compensate such a closure. The idea for this scenario is loosely based on a real closure of the Schöneichtunnel due to maintenance works in the year 2001 [24].

Both scenarios are using the **Base Case** as input and run for another 1000 iterations with the same time and route adaptation settings as described in Sec. 4.3. As in the previous test the marginal utility for congested car travel times, i.e. $\beta_{tt_{car}}$, is set to -12utils/h.

The value range in Fig. 11 is limited for visualisation purposes. This means, that only accessibility outcomes between the values 5 and 2 are plotted. Fig. 11(a) shows the **Base Scenario**. For Fig. 11(b) the following was done: (i) The tunnel was closed. (ii) For all routes that used the tunnel, an alternative route was computed, based on the free speed travel times, but minus the tunnel. (iii) A traffic flow simulation was run based on these routes. The result (Fig. 11(b)) is significantly reduced accessibility in the north-eastern sector of the city. Strong congestion upstream and parallel to where the tunnel was significantly hinders car traffic. Fig. 11(c) then shows accessibility after the system had a chance to adjust to the closed tunnel. Surprisingly, there seem to be *no* accessibility consequences. Seemingly, the system re-equilibrates in a way that the status quo ante in terms of accessibility is recovered.

One might speculate that the effect of the tunnel closure manifests itself in the departure time choice. This would mean that accessibility during the peak period could remain virtually unchanged while at the same time the peak period itself would be extended. The simulation results were checked accordingly; it was not possible to identify any change

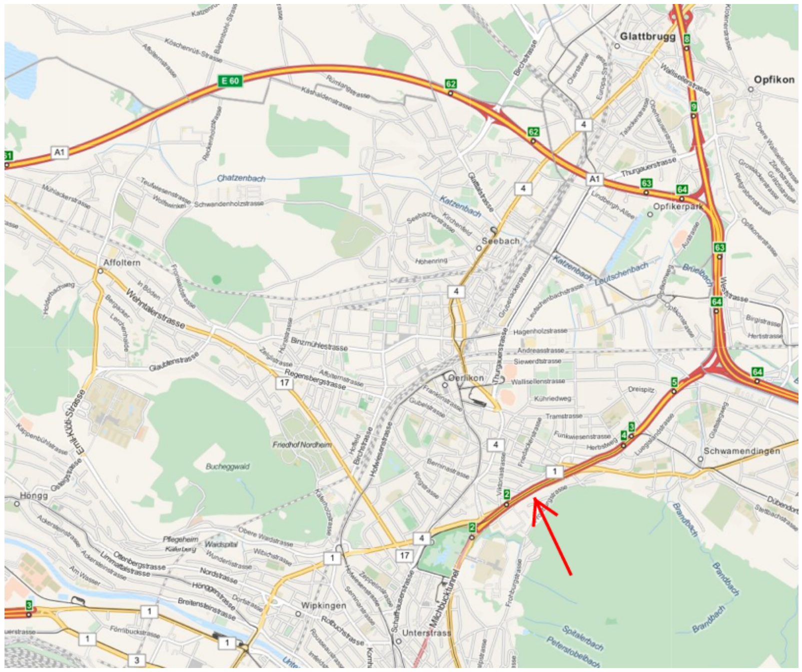


Figure 10: Network from `www.openstreetmap.org`. The arrow points to the links that are removed. The downtown area is to the bottom left of the picture.

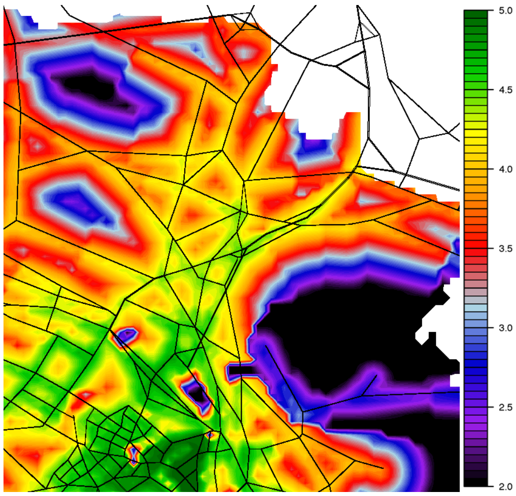
in the departure time distribution (Fig. 12). The simulation results are, however, distinctly different, since the average trip distances in the simulation area drop from $9800m$ to $9350m$. Thus, the long-term effect of the tunnel closure seems to be a reduction in average trip distances, while the average travel times remain the same. This may seem a bit counter-intuitive. We have, however, seen similar results in previous studies. Presumably, a local change in a networked transport system can lead to a re-arrangement of the traffic patterns in such a way that it redistributes the effects of the change throughout the system; the overall effect is then a small but globally felt accessibility change [25, 26]. In the present situation, there does not even seem to be that globally felt accessibility change; it may therefore be a real-world example of the Braess paradox [27]. Such results, however, do not hold in all situations; Ref. [28] describes a modification where the gains and losses (albeit differently measured) show a clear spatial picture.

6 Discussion

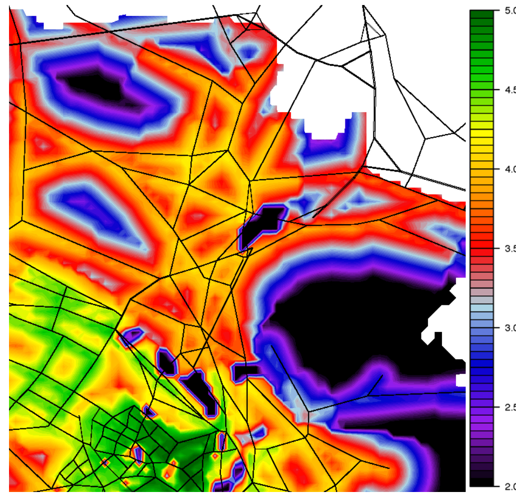
The unit of the accessibility measurement In Eq. (1), the logsum term is divided by the logit model scale parameter. Assume that the travel utility is of form

$$V_{ik}^{trav} = Const + \beta_{car} \cdot t_{car} + \beta_{walk} \cdot t_{walk} + ... + \beta_m \cdot m \ ,$$

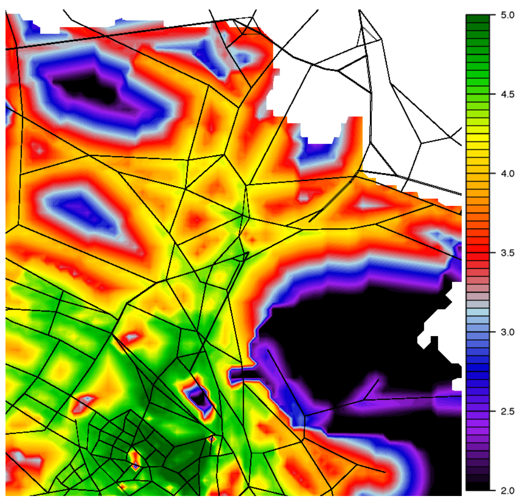
where β_x are the (typically negative) parameters, t_x are the travel times by mode, and m is the monetary cost of the trip. Eq. (1) thus returns a result in utils. Since the scale parameter cannot be separately estimated, it is essentially arbitrary and just rescales the accessibility landscape without changing the pattern.



(a) Base Scenario after 1000 iterations



(b) Schöneichtunnel closure after 1 iteration

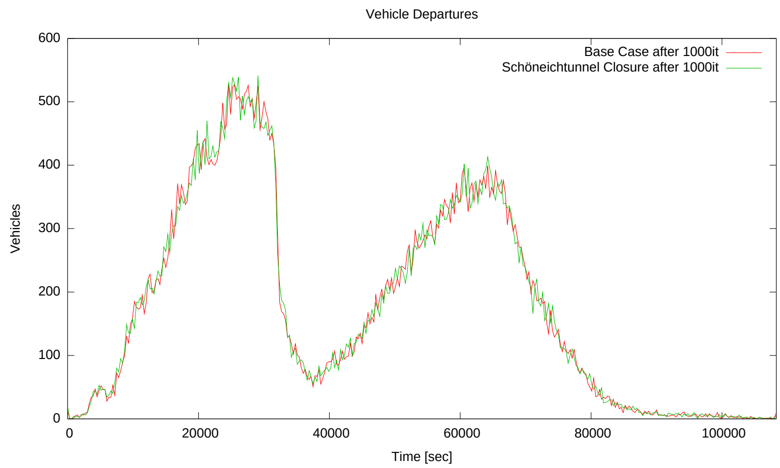


(c) Schöneichtunnel closure after 1000 iterations

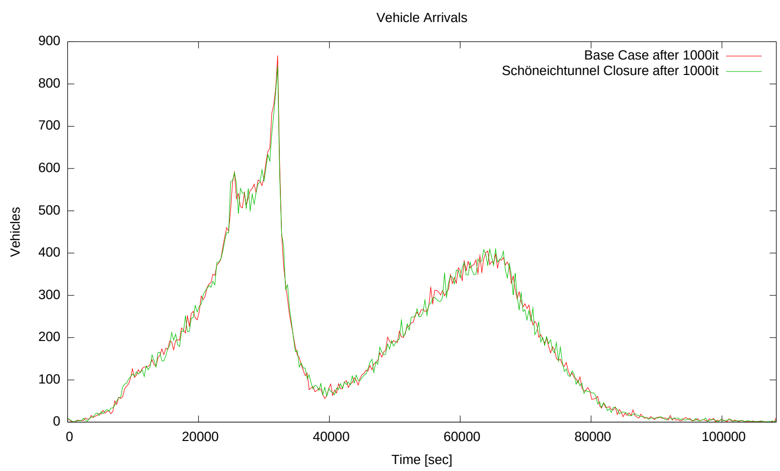
Figure 11: The sensitivity test illustrates the impact from a change in the transport system, simulated by a tunnel closure, on the accessibility measure. Note the reduction in accessibility on both ends of the closed tunnel immediately after closure (b). After 1000 iterations, there is no discernible difference to the base case (c). The color scale is different from the previous figures in order to highlight the differences between (a) and (b).

The utility value could, however, be converted into monetary units by dividing it by β_m, the marginal utility of money. The parameters for the results were set such that 12 utils corresponds to one hour of travel time, independent of the mode. Assuming a value of time of 12 Eu/h, one obtains that one util (e.g. in Figs. 6– 11) roughly corresponds to one Euro.

The plots in this paper are based on a grid resolution of $100m \times 100m$, and the road network as shown in some of the figures. Higher spatial resolutions with the same road network do not lead to discernible improvements [29]. In contrast, a higher resolution road network would clearly make a difference – the present method assumes that the access from an arbitrary location to the given road network is done by walking while there



(a) Comparing the departure times between Base Scenario and Schöneichtunnel closure after 1000 iterations



(b) Comparing the arrival times between Base Scenario and Schöneichtunnel closure after 1000 iterations

Figure 12: This shows the departure and arrival pattern for the Base- and Schöneichtunnel scenario.

may be minor roads in reality. Using a higher resolution road network is feasible – the computational cost scales roughly in the number of links. In the present situation, we decided to stick with the lower resolution network. One reason was that we wanted to investigate how our approach would perform in such a situation. Another reason was that we had no higher resolution network together with a calibrated scenario available.

7 Conclusion

Accessibility measures are, for a given origin, a weighted sum over possible destinations. In this paper, the econometric logsum term is used as an example. It measures accessibility as a benefit that someone at a specific location derives from access to spatially distributed opportunities. It includes, as usual, a land-use component by considering the distribution of opportunities and a transport component by determining the effort to get there.

A previous paper [29] presented an implementation approach that allows to calculate the logsum term at high spatial resolutions. The present paper applies this approach to a real-world scenario, the city of Zurich (Switzerland), with the example of measuring work place accessibilities. The measure is tested for different transport modes such as car, bicycle and traveling on foot.

In addition, a sensitivity test was carried out, where the Schöneichtunnel, an important access road, is closed.

Important results include:

- The approach is able to provide a spatially differentiated picture. Artefacts such as supposedly homogeneous accessibility within zones are removed.

- The effect of congestion is very clearly visible. The result also confirms that, in the urban core, accessibility by bicycle is similar to accesibility by car during congested peak hours. Outside the urban core, however, accessibility by bicycle is clearly worse than by car also during peak hours.

  In contrast, accessibility when walking is definitely much worse than either by car of by biclye, and reaches levels comparable to accessibilities by bicycle or by car only in the inner center of the city.

- The approach clearly visualizes accessibility changes after a major change in the transport infrastructure.

  Somewhat surprisingly, the infrastructure change (the removal of a major inner-urban freeway section) has no discernible effect after the system has equilibrated.

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References

[1] Hansen, W., Journal of the American Planning Association **25** (1959) 73 .

[2] Moeckel, R., *Business Location Decisions and Urban Sprawl A Microsimulation of Business Relocation and Firmography*, PhD thesis, University of Dortmund, 2006.

[3] Vandenbulcke, G., Steenberghen, T., and Thomas, I., Journal of Transport Geography **17** (2009) 39 .

[4] Borzacchiello, M. T., Nijkamp, P., and Koomen, E., Environment and Planning B: Planning and Design **37** (2010) 148.

[5] Geurs, K. and Ritsema van Eck, J., Accessibility measures: review and applications, Technical report, National Institut of Public Health and the Environment, RIVM, P.O. Box 1, 3720 BA Bilthoven, 2001.

[6] Geurs, K. T. and van Wee, B., Journal of Transport Geography **12** (2004) 127 .

[7] de Jong, G., Daly, A., Pieters, M., and van der Hoorn, T., Transportation Research Part A: Policy and Practice **41** (2007) 874.

[8] Ben-Akiva, M. and Lerman, S. R., *Discrete choice analysis*, The MIT Press, Cambridge, MA, 1985.

[9] Waddell, P., Journal of American planning Association **68** (2002) 297 .

[10] Miller, E., Nagel, K., Ševčíková, H., Socha, D., and Waddell, P., OPUS: An open platform for urban simulation, in *9th Conference on Computers in Urban planning and urban management (CUPUM)*, University College London, UK, 2005, See www.cupum.org.

[11] OPUS User Guide, *The Open Platform for Urban Simulation and UrbanSim Version 4.3*, University of California Berkley and University of Washington, 2011.

[12] Balmer, M., Raney, B., and Nagel, K., Adjustment of activity timing and duration in an agent-based traffic flow simulation, in *Progress in activity-based analysis*, edited by Timmermans, H., pages 91–114, Elsevier, Oxford, UK, 2005.

[13] Raney, B. and Nagel, K., An improved framework for large-scale multi-agent simulations of travel behaviour, in *Towards better performing European Transportation Systems*, edited by Rietveld, P., Jourquin, B., and Westin, K., pages 305–347, Routledge, London, 2006.

[14] Balmer, M. et al., MATSim-T: Architecture and simulation times, in *Multi-Agent Systems for Traffic and Transportation*, edited by Bazzan, A. and Klügl, F., pages 57–78, IGI Global, 2009.

[15] Nicolai, T. and Nagel, K., Coupling transport and land-use: Investigating accessibility indicators for feedback from a travel to a land use model, in *Latsis Symposium 2012 – 1st European Symposium on Quantitative Methods in Transportation Systems*, Lausanne, Switzerland, 2012, Also VSP WP 12-16, see www.vsp.tu-berlin.de/publications.

[16] Dijkstra, E., Numerische Mathematik **1** (1959) 269.

[17] Schirmer, P., Zöllig, C., Bodenmann, B. R., and Axhausen, K. W., The Zurich case study of UrbanSim, in *European Regional Science Association Conference*, 2011.

[18] Schirmer, P., Options and constraints of a parcel based approach in 'UrbanSimE', in *Proceedings of the 10th Swiss Transport Research Conference (STRC)*, 2010, see www.strc.ch.

[19] Vrtic, M., Fröhlich, P., and Axhausen, K., Schweizerische Netzmodelle für Strassen- und Schienenverkehr, in *Jahrbuch 2002/03 Schweizerische Verkehrswirtschaft*, edited by Bieger, T., Lässer, C., and Maggi, R., pages 119–140, Schweizer Verkehrswissenschaftliche Gesellschaft, St. Gallen, 2003.

[20] Grether, D., Chen, Y., Rieser, M., Beuck, U., and Nagel, K., Emergent effects in multi-agent simulations of road pricing, in *Proceedings of the Annual Meeting of the European Regional Science Association (ERSA)*, 2008.

[21] Chen, Y., Rieser, M., Grether, D., and Nagel, K., Improving a large-scale agent-based simulation scenario, VSP Working Paper 08-15, TU Berlin, Transport Systems Planning and Transport Telematics, 2008, see www.vsp.tu-berlin.de/publications.

[22] Nagel, K., *Multi-agent transport simulation (draft-in-progress)*, 2007, Draft-in-progress for a book.

[23] Rieser, M. and Nagel, K., European Journal of Physics **63** (2008) 321.

[24] Rederlechner, N., Änderung der Luftbelastung in Zürich Nord während der Sanierung des Schöneichtunnels im Sommerhalbjahr 2001, Bericht 2002070, Stadt Zürich, 2001.

[25] Nagel, K., Towards simulation-based sketch planning: Some results concerning the Alaskan Way viaduct in Seattle WA, VSP Working Paper 08-22, TU Berlin, Transport Systems Planning and Transport Telematics, 2008, see www.vsp.tu-berlin.de/publications.

[26] Balmer, M. et al., Wirkungen der Westumfahrung Zürich: Eine Analyse mit einer agentenbasierten Mikrosimulation, IVT Working paper 550, Institute for Transport Planning and Systems, ETH Zurich, Zurich, Switzerland, 2009.

[27] Braess, D., Unternehmensforschung **12** (1968) 258.

[28] Nagel, K., Towards simulation-based sketch planning, part II: Some results concerning a freeway extension in Berlin, VSP Working Paper 11-18, TU Berlin, Transport Systems Planning and Transport Telematics, 2011, see www.vsp.tu-berlin.de/publications.

[29] Nicolai, T. and Nagel, K., High resolution accessibility computations, VSP Working Paper 12-XX, TU Berlin, Transport Systems Planning and Transport Telematics, 2012, See www.vsp.tu-berlin.de/publications.

[30] VSP working paper, TU Berlin, Transport Systems Planning and Transport Telematics, see www.vsp.tu-berlin.de/publications.