SUBPART TEN

Analysis

CHAPTER 35

Accessibility

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35.1 Basic Information

Entry point to documentation:

`http://matsim.org/extensions` → accessibility

Invoking the module:

`http://matsim.org/javadoc` → accessibility → `RunAccessibilityExample` class

Selected publications:

Nicolai and Nagel (2014); Joubert et al. (2015)

In transport science and planning, the term accessibility can refer to at least three different concepts. First, accessibility may be used to describe how well a certain transport infrastructure component can be utilized by travelers, particularly those with handicaps (Faura, 2012). In this sense, *accessibility guidelines* tell engineers and planners how to design transport infrastructure elements, such as public transport facilities, to make them accessible, i.e., useable for all travelers. Second, accessibility may be used to describe how easy/convenient the approach to a given land-use facility is. There are, for instance, studies (Fujiyama, 2004) to improve the accessibility of shopping centers by redesigning access roads and their connection to major roads. Finally, the term accessibility can be used in a more global way, to describe availability and spatial distribution of activity facilities within a given area, e.g., a metropolitan region and the ease with which these facilities can be reached from other locations in the area. MATSim's accessibility extension focuses on all these aspects; the discussion in this chapter draws on Nicolai and Nagel (2014).

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35.2 Introduction

Improvement in accessibility is often defined as a central goal of proposed transport or infrastructure schemes (Geurs et al., 2012b) and accessibility is usually a precisely-defined, quantitative measure. While Batty (2009) traces the origins of the accessibility concept back to location theory and regional economic planning in the 1920s (when transport planning began in North America; Geurs et al., 2012b), Hansen, with his widely-cited paper (Hansen, 1959), is generally credited with the first real definition of accessibility, defining it as *the potential of opportunities for interaction*. In more detail, Morris et al. (1979) define accessibility as "the ease with which activities may be reached from a given location using a particular transportation system". The concept of accessibility is a potential methodology for the assessment of transport systems, as it is a comprehensive and inclusive way to evaluate how, where and why people move, taking well-known dependencies between transport and land use into account. Hansen (1959) was probably the first to develop a procedure for quantitative consideration of accessibility, discussed in more detail in Section 35.3.

In their widely-cited review, Geurs and van Wee (2004) identify four accessibility components from existing definitions and applied measures:

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

In this review, Geurs and van Wee (2004) list and summarize typical approaches applying the accessibility concept, focusing on the accessibility components discussed above:

1. **Infrastructure-based** measures focus on the (observed or simulated) performance or service level of transport infrastructure, e.g., represented as average travel speed. These measures are typically used in transport planning.
2. **Location-based** measures describe level of accessibility to spatially distributed activities, such as number of jobs within 30 minutes travel time from origin locations. These measures are typically used in urban planning and geographical studies.
3. **Person-based** measures analyze accessibility at the individual level, such as the activities in which an individual can participate at a given time. These measures are grounded in Hägerstrand (1970)'s space-time geography.
4. **Utility-based** measures analyze the economic benefits that people derive from access to spatially distributed activities. These measures have their origin in economic studies.

Geurs and van Wee (2004) intersects these approaches with the four accessibility components identified above, creating a matrix. This matrix illustrates how each of the four accessibility components is represented in the four different accessibility measures. There, each measure focuses on certain weaknesses in those accessibility components outside the focus of a specific measure. Accordingly, Geurs and van Wee (2004) recommend that an accessibility measure include all four discussed accessibility components. The accessibility extension of MATSim, described in the following, could be one way to achieve this goal.

In other recent research, as identified by Geurs et al. (2012b), the accessibility concept is also applied to social exclusion analysis (e.g., by examining the benefit of employment accessibility for disadvantaged populations before and after the implementation of a transport scheme), economic valuation of accessibility effects (e.g., in cost-benefit analyses and studies assessing the impact of changes in public transport accessibility on house prices) and behavior analysis vis-a-vis accessibility measures (e.g., walking behavior dependence on different residential neighborhood accessibility qualities). It has also been used to explore questions of oil dependence, climate change and other concerns (Curtis et al., 2013).

35.3 The Measure of Potential Accessibility

Today, methods to assess accessibility quality are often used in superordinate planning procedures, like regional transport planning, where a central goal is to provide citizens with a certain level of access to various services. For instance, the approach used by Germany's agency responsible for regional planning calculates travel times to major service facilities, like airports or hospitals (Bundesinstitut für Bau-, Stadt- und Raumforschung, accessed March 2015). The results, typically visualized by multi-colored maps, give useful insights into population access to certain services, thus aiding transport infrastructure planning. In this approach, travel times are calculated to a *next* airport, *next* hospital and *next* autobahn access; thus, the implicit assumption is that citizens' needs are fulfilled by one (i.e., the *next*, or closest in terms of travel times) type of facility.

An accessibility measure becomes significant, however, if not just the ability to reach *the nearest* facility serving a particular need is taken into account, but also a *set of multiple reachable* facilities serving the same need; different facilities of the same type may offer varying qualities of a given service. Services may also expand and improve when combined with complementary services provided by another facilities of the same type. For instance, a person planning to take a holiday trip by plane will probably consider several airports in his/her vicinity, instead of just looking at flights offered from the nearest airport. Thus, accessibility to airports should be made dependent on the ability to reach all local airports instead of just the nearest one. Facilities offering medical services may serve as another example. Considering the nearest hospital may be sufficient when looking at simple services like first aid, presumably available at almost *any* hospital. In other cases, however, medical services accessibility should consider several hospitals in the vicinity because they are likely to offer different specialized medical treatment. Consideration of a set of multiple facilities, potentially useful from the perspective of a person at a given location, corresponds to taking into account the **land-use component** of accessibility defined above.

Hansen (1959) considers the whole scope of potential activity facilities, where an accessibility measure *potential accessibility* is defined. Such measures of potential accessibility are specified as the (weighted) sum over the accessibilities of several specific activity facilities (e.g., shopping, leisure etc.) and take the mathematical form

$$A_\ell = g\Big(\sum_j a_j f(c_{\ell j})\Big), \tag{35.1}$$

where j are all possible destinations (opportunities), a_j describes opportunity attractiveness, $c_{\ell j}$ denotes the generalized traveling cost between origin ℓ and destination j, $f(c)$ is an impedance function which (typically) decreases with increasing distance and $g(.)$ denotes an arbitrary, but usually monotonically increasing function. The weight of each opportunity j is thus the product of the destination's attractiveness, a_j, and the ease of getting there, $f(c_{\ell j})$. As seen in its functional form, this type of accessibility measure is related to gravity models used in trip generation models, explaining why this measure is sometimes also referred to as a "gravity type" accessibility indicator (Morris et al., 1979). The (quantitative) accessibility measure used in the MATSim accessibility extension is expressed in this mathematical form and may thus be seen as a *potential accessibility* measure.

It is important to note that the above-defined measure quantifies how accessible a given location ℓ is *to* certain services j. This kind of accessibility is *outgoing accessibility*, while a measure of *ingoing accessibility* quantifies how accessible a given destination location j is *from* other locations. Nicolai and Nagel (2014) discuss circumstances under which these measures are interchangeable.

35.4 Accessibility Computation Integrated with Transport Simulation

As mentioned above, accessibility computations are often based on travel times (Bundesinstitut für Bau-, Stadt- und Raumforschung, accessed March 2015; Büttner et al., 2010), which serve as an impedance measure. Ways of calculating these travel times can, however, vary significantly. The simplest way to calculate a travel time between two locations is to measure the Euclidean distance (beeline distance) between these two locations and multiply with some average speed. According to Geurs and van Wee (2004), this is the usual approach in location-, person-, and utility-based accessibility approaches, where the focus is not specifically on the transport system.

To strengthen the **transport component** of accessibility (as introduced above) and make accessibility measure sensitive to transport infrastructure changes, a better representation of the travel impedance between origins and destinations is required. The most common approach is travel time calculation using shortest-path algorithms on a real-world transport infrastructure network representation. Many accessibility computations are embedded into GIS software, offering procedures for network-based computations (Bundesinstitut für Bau-, Stadt- und Raumforschung, accessed March 2015; Curtis et al., 2013; Büttner et al., 2010).

The accessibility extension in MATSim also offers this type of accessibility computation. To run it, an accessibility controler listener, e.g., the `GridBasedAccessibilityControlerListenerV3` must be added to the MATSim controler. An example is given in `RunAccessibilityExample` (see `http://matsim.org/javadoc` → accessibility → `RunAccessibilityExample` for details). As input, a network file and a facilities file are required (for more information on networks and facilities, refer to Section 4.1.1 and Section 6.4 of this book). This procedure is more disaggregate than many common approaches to accessibility computations, where single facilities are seldom considered; there, structural data like zone sizes, number of jobs, or total sales area are used to represent the *potential* of a given zone (Büttner et al., 2010; Gulhan et al., 2014) (also see Section 35.6).

Either way, performing an accessibility computation this way can be regarded as a *supply-based approach*, since both supply with transport infrastructure (required to reach a given location) and supply with activity opportunities at these locations are taken into account. The utilization of these two supply dimension by users, i.e., the dimension of *demand* is, however, not considered in this approach. Therefore, no *effects of competition* (Geurs and van Wee, 2004), either for transport infrastructure resources (defined by network capacities), or activity facilities capacities, are taken into account. It is obvious, however, that supply and demand interaction effects are relevant, because opportunities may disappear if they can no longer be reached within reasonable travel times, or when activity facility capacities are exceeded.

By considering demand-supply interaction effects in addition to just the supply side, the scope of the accessibility calculation can be significantly increased. Gauging these effects on *facility capacities* can be addressed by specifying facility capacities in the according value in the `facilities` input file. Observation of *network capacities* and their effects on agents' behavior is one of the core features of the MATSim transport simulation. This is also one major argument for the integration of an accessibility computation with the dynamic transport simulation system MATSim. While other accessibility tools—the majority based on GIS systems (Bundesinstitut für Bau-, Stadt- und Raumforschung, accessed March 2015; Curtis et al., 2013; Büttner et al., 2010; Liu and Zhu, 2004;

Gulhan et al., 2014)—can calculate travel times on a routed network, they do not calculate accessibilities dependent on transport infrastructure usage level. This property, is, however, essential when making accessibility measures sensitive to transport demand management policies, i.e., transport system changes that do not alter the transport infrastructure and are thus not captured by models considering only the supply side.

To take these effects into account, the MATSim accessibility extension must be run with a MATSim transport simulation. To do so, an initial plans file (as described in Chapter 2 of this book) needs to be specified in the MATSim config file. Furthermore, the value `timeOfDay` in the `accessibility` module of the MATSim config file needs to be specified. If then, as described, an accessibility controler listener is added to the MATSim controler, the best-path travel times, on which the accessibility computation will be performed, are taken from travel times observed in the MATSim transport simulation at the time specified by the value `timeOfDay`. This is useful when transport demand level varies significantly during the day; for instance, with morning and afternoon peaks; it also allows transport policy accessibility changes (and decision makers' reactions) to be better analyzed.

35.5 Econometric Interpretation

As pointed out by Morris et al. (1979), accessibility indicators provide a very useful way to summarize a large volume of information on household locations and how they relate to urban activities' distribution and connecting transport systems. They also take land use, the transport system and their inter-dependencies into account holistically. Curtis et al. (2013) explain that accessibility assessment tools overcome policy innovation restrictions associated with traditional transport planning practice, pointing out that use of such tools enables examination of a broader range of policy issues.

For effective policy decisions, accessibility assessment tools must be economically interpretable. To make an accessibility measure clearest in an econometric evaluation (e.g., cost-benefit analyses), it seems sensible to adapt equation 35.1 as follows: $g(.) = \ln(.)$, $a_j = 1, f(c_{\ell j}) = e^{-c_{\ell j}}$, and $-c_{\ell j} = V_{\ell j}$. Thus, equation 35.1 becomes

$$A_\ell := \ln \sum_k e^{V_{\ell k}} \,, \tag{35.2}$$

where k denotes all possible destinations and $V_{\ell k}$ equals the disutility of traveling from location ℓ to destination k. Equation (35.2) is the so-called logsum term of exponentials and can be interpreted as the expected maximum utility (e.g., Ben-Akiva and Lerman, 1985; de Jong et al., 2007). Equation 35.2 can be derived by assuming that the full utility of destination location k as perceived at origin location ℓ, is $U_{\ell k} = V_{base} + V_{\ell k} + \epsilon_{\ell k}$, where V_{base} is a base utility for performing a given activity without considering its location, $V_{\ell k}$ is the systematic or observed disutility of traveling to from origin ℓ to destination k, and $\epsilon_{\ell k}$ is a random term which absorbs the randomness of the disutility of traveling, as well as fluctuations in utility around V_{base}. Under the usual assumption that the $\epsilon_{\ell k}$ are independent and identically (iid) Gumbel-distributed random variables, the expectation value of $U_{\ell k}$ becomes

$$E(U_\ell) = E(\max_k U_{\ell k}) = \ln \sum_k e^{V_{\ell k}} + Const \equiv A_\ell + Const \,. \tag{35.3}$$

Const does not need to be considered, as it is invariant for all locations. As a consequence of dropping the positive *Const*, A_ℓ may take negative values.

Geurs et al. (2012a), for instance, use the logsum measure of user benefits as an alternative to the travel time savings method (i.e., rule-of-half measure) in a case study examining the effects of spatial planning on accessibility benefits and economic efficiency of public transport projects.

35.6 Spatial Resolution, Data, and Computational Aspects

In contrast to many other transport simulations, MATSim is based on coordinates (see Chapter 2 of this book), not zone-based. Therefore, accessibility computation in MATSim can also be conducted independent from any zoning system and, instead, be based on a raster with arbitrary granularity, i.e., adjustable grid size. Depending on the calculation planned (zone-based or grid-based), a `ZoneBasedAccessibilityControlerListenerV3`, or a `GridBasedAccessibilityControlerListenerV3`, respectively, need to be added to the MATSim controler. Unlike the MATSim accessibility extension, most other accessibility assessment tools rely on the zone-based approach (Curtis et al., 2013; Liu and Zhu, 2004; Büttner et al., 2010). More detail about the interpretation of cell- and zone-based accessibility measures is given by Nicolai and Nagel (2014).

Running a grid-based calculation, especially if a high spatial resolution is selected, avoids several issues that could arise (like"self-potential") if accessibility computations are based on zones (see, e.g., Nicolai and Nagel, 2014). A zone-based approach also makes the measure dependent on size and shape of the geographical units (cf. MAUP (Modifiable Areal Unit Problem)). Due to its typically lower resolution level, a zone-based approach may also not adequately represent local details (Kwan, 1998). This is especially relevant when lower-speed mode accessibilies (like walking) must be considered.

The MATSim accessibility calculation does not require typical zone-based statistical data. Instead, the calculation can be conducted on the basis of so-called VGI (Voluntary Geographic Information) like OSM, which contains activity facilities data on a coordinate-based level. Hence, no reference to any zoning system is necessary when using these data. Furthermore, data from OSM is publicly and freely available; the amount of these data are steadily increasing and quality is improving. In particular, OSM seems to have established itself as a uniform and globally-accessible standard for crowd-sourced and other geo-data, which makes the MATSim accessibility assessment highly portable.

If the coordinate-based (= grid-based = raster-based = cell-based) version of the MATSim accessibility computation is selected, its results can be interpreted as an accessibility field, i.e., as a measure that varies continuously in space. This *accessibility field*, can be visualized by calculating the values on regular grid points. Figure 35.1 gives an example of such a visualization and depicts the accessibility of work places in Nelson Mandela Bay Municipality in South Africa, as calculated by the grid-based MATSim accessibility computation with a grid size of 1 000 meters.

To calculate the accessibility A_ℓ of a given origin location ℓ to opportunity locations k, both the origin location ℓ, and opportunity locations k, are assigned to a road network. If the option to integrate the accessibility computation with the transport simulation, as described in Section 35.4, is chosen, a congested network with time-dependent travel times (as they have been simulated in MATSim) is used. For every ℓ, a so-called *least cost path tree* computation (Lefebvre and Balmer, 2007) is carried out. Accessibility of the same location at a different time of day will usually be different, since congestion patterns vary. The least cost path tree computation determines the best route and the least negative travel utility $V_{\ell k}$ from the origin location ℓ to each opportunity location k, based on Dijkstra's shortest path algorithm (Dijkstra, 1959). Once the least cost path tree has explored all nodes, the resulting disutilities $V_{\ell k}$ for all opportunities k are queried and the accessibility is calculated, as stated in Equation (35.2) (Nicolai and Nagel, 2014). A crucial question is how to choose the point, i.e., the coordinate, where the accessibility computation is anchored. Most quantitative accessibility tools use geographical centroids of given zones. This is also true when the zone-based MATSim accessibility computation is selected. Alternative ways to select a centroid (e.g., land-use-based centroids; Büttner et al., 2010) are discussed as well. If the grid-based MATSim accessibility computation is selected, the question of choosing a representative point for a spatial zone becomes less relevant, as cells are usually not selected to be as large.

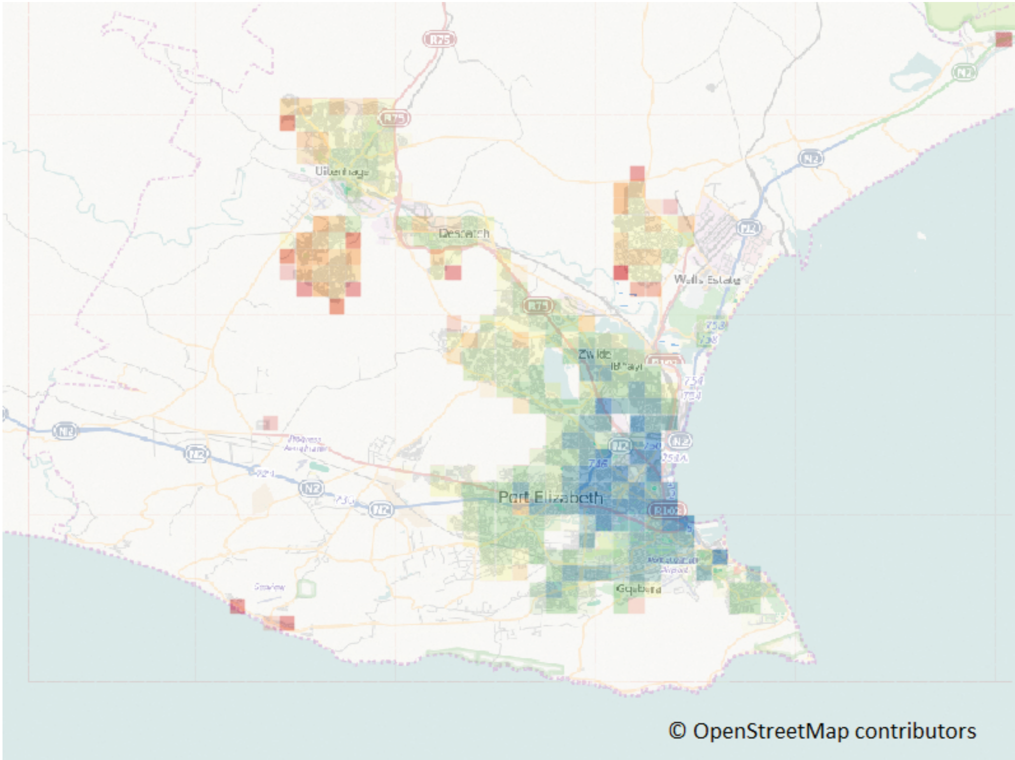

Figure 35.1: Accessibility of work places in Nelson Mandela Bay Municipality calculated by the grid-based MATSim accessibility computation

If the granularity of the grid-based MATSim accessibility computation is increased, origin locations ℓ and opportunity locations k, possibly located off the network, become increasingly important. To keep the approach consistent, the $V_{\ell k}$ calculation has to include disutility of travel to overcome the gap between locations and the road network. Therefore, the disutility of travel calculated by running the least cost path tree computation on the network has to be supplemented by the disutility to access the network from the origin ℓ (network access) and the disutility to access the destination k from the network (network egress). For origin locations ℓ, shortest distance to the network is given either by the Euclidean distance to the nearest node, or the orthogonal distance to the nearest link on the network. For destination locations k, the Euclidean distance to the nearest node is used to determine the shortest distance to the network.

This assumption (i.e., that opportunity locations are attached to the nearest network *node* rather than the nearest network *element*) is, in fact, the only approximation that the MATSim accessibility extension makes for the spatial resolution of opportunities (Nicolai and Nagel, 2014). While this assumption is unlikely to significantly alter accessibility results, it offers great potential for the optimization of computational performance, which has often been a major obstacle to higher-resolved accessibility computations (Kwan, 1998; Büttner et al., 2010). In the concrete case of the MATSim accessibility computation, exploration of the entire network by the least cost path tree is a computationally expensive task.

Thanks to the assumption, it is enough to sum over all opportunities k attached to a node j only once. The travel disutility $V_{\ell k}$ can be deconstructed as

$$V_{\ell k} = V_{\ell j} + V_{jk} \ \forall k \in j \,, \tag{35.4}$$

where $k \in j$ denotes all opportunities k attached to node j,

$$\sum_{k \in j} e^{V_{\ell k}} = \sum_{k \in j} e^{(V_{\ell j}+V_{jk})} = \sum_{k \in j} e^{V_{\ell j}} e^{V_{jk}} = e^{V_{\ell j}} \sum_{k \in j} e^{V_{jk}} =: e^{V_{\ell j}} \cdot Opp_j \, . \tag{35.5}$$

It is thus sufficient to compute Opp_j once for every network node j, and compute accessibilities as

$$A_\ell = ln \sum_k e^{V_{\ell k}} = ln \left[\sum_j e^{V_{ij}} \cdot Opp_j \right] . \tag{35.6}$$

Therefore, the loop performing the calculation does not have to run over all opportunities k, just over all network nodes j.

Similarly, for each origin location ℓ, the nearest road network node is identified. Locations ℓ that share the same nearest node have different travel disutilities to reach that node, but from then on have the same travel disutility to any other network node j. Exactly like the destinations, the least cost path tree is executed only once and calculated disutilities on the network are reused for all origins ℓ that are mapped on the same nearest network node. Therefore, only the calculation of the network access disutility needs to be performed individually for each origin ℓ. Nicolai and Nagel (2014) show that, due to this run time optimization, computation time increases sub-linearly with resolution. At the same time, they find that no significant further insights can be gained by increasing the resolution beyond a grid resolution of 100 meters.

The application example `RunAccessibilityExample` (see `http://matsim.org/javadoc` → accessibility) performs multiple accessibility computations for different types of activity facilities (e.g., accessibility of workplaces or accessibility of leisure facilities) by adding multiple instances of `GridBasedAccessibilityControlerListenerV3` to the MATSim controler. Other ways of performing distinct accessibility assessments for parts of the land-use system are just as feasible. Figure 35.1 is an example of work place accessibilities.

35.7 Conclusion

There are many different approaches to calculating accessibilities; most focus on a particular component of accessibility, while other components influencing accessibility are represented only in a limited way. Accessibility computations used in transport planning, for instance, represent transport networks, and thus the transport component of accessibility very well, while they usually do not represent facility properties or temporal effects. As pointed out by Geurs and van Wee (2004), it would be optimal if an accessibility computation considered all accessibility components (i.e., transport, land-use, temporal, and the individual component) well. The accessibility extension of MATSim could be an approach to achieve this.

First, transport system dynamics are represented by the accessibility computation integration with the MATSim dynamic traffic simulation. Second, land use is represented in a very disaggregate way; single facilities' locations and attributes are taken into account. Third, the temporal dimension can be observed by representing facilities' opening times and time-dependent travel times on the network; these are given as a MATSim dynamic traffic simulation output. Finally, individual characteristics can be taken into account; in the MATSim simulation, each individual is represented by its own software object, i.e., an agent, whose properties could be considered in the accessibilities calculation.

Actual accessibility values calculated by the MATSim accessibility extension take the form of *potential accessibility measure*, as originally defined by Hansen (1959). The specific selection of the measure's mathematical form allows results to be interpreted as logsum values, making them suitable for utilization in economic evaluations like benefit-cost analyses. Because the MATSim accessibility extension can rely solely on publicly and freely available data, e.g., data from OSM, it is highly portable. By distinguishing activity facilities along various potential dimensions, many different analyses can be conducted. In the code example given (see `http://matsim.org/javadoc` → accessibility → `RunAccessibilityExample`), for instance, accessibilities for different land uses, i.e., different types of activity opportunities, are calculated. Being grid- instead of zone-based (which most other accessibility tools are), avoids certain problems associated with zones. At the same time, computations are still within reasonable ranges, partly due to a runtime optimization that reuses computational steps for locations sharing the nearest network node.