

# Investigating accessibility indicators for feedback from a travel to a land use model

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## Abstract

Activity locations such as work locations or leisure facilities are not uniformly distributed geographically. Also, the travel access to different locations is not uniform. It is plausible to assume that locations with easier access to other activity locations are more attractive than locations with less access.

In consequence, urban simulation models like UrbanSim use accessibility measures, such as “number of jobs with 30 minutes by car”, for several of their sub-models. A problem, however, is that accessibility variables are not easy to compute within UrbanSim, for two reasons: (1) UrbanSim does not contain a travel model, and in consequence is not able to compute by itself the congestion effects resulting from land use decisions. (2) The travel times are fed back from the travel model in the form of zone-to-zone travel time matrices. As is well known, such matrices grow quadratically in the number of zones. This limits the number of attributes that can be passed, for example different values for different times-of-day and/or for different activity purposes.

These issues could be solved within UrbanSim, but only with considerable implementation effort. For that reason, it is important to consider how accessibility measures could be fed back from a travel model to UrbanSim. The present study looks at the question in which extend location-based accessibility measures that are computed in the travel model and then fed back to UrbanSim could be used for this purpose. Those accessibility measures are no longer measures belonging to *pairs* of locations, but just belong to *one* location; a typical representative is a logsum term. In consequence, the number of entries now grows linearly in the number of locations, allowing much more freedom both in the number of considered locations and in the number of attributes that could be attached to every location that is considered in this way. This preliminary study will address issues such as different spatial resolutions of such accessibility measures and computing times.

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# 1 Introduction

UrbanSim (Waddell, 2002) is an agent-based urban simulation model. It aims at simulating interactions between land use, transportation, economy and the environment at large-scale metropolitan areas and over a long time period. UrbanSim consists of several models reflecting the decisions of households, businesses, developers, governments (as policy inputs), and their interactions in the real estate market.

UrbanSim does not model transport itself. Instead, it relies on an interaction with external transport models to update the traffic conditions resulting from the land use. It shares this approach with many other urban simulation models such as e.g. DELTA or MUSSA (Wegener, 2004).

In the past, some integration efforts with external travel models like EMME (Babin et al., 1982) or VISUM (PTV AG, 2009a,b) have been made. Both EMME and VISUM are traditional assignment models using origin-destination matrices (OD-matrices) as inputs (e.g. Ortúzar and Willumsen, 2001).

As part of the SustainCity<sup>1</sup> project a first prototype approach coupling MATSim (e.g. Raney and Nagel, 2006; Balmer et al., 2005) with UrbanSim has been made (Nicolai et al., 2011). A disaggregated, agent-based traffic simulation model like MATSim simulates each traveler individually. Therefore MATSim takes the synthetic UrbanSim population directly on the agent level and simulates its travel behavior. The travel demand is, in principle, a result of individual decisions made by each agent trying to organize its day and its in activities at and out of home. Besides, MATSim provides additional advantages such as simulating time-dependent congestion and time-dependent mode choice.

The standard feedback from the travel model to UrbanSim are generalized costs of travel between any given pair of zones, i.e. an  $n \times n$  matrix, where  $n$  is the number of zones. Such matrices quickly become very large: a typical number of, say, 10'000 zones leads to  $10'000^2 = 100'000'000$  entries; if each of them is represented as a 8Byte floating point number, this results in  $8 \times 100'000'000 = 800$  MB of memory. Although this may still be possible, it does not leave a lot of room for additional matrices such as separate morning and afternoon matrices, or different matrices by transport mode.

Meanwhile, if one would approximate zones by grid cells, then those 10'000 zones would correspond to  $100 \times 100$  grid cells. For a study area of, say,  $100 \times 100$  km, this would imply a maximum resolution of 1km. With 2000 zones, the resolution would accordingly be less.

It therefore makes sense to search for alternatives. UrbanSim models that make use of results from the travel model are the Expected Sales Price Model, the Real Estate Price

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<sup>1</sup>see [www.sustaincity.org](http://www.sustaincity.org)

UrbanSim Models	Accessibility Variables
Expected Sales Price Model Real Estate Price Model	art300, art600, hbwavgtmda, hwy200, hwy2000, lnemp10da, lnemp20da, lnemp30da, lnemp20tw, lnemp30tw, lnemp10wa, lngcdacbd, lngcdacdbell
Household Relocation Model	tt_to_work, has_tt_to_work
Household Location Choice Model	max_logsum_hbw_am_from_home_to_work, max_network_distance_from_home_to_work, 0workers_x_avg_work_logsum, neigh_shopping
Employment Location Choice Model	lngcdacbd, lngcdacdbell, lngcwempda, lngcwpopda
Work at Home Choice Model	kemp30m
Workplace Choice Model for Residence	logsum_hbw_am_from_home_to_work, network_distance_from_home_to_work

Table 1: Used accessibility variables in UrbanSim Models.

Accessibility Variable	Specification
artXXX	true, when distance to arterial is less than XXX distance
max_logsum_hbw_am_from_home_to_work	logsum of different generalized costs to travel to work
max_network_distance_from_home_to_work	network distance from home to work
has_tt_to_work	true if the driving time to work is larger than zero
hbwavgtmda	trip weighted average travel time to work (drive alone)
hwyXXX	true when distance to highway is less than XXX distance
logsum_hbw_am_from_home_to_work	logsum of generalized costs to travel to work
emp30m	employment with 30 minutes of travel time by car (divided by 1000)
lnempXXda	log of employment within XX minutes of travel time (driving alone)
lnempXXtw	log of employment within XX minutes of travel time (using public transit with walk access)
lnempXXwa	log of employment within XX minutes of walk time
lngcdacbd	log of generalized cost to travel to the (Seattle) CBD
lngcdacdbell	log of generalized cost to travel to the Bellevue CBD
lngcwempda	log of access to employment by car weighted by generalized cost
lngcwpopda	log of access to other persons by car weighted by generalized cost
network_distance_from_home_to_work	network distance from home to work
0workers_x_avg_work_logsum	if household has zero workers: income-dependent logsum of different generalized costs to travel to work
neigh_shopping	essentially the logarithm of all shopping opportunities within walking distance
tt_to_work	car travel time to get from home to work

Table 2: Accessibility variable specifications.

Model, the Household Location Choice Model, and the Employment Location Choice model. For all of these, it is plausible to assume that their *accessibility*, i.e.

- the ease with which these these places can be reached, as well as

- the ease with which other places can be reached from these places,

could have an important impact on those models. Accessibility is, however, a measure that is not measured for every pair of locations, but rather just for every location itself. That is, rather than  $n \times n$  numbers, one only needs to pass  $n$  numbers. Since this would result in significant computational performance savings, one could re-invest those savings, for example into increasing the resolution, or into many different accessibility measures e.g. by activity type, or into accessibility measures by time-of-day and/or mode of transport. For this study the Puget Sound Regional Council (PSRC) implementation of UrbanSim is used. All models from this implementation using travel model data are shown in Table 1. One notices that many of those variables, such as “lnemp10da” or “art600”, are in fact accessibility variables, i.e. they only depend on the location itself. Other variables, such as “lngcdacbd” are seemingly pair wise, but since they are only computed to one specific destination, they are in fact also accessibility variables.

This paper will specifically look into high-resolution accessibility calculations, their performance, and the influence of spatial resolution on the results. It is organized as follows. In Sec. 2 the concept of accessibility is explained. Section 3 introduces the simulation approach. Details on the data and configuration setups are presented in Sec. 4. Section 5 illustrates the main results of the accessibility measures, which are discussed in Sec. 6. The paper is concluded by a summary.

## 2 Accessibility

Hansen (1959) defines accessibility as the potential of opportunities for interaction. He shows that areas, which are more accessible to certain activities like work, leisure or shopping, have a greater growth potential in residential development. In other words: If locations are equal otherwise, a location with easier access to certain other locations is more attractive than locations with less access. Moeckel (2006) confirms that this approach is also true for businesses.

Accessibility can be seen as the result of the interaction of many elements (Geurs and Ritsema van Eck, 2001). These authors identify different types of accessibility measures, such as based on infrastructure, on activity participation, or on utility, and different components of accessibility for instance the transport, land-use, temporal or social demographic components.

An approach in line with consumer theory is the so-called logsum term (see, e.g., Ben-Akiva and Lerman (1985) for more information),

$$A_i := \ln \sum_j e^{-\beta c_{ij}} , \quad (1)$$

where  $A_i$  is the accessibility of location  $i$ . This measure consists of the log sum of the deterrence function  $e^{-\beta c_{ij}}$  for each location  $j$ , where  $c_{ij}$  is the generalized cost in order to get from location  $i$  to location  $j$ , and  $\beta$  is a scale factor, related to the scale parameter of a logit model.

In our simulation studies we will use the logsum term. As one notices in the many different variables (Tab. 2), this is not the only accessibility indicator used by the various models. It does, however, present a special computational challenge in that it is a weighted average over *all* opportunities.

A remaining question is the choice of the  $\beta$  parameter. In this paper,  $c_{ij}$  is the same as the one used by the travel model. The travel model, for this study, is entirely based on the travel time, and uses a (dis)utility of travel time of  $-12/h$ . In addition, it uses a logit model scale parameter of 2, which in consequence is also used as the scale parameter for the accessibility calculation.

## 3 Simulation Approach

### 3.1 Coupling UrbanSim and MATSim

The input to the UrbanSim models includes the base year data and the access indicators from the external travel model. The base year data store contains the initial state of a scenario. Typically the database includes geographic information, initial household and job information for a given base year. The primary source of the base year data usually comes from surveys or census. The UrbanSim models, including the external travel models such as MATSim simulate its evolution from one year to the next.

The general set-up of the integration of MATSim into UrbanSim is fairly generic. The interaction between both simulation models is a bi-directional relationship. When UrbanSim moves forward in time from year to year, it calls MATSim in regular intervals and passes the traffic network together with the persons and jobs data set table as input (see Fig. 1) including the person id of each individual person as well as their geographical residence and job location in UrbanSim. Based on this information MATSim generates the traffic assignment and returns the computed accessibility indicators as a zone-to-zone impedance matrix <sup>2</sup>. UrbanSim then uses this updated matrix as input to its models for its next iteration.

In the present study this mechanism is used to construct the input for MATSim from the UrbanSim base year cache that contains the initial state of a scenario. After the input

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<sup>2</sup>A description of the zone-to-zone impedance matrix can be found in Nicolai et al. (2011).

data is compiled MATSim uses the data for simulation runs. In this setting UrbanSim is not needed furthermore.

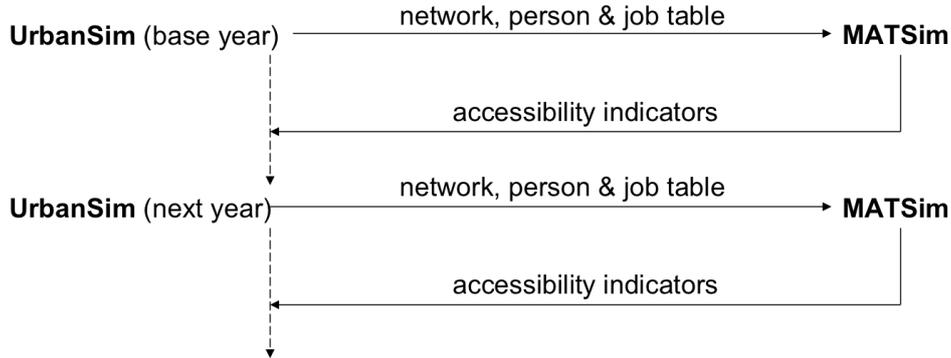


Figure 1: Interaction sequence between UrbanSim and MATSim.

The calculation of accessibility in MATSim consist of two steps.: First, MATSim performs a traffic simulation. Than it uses the resulting, congested traffic network to perform accessibility measurements (see Sec. 3.2).

The traffic simulation approach in MATSim consists of the following steps:

1. **Initial demand:** Given the input tables from UrbanSim, MATSim constructs agents. All agents independently generate daily *plans* that encode their activities during a typical day. In order to keep the model as simple as possible, only “home-to-work-to-home” activity chains are generated for the investigations described here, where the home and the work location are both taken from the UrbanSim information. Routes are calculated on an empty network.
2. **Traffic flow simulation:** The microscopic simulation of the traffic flow is implemented as a queueing model with physical queues and spillback (Cetin et al., 2003).
3. **Scoring:** All executed plans are scored by a utility function.
4. **Learning:** Some of the agents create new plans for the next iteration by modifying existing plans with respect to the two choice dimensions considered in this paper: route and time choice. More precisely, 10% of the agents copy one of their plans and obtain new routes computed as best reply to the last iteration, and another 10% of the agent’s copy one of their plans and obtain new activity starting and ending times based on a random “mutation” of the existing times. All other agents select between a maximum of five existing plans according to a logit model.

The repetition of the iteration cycle coupled with the agent database (i.e. the capability to remember more than one plan per agent) enables the agents to improve their plans over many iterations (Balmer et al., 2005). In the situation described here, MATSim

reaches an approximately relaxed state of the traffic system within 60 iteration cycles of the learning-based solution procedure.

### 3.2 High Resolution Accessibility Calculation

This paper will specifically look at the econometric workplace accessibility, as in Eq. (1). This is typically computed at the zonal level, i.e.

- the possible origins  $i$  are zones; but also
- the possible destinations are given at the zone level.

The latter implies that for all destinations  $j$  in a given zone  $z$ , the generalized cost of travel  $c_{ij}$  will have the same value in the computation. One can thus sum up over those destinations,  $\sum_{j \in z} e^{-\beta c_{ij}} = n_z e^{-\beta c_{iz}}$ , and hence obtains  $A_i := \ln \sum_z n_z e^{-\beta c_{iz}}$ . This aggregation accelerates the computation, since instead of computing the generalized cost of travel to all possible destinations, this is reduced to computing the generalized cost of travel to all possible zones. At the same time, however, it makes the resolution more coarse, which is a problem in particular near the starting location  $i$  since here locally varying  $c_{ij}$  have a strong influence.<sup>3</sup>

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 the other one that defines to what level the destinations,  $j$ , are to be resolved. At first glance one may argue that these two resolutions should be the same, since it is an  $n \times n$  calculation which should be symmetric. The underlying network-based travel model information, however, suggests a different point of view: *Computing the generalized cost from one starting point to all others is, in fact, not much more expensive than computing the generalized cost from one starting point to some others.* Technically, this has to do with the fact that the worst-case complexity of the Dijkstra shortest path algorithm is the same, no matter if one computes the generalized cost to *one* destination or to *all* destinations. Intuitively, the reason is that, in order to compute the shortest path to the most remote destination, the shortest paths to all other possible destinations

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<sup>3</sup>This problem becomes particularly obvious in the question of which  $c_{zz}$  to use for those destinations that are in the same zone. A choice of  $c_{zz} = 0$  often leads to singularities in some calculations (albeit not in Eq. (1)), but at the same time any choice larger than zero runs the risk that, in the computation, the opportunities in a given zone end up being easier to reach from neighboring zones than from the zone itself. This explains why in some such computations one finds central business districts (CBD) with *lower* accessibility than the surrounding zones. – The approach in the present paper resolves this issue since (1) on the one hand, it makes perfect sense to have  $c_{ii} = 0$  since some opportunities may be in the same building, (2) on the other hand, the generalized cost of travel obtains a much higher resolution so that opportunities in the same zone but a bit farther away are included with a realistic microscopic measure of  $c_{ij}$ .

are computed as a side effect ( see e.g. (Dijkstra, 1959)). For that reason, it will be assumed for the remainder of this paper that the sum over all destinations  $j$  in Eq. (1) always goes over all nodes (destinations) that the travel model knows about.

The remaining question then is for how many *origins* the accessibility should be computed. A related question is: Given accessibilities at locations  $\vec{x}_1$  and  $\vec{x}_2$ , under which circumstances can the accessibility in between these two locations be approximated by an interpolation between  $A(\vec{x}_1)$  and  $A(\vec{x}_2)$ . If such an interpolation is valid, any additional spatial resolution on the side of the origins would not be necessary, and the related computational effort could be saved.

This paper approaches the problem from a computational perspective. The study area will be divided into square zones (“squares”), and the accessibility will be computed for every square. Recall that the resolution on the destination side will always be the highest resolution possible within the existing model and scenario. The size of the squares will be configurable. The first question will be at what level of square size will any further size reduction no longer lead to meaningful improvements of the accessibility details. The implementation will be described in the following.

### 3.3 Accessibility Measure Implementation

This section aims at describing step by step the computing procedure for the accessibility calculations. As a preparation for the accessibility calculation the study area is approximated by square zones (“squares”), whose size is configurable.

The localization of workplaces (destinations) in the study area is another integral part that is required for workplace accessibility measures. The information required for this purpose already exists in the job data set table that UrbanSim created as input for MATSim (see Sec. 3.1). This table contains for each workplace an id and the parcel-based coordinates. MATSim reads the table row by row, extracts the workplace id and coordinates and stores them in a list.

The calculation of workplace accessibility follows the following algorithm (see Listing 1): MATSim initializes a “SpanningTree” that runs through the simulated traffic network, containing the congested link travel times, for a given origin location (see line 10 and 11). The computation starts on the node of the traffic network that is nearest to the location of the origin. No generalized cost of travel is assumed for the travel from the origin to the node, which explains some of the results in areas with a low network density.

The `spanningTree` uses the Dijkstra algorithm, which finds the best route to all other nodes depending on the given `costFunction`. The cost function needs to be the same as the one used for the accessibility measure, since different cost functions lead to different best routes.

Once the spanningTree has explored all nodes from a given origin  $i$ , it queries the resulting “travel costs”  $c_{ij}$  to any destination node  $j$ . For each job location  $j$ , the expression  $\exp(-\beta c_{ij})$  is computed, and the resulting values are summed up until all destination nodes (workplaces) are visited. Finally, the log of the sum is stored. This measurement is repeated for all origin nodes.

Listing 1: Measuring workplace accessibility

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```

1 spanningTree = initialize( congested network, costFunction );
2
3 for all squares in squareList do
4 {
5     sum = 0; // stores measure for current square
6
7     centroidCoord = get square centroid coordinate
8     origin = get corresponding nearest network node
9
10    spanningTree.setOrigin( origin );
11    spanningTree.runDijkstra();
12
13    for all workplaces in jobList do
14    {
15        jobCoord = get workplace coordinate
16        destination = get corresponding nearest network node
17
18        spanningTree.setDestination( destination );
19        cost = spanningTree.getCost();
20
21        sum += exp( - beta * cost );
22    }
23
24    store ln( sum ) per current square
25 }
```

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## 4 Scenario

We take the UrbanSim scenario (base year cache) currently being used by Puget Sound Region Council (PSRC). This real-world scenario is the parcel-based Puget Sound region application, which is one of the most disaggregate metropolitan-scale modeling systems in operation. It contains 938 zones and 1 500 004 parcels. Figure 2 shows the zonal level of the simulation area.

This preliminary study analyses the workplace accessibility of the initial PSRC base year cache, comprising the year 2000, by running the accessibility measures with diverse spatial resolutions. Also the computation times of different resolutions are considered and compared. The following subsections provide a simplified description of the scenario.

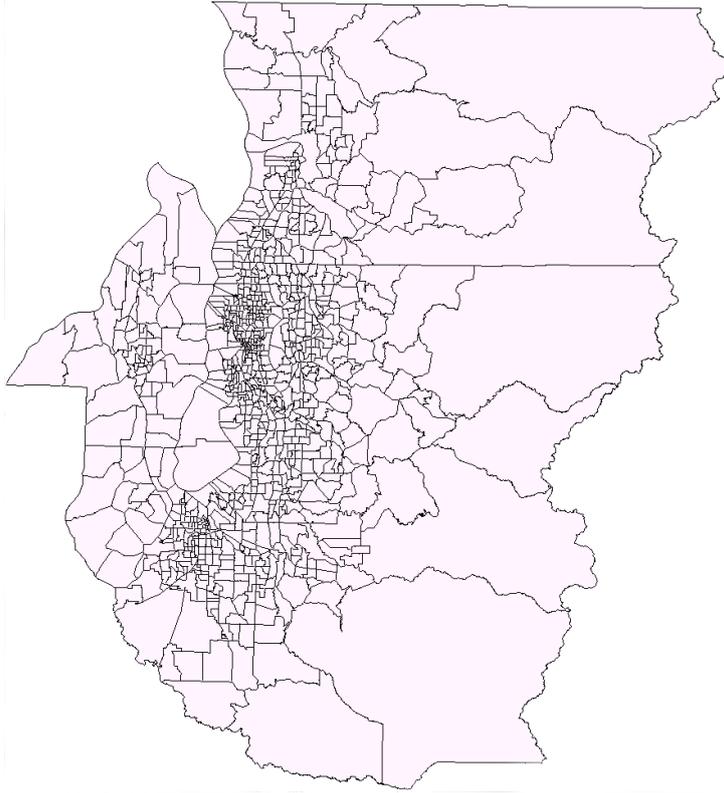


Figure 2: Puget Sound simulation area with UrbanSim zone boundaries.

## 4.1 Population and Travel Demand

The metropolitan area of the Puget Sound region counts about 3.2 million inhabitants, “agents”, in the UrbanSim base year 2000.

All MATSim agents have complete day plans with “home-to-work-to-home” activities (work activities) based on their residence and job location in UrbanSim as described in Sec. 3.1.

Work activities can be started between 7 o’clock and 9 o’clock with a duration of 8 hours. The home activity has no temporal restrictions. Agents try to optimize their plans with respect to the choice dimensions available: route choice and time choice as described in Sec. 3.1.

## 4.2 Workplace Sample and Spatial Resolution

As described in Sec. 3.3 the study area is approximated by squares of configurable size. The selected edge lengths in ascending order are:  $250 \times 250$ ,  $500 \times 500$ ,  $1000 \times 1000$ ,  $2500 \times 2500$ ,  $5000 \times 5000$ ,  $7500 \times 7500$  and  $10.000 \times 10.000$  meter. The size of squares, influenced by the edge length, varies between 180 squares for a resolution of  $10.000 \times 10.000$  meter and 284916 squares for a resolution of  $250 \times 250$  meter.

The total number of available workplaces in the whole region counts 1849447. In this preliminary study, a 1% random sample of all workplaces is used to measure the accessibilities for all squares in order to save computing time.

### 4.3 Traffic Network

The Puget Sound traffic network includes the major roads in this area (see e.g. Fig. 4). It consists of 5024 nodes and 15472 links. Roads are typically described by two links, with one link for each direction. Furthermore, each link is defined by its origin and destination node, length, free speed, average car flow capacity per hour and number of lanes.

The study area also includes numerous ferry services, e.g. between Seattle and the surrounding islands. In MATSim, these ferry connections are also modeled as roads.

### 4.4 Computing Issues

All simulations are performed on a cluster, where for each simulation run 4 CPUs and 16GB RAM are requested. For technical reasons it cannot be ensured that all simulations run on the same computing node (hardware). The hardware may differ on the individual nodes, e.g. in the clock speed of the CPUs (central processing unit). Also, other runs on the same machine may slow down our run, for example because of I/O bandwidth limitations. Therefore the presented speed measurements serve as approximate indications only.

## 5 Results

### 5.1 Spatial resolution of the accessibility computation

Figure 3 shows results of accessibility calculations with resolutions of  $250 \times 250$ ,  $500 \times 500$ ,  $1000 \times 1000$ ,  $2500 \times 2500$  and  $7500 \times 7500$  meter. One clearly sees that increasing the resolution by using smaller squares increases the level of detail. However, that trend stops at a resolution of  $1000 \times 1000$ ; increasing the resolution beyond that point does not lead to additional detail. Possible reasons for this are discussed in Sec. 6.

Figure 4 shows the accessibility computation at resolution  $500 \times 500$  meter together with the road network. One clearly sees that areas with many links coincide with areas of high accessibility. It is plausible to assume that this is *not* a consequence of the traffic network alone, but rather a consequence of the fact that areas with a high density of opportunities are served by high-density road networks.

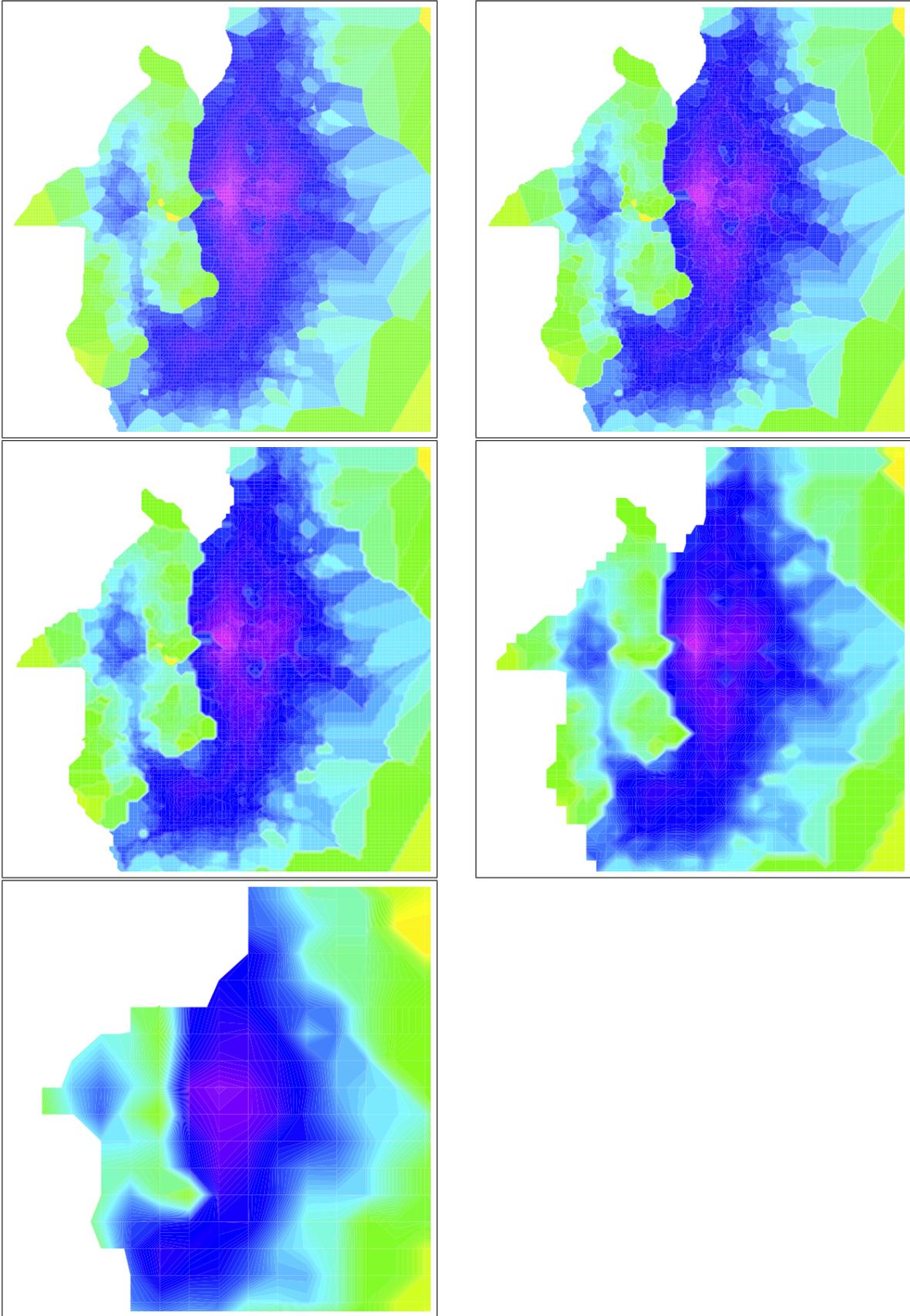


Figure 3: Results of the accessibility calculation with resolutions of  $250 \times 250$ ,  $500 \times 500$ ,  $1000 \times 1000$ ,  $2500 \times 2500$  and  $7500 \times 7500$  meter sorted from top left to bottom right.

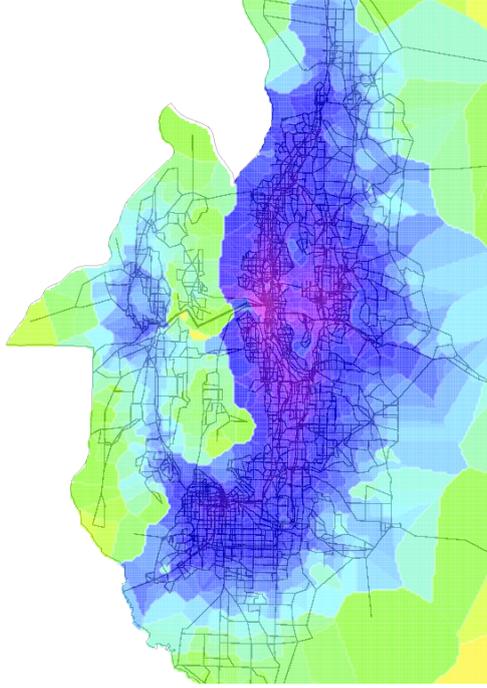


Figure 4: Accessibility computation with a resolution of  $500 \times 500$  together with the traffic network.

## 5.2 Computing Times

Higher spatial resolutions lead to simulation runs with increasing computation time (see Table 3). An exception is the simulation run with the lowest resolution ( $10.000 \times 10.000$  meter). This is probably due to the fact that simulations run on a shared machine with varying load (see Sec. 4.4). Hence, the measurements only serve as approximate indicators.

Considering that the measurements also include the computing time for the traffic simulation of approximately 150min one can see that with an increasing resolution, accessibility computation takes longer and longer.

## 6 Discussion

The accessibility computations show no further improvements with resolutions finer than  $1000 \times 1000$  meter. This is, at this point, an empirical result, valid only for the specific situation for which it was generated. We have already tested that this is *not* an artifact of the plotting routine (see Fig. 5). Other possible causes include:

- The functional spatial resolution inside MATSim is at the link level. That is, destinations, which are attached to the same link are effectively aggregated into the same location. Thus, there will be no additional resolution beyond the typical length of

Spatial Resolution	Computing Times	Number of Squares	Number of Workplaces
250x250 [meter]	1371 [min]	284916	18494
500x500 [meter]	441 [min]	71212	18494
1000x1000 [meter]	272 [min]	17799	18494
2500x2500 [meter]	178 [min]	1775	18494
5000x5000 [meter]	156 [min]	706	18494
7500x7500 [meter]	155 [min]	323	18494
10000x10000 [meter]	174 [min]	180	18494

Table 3: Approximate total computing times regarding different spatial resolutions. This includes the computing time for the iterative assignment, which takes about 150min. Computing times are approximate since the simulations are run on a shared machine with varying load.

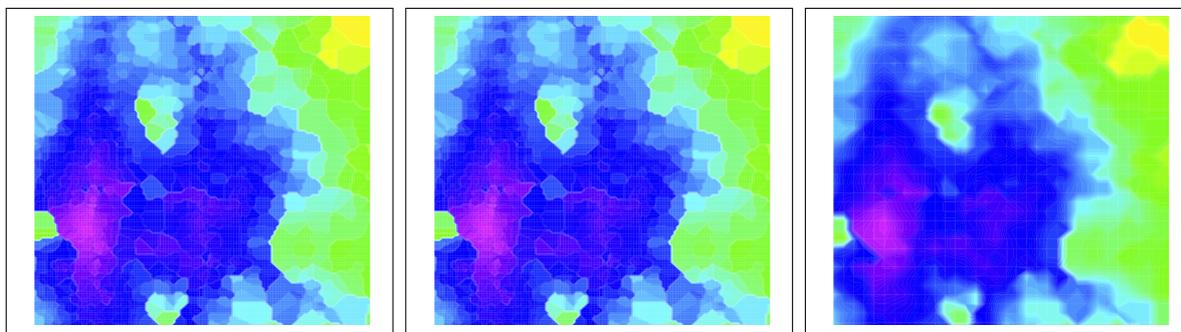


Figure 5: Enlarged section of study area that includes Seattle and Bellevue. Images are sorted in descending order from left to right, with resolutions of  $250 \times 250$ ,  $500 \times 500$  and  $1000 \times 1000$  meter.

short links. However, there are many areas where links are shorter than 1000 meter, so this possible explanation does not seem credible.

- The accessibility calculations are done based on a 1% sample of the possible destinations. Clearly, this increases the average distance between possible destinations, and thus the average resolution of any accessibility measure. However, there should be a higher density of opportunities, even after sampling, in many areas of the simulation scenario, and even there, a higher resolution does not show any effect (Fig. 5).
- The accessibility plots show high detail in the urban areas, and low detail in the rural areas. This is, obviously, also reflected in the zones (Fig. 2). It should be investigated if those zones could just be used as origins of the accessibility calculations. At the same time, one should investigate if the accessibility should really be reported as constant within zones, or if it should rather be interpolated between zone centroids. The latter would result in a smoother picture, with the artificial effects of the zone boundaries removed.

An additional advantage, within the UrbanSim/MATSim context, of such an approach would be that the accessibility computations could be done together with the zone2zone impedance matrix computations.

## 7 Conclusion

Accessibility calculations are, for a given origin, weighted sums over as possible destinations. The present paper demonstrates that it is computationally feasible to do this sum over all possible destinations separately, rather than aggregating them into zones. This removes all zonal artifacts from the destination side of the computation.

On the origin side, we investigated arranging the origins in a regular square grid. Many different resolutions were investigated, ranging from  $250 \times 250$  to  $10.000 \times 10.000$  meter. It was found that for the present set-up, the spatial resolution of the origins has a strong impact, but a resolution finer than  $1.000 \times 1.000$  meter produces little additional detail.

Computing times for the accessibility at the resolution of  $1.000 \times 1.000$  were significant, nearly doubling the running time of the travel model from approximately 150min to approximately 270min. Reducing the resolution to  $2500 \times 2500$  meter reduces the additional computing time to less than 20min.

## Acknowledgments

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## References

- A. Babin, M. Florian, L. James-Lefebvre, and H. Spiess. EMME/2: Interactive graphic method for road and transit planning. *Transportation Research Record*, 866:1–9, 1982.
- M. Balmer, B. Raney, and K. Nagel. Adjustment of activity timing and duration in an agent-based traffic flow simulation. In H.J.P. Timmermans, editor, *Progress in activity-based analysis*, pages 91–114. Elsevier, Oxford, UK, 2005.
- M. Ben-Akiva and S. R. Lerman. *Discrete choice analysis*. The MIT Press, Cambridge, MA, 1985.

- N. Cetin, A. Burri, and K. Nagel. A large-scale agent-based traffic microsimulation based on queue model. In *Proceedings of the Swiss Transport Research Conference (STRC)*, Monte Verita, CH, 2003. See [www.strc.ch](http://www.strc.ch). Earlier version, with inferior performance values: Transportation Research Board Annual Meeting 2003 paper number 03-4272.
- E. Dijkstra. A note on two problems in connexion with graphs. *Numerische Mathematik*, 1:269–271, 1959.
- K.T. Geurs and J.R. Ritsema van Eck. Accessibility measures: review and applications. Technical report, National Institut of Public Health and the Environment, RIVM, P.O. Box 1, 3720 BA Bilthoven, June 2001.
- W. Hansen. How accessibility shapes land use. *Journal of the American Planning Association*, 25(2):73 – 76, 1959.
- R. Moeckel. *Business Location Decisions and Urban Sprawl A Microsimulation of Business Relocation and Firmography*. PhD thesis, Department of Spatial Planning at the University of Dortmund, 2006.
- T. W. Nicolai, L. Wang, K. Nagel, and P. Waddell. Coupling an urban simulation model with a travel model – A first sensitivity test. 2011.
- J. de D. Ortúzar and L.G. Willumsen. *Modelling transport*. John Wiley Sons Ltd, Chichester, 3 edition, 2001.
- PTV AG. *VISUM 11.0 Grundlagen*. 76131 Karlsruhe, Juni 2009a.
- PTV AG. *VISUM 11.0 Benutzerhandbuch*. 76131 Karlsruhe, Juni 2009b.
- B. Raney and K. Nagel. An improved framework for large-scale multi-agent simulations of travel behaviour. In P. Rietveld, B. Jourquin, and K. Westin, editors, *Towards better performing European Transportation Systems*. Routledge, London, 2006.
- P. Waddell. UrbanSim: Modeling urban development for land use, transportation, and environmental planning. *Journal of American planning Association*, 68(3):297 – 314, 2002.
- M. Wegener. *Overview of land-use transport models*, pages 127–146. Pergamon/Elsevier Science, 2004.