

Geospatial Solutions for Public Service Planning in Smart Cities

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Abstract

Public services refer to the provision of immaterial (services) as well as physical goods (infrastructures) for the general public. Examples are healthcare facilities like hospitals or medical practices, education infrastructures like schools, retail, and local amenities. The planners of such services must ensure that facilities are provided for all citizens within a reasonable distance, i.e., traveling time. At the same time, the actual quality of the supply is relatively difficult to measure. A comprehensive analysis requires population data, detailed information about public service infrastructures and their capacities, as well as their accessibility with different means of transport. The chapter demonstrates how geospatial Web applications and analysis tools can support public service planning and how such centrally provided Web applications can increase the transparency and the quality of planning decisions. At the same time, the workload for planners or decision-makers is reduced since they no longer have to spend time on preliminary data search and integration or on building complex analysis methods and models themselves. In this context, the paper introduces three prototypically implemented applications with their provided functionalities and targeted user groups (e.g., policymakers at different levels, public services planners, or citizens). The applied technologies, architectures, relevant data, and services are discussed.

Keywords: Public Services, Planning, Accessibility, Smart City

1 Introduction

Transport plays a key role in sustainable development, not only in cities. In the 2030 Agenda for Sustainable Development of the United Nations, the 11th goal is to "make cities and human settlements inclusive, safe, resilient and sustainable". To achieve this goal, "sustainable transport" is recognized as one of the related topics¹. In [1], the UN emphasizes the urgent need to achieve "equitable access to public transportation and essential services", especially for the urban population living in slums or informal settlements. Accessibility is one of the key features in transport and urban planning and sustainable urban development, considering both the environmental and social aspects of sustainability[2]. It is defined as "the ease of reaching valued destinations"[3]. Hence, accessibility is a key measure for the efficiency and inclusiveness of the transport infrastructure within modern cities.

The relation between the concepts of sustainable cities and smart cities with their respective assessment frameworks have been compared in [4]. They point out that for smart cities, there is a much stronger focus on modern technologies and their "smart" application. The goal is to improve sustainability with the help of technologies, focusing on social and economic aspects rather than environmental indicators. Geographic information systems (GIS) serve as an enabler for smart cities. Their real-time geodata processing, simulation, analysis, and visualization capabilities support smart city solutions for many application domains, including urban and landscape planning, transport and mobility, energy, disaster management, and others [5][6].

This chapter illustrates different geospatial applications and tools that support planning decisions within smart cities. The focus is on decision tools for planning public services, particularly considering their accessibility. Public services, also called services of general interest refer to the provision of immaterial (services) as well as physical goods (infrastructures) for the general public. The provision of such services is an essential task of the public sector. The overarching goal is to ensure, as far as possible, homogeneous living conditions in all rural and urban areas. Examples of public services are healthcare facilities like hospitals or locations of general practitioners, education infrastructures like schools, retail, and local amenities. Compared to other smart city applications, decision tools for this domain rely less on real-time data. However, such planning decisions require accurate, consistent, and up-to-date geodata with high spatial resolution and detailed thematic information. Official geodata that fulfill these requirements are becoming increasingly available and published as open data [7][8].

The following chapter illustrates the potential of geospatial applications using such data to support public service planning. After discussing related work, the relevant user groups and required data are elaborated. Based on that, three geospatial Web applications are introduced, and the benefits for sustainable urban development and smart cities are illustrated. For each, the applied technologies, architectures, relevant data, services, functionalities, and lessons learned are discussed.

¹<https://sdgs.un.org/topics/sustainable-transport>

2 Related Work

Accessibility is a key concept in urban planning and public service delivery. It is vital to understand the distribution of and access to the services. This chapter reviews foundational and contemporary approaches to measuring accessibility, focusing on spatial accessibility, which combines service availability with ease of access. Additionally, it explores methodological advancements in accessibility modeling, the role of central places in regional planning, and concepts like the 15-minute city, highlighting their importance in ensuring equitable access in urban and rural areas.

2.1 Access and Spatial Accessibility

A generally agreed concept definition of access has been given in [9]: access represents "the degree of 'fit' between clients and the system". Transferred to the context of this chapter, the public service offerings represent the system. [9] defined five subdimensions of access: availability, accessibility, accommodation, affordability, and acceptability (often called the five A's). In this study, the first two are specifically considered. Availability refers to the capacity of a service. It defines the relationship between the volume, type, and resources of a service and the corresponding demand of its clients. Accessibility (i.e., reachability) refers to the actual transportation resources and the distance and travel time between the service location and the client's location. At this point, it should be noted that the umbrella term 'accessibility' is often imprecisely or ambiguously used and not separated from the service capacity. To develop analytical methods to measure access, the subdimensions availability and accessibility are usually combined and called spatial accessibility [10][11].

It should be mentioned that particularly in the context of further developing smarter and more sustainable cities, transport accessibility is not only relevant from the perspective of time or distance cost for individual transportation. Socio-ecological approaches to accessibility that include the analysis of social disadvantage and environmental impacts are equally important. An overview of the approaches can be found in [12].

2.2 Methodological Concepts for Measuring Accessibility

Modeling and measuring spatial accessibility was already being developed in the 1960s [13]. The idea is that simple reachability, with a threshold of costs (as a unit of time or distance), does not have enough informative value to generate sufficient statements about the balance of supply and demand, i.e., capacity is not considered. Accessibility was therefore extended to include further determinants: [13] defined criteria of a demand area and assigned to it a series of gradients or zones of a probabilistic nature that reflect different customer and sales potentials. This allows for modeling the gap between supply and demand under consideration of competing providers with overlapping supply areas. Such gravity-based modeling approaches work similarly to the concept of gravitational pull in physics. Just as larger objects have a stronger gravitational force, locations with a higher supply (e.g., larger stores or better-equipped hospitals) exert a stronger "attraction" on the demand. At the same time, the further away a location is, the weaker its influence becomes, similar to how gravity decreases

with distance. This means that customers or users are likelier to choose closer and larger service providers rather than smaller or more distant ones. The model calculates the probability of people choosing a certain provider based on both its size (i.e., capacity, attractiveness) and how far away it is. As a result, it helps estimate accessibility and competition within a given area.

Gravity-based models use different approaches to downgrade weights per unit of distance (distance decay). Such distance decay functions (examples in figure 1) model the extent to which the attraction between the supply and demand locations increases or decreases as a function of distance. Very simple models do not consider distance decay and assume that no supply occurs above a certain maximum distance (binary weighting). More advanced functions have a graded distance weighting (hybrid weighting) or a weighting function. Depending on the technical application, the weighting function can be described in many ways, ranging from linear to exponential to inverse weighting.

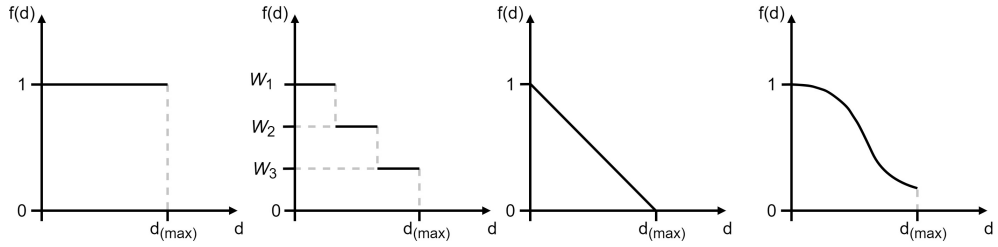


Fig. 1 Examples of distance decay functions: binary decay, hybrid decay, linear decay and continuous decay (adapted from [14])

Gravity-based models have been continuously improved to generate spatial accessibility indices [15]. In the context of improved computing and GIS capacities in the first decade of this century, newer approaches to model accessibility emerged [16][17]. The Enhanced Two-Step Floating Catchment Area (E2SFCA) method deserves special attention here. It combines gravity-based approaches with models of the capacity utilization of service providers. To adjust the analysis to specific application requirements, [14] compare twenty-four 2SFCA parameterizations for various urban planning, service delivery, and spatial equity issues. Further, to provide effective and realistic accessibility measures, different distance decay functions have been developed and adjusted for various applications (e.g.[11][18][19][20]). With all these advances, the method has become quite powerful. It can provide information on spatial accessibility for consumers (i.e., local population) and also for service providers since the following determinants are incorporated into the model:

- the size of the catchment area of the providers,
- the size of the catchment area of the consumers,
- a distance decay function that sets the probability of utilization in relation to distance (gravity model),

- the competition situation of the providers due to their overlapping catchment areas (considering the distance decay function) and
- the capacity utilization of a service provider considering the expected demand (considering the distance decay function).

2.3 Central Places and Analytical Concepts for Urban Planning

Regional or state planning often refers to systems based on the Central Places Theory [21]. Following this theory, the necessary services of general interest are concentrated in centrally located settlements, which are responsible for providing themselves and the surrounding areas with these goods and services. Planners explicitly identify these central settlements by recording the existing services of general interest and determining supraregional importance. They can also identify suitable settlements due to their location close to residential areas, transport connections, and commuter flows and develop the required services through planning policy or funding measures, for instance. For a realistic analysis of central places, two aspects are crucial: Firstly, because central places include a wide range of service infrastructure types, multi-criteria analyses are suitable for examining the supply situation in a particular area or region [22]. Secondly, a realistic assessment of the supply situation of central places requires an evaluation of multimodal accessibility. This means that private transport on foot, by bicycle, by car, and public transport should be included in the analysis.

In this context, many scientific studies provide more practical analysis results for planning. The multimodal accessibility to jobs within urban areas has been addressed by many researchers, for instance, as a comparison of the accessibility within cities across the globe [3] or the changes of accessibility in urban areas within the US [2]. Governmental initiatives tend to promote ideals like a 15- or 30-minute city, in which selected destinations important for daily life (e.g., employment, public transport, retail) can be reached within a limited walking distance from home (defined by the time). In particular, the chronometric view of the 15-minute city has experienced a substantial boost among city leaders around the globe in the context of the coronavirus pandemic and the sustainability and (climate) resilience debate of urban neighborhoods. Still, it has also been criticized [23][24]. A central point of criticism is the use of simple reachability without considering the capacity aspects of the infrastructure, which can lead to misplanning [25]. The feasibility of a 30-minute city considering different modes of transport and destinations has been analyzed in [26].

For travel infrastructure planning, [27] illustrated different techniques to visualize the effects of changes in the travel infrastructure on accessibility and travel times.

3 User Groups

Decision problems usually involve diverse stakeholders with different requirements, views, goals, and background knowledge. This chapter elaborates on the three main stakeholder groups addressed by geospatial applications in the field of public service planning.

Polymakers at Different Levels: This stakeholder group includes governmental officials and polymakers of city councils or local and regional governments. Here, geospatial solutions can help to create new insights and support strategy generation and, therefore, support policies and regulations for smarter, environmentally conscious, and socially sustainable urban development. The applications can provide measures or indicators to inform policy development, steer funding initiatives, evaluate the availability of services and infrastructure, or monitor policy implementation.

To support polymakers, Web applications must be intuitive and limited to specific functions. Ideally, they should provide visualizations that are easy to understand and interpret. However, the analysis functions should be transparent and well-documented, including their data inputs and parametrization.

Planning Practitioners: This group combines urban and regional planners and designers of public services (e.g., health, education, or retail planners). The planners of transport infrastructures could also be included here, although this is not the scope of this paper. To support this group, spatial accessibility analysis and other geospatial technologies are ideally implemented as planning support systems for tasks like design, analysis, evaluation, monitoring, etc.[28]. The applications should support them in creating more efficient, sustainable, and liveable cities. They could even improve the coordination between urban, regional, and transport planning [28].

To be useful for planners, applications should be integrated into the planning process, and the functionalities should be adjusted to the planning requirements. The applied algorithms must be well-established, and the analysis results must be transparent. Commonly, public service planners focus on single types or even subtypes of service infrastructures (e.g., primary schools or general practitioners). Their analyses do not only rely on the spatial locations of the service infrastructures but also include information regarding service times and service capacity, for instance. Ideally, options are given to parameterize the analysis or even to exchange or manipulate input datasets. The planners should be able to adjust the spatial unit or analysis area/zone to the corresponding planning scenario. The tools should support accessibility analysis for different modes of transport (cycling, walking, public transport, etc.). The visualization of analysis results should allow the comparison of different planning scenarios. Corresponding data export options to standardized formats should be provided to support postprocessing in other software tools.

Citizens: Geospatial technologies can be used to support community engagement and support democracy and transparency of political decisions. They can incorporate citizens and public stakeholders into the planning and decision-finding process or, later, justify decisions or positions. Such tools are commonly framed under the term Public Participatory Geographical Information System (PPGIS)[29].

The functionalities offered can generally be very different in complexity and interactivity. Analysis and results should be transparent and visualized; documentation should guide interpretation. The tools often provide commenting functions or even support discussions or more extensive communication.

4 Relevant Data and Analysis Tools

For public service planning, three groups of input data are required to represent the service providers, service consumers, and the transport network. The detailed data properties and availability differ depending on the geographic region. The required data contents depend on the planned analysis functionalities. Therefore, this chapter can only present a rough overview and introduction to the relevant data.

4.1 Service Infrastructure Data

The location information of public service infrastructures can be taken from the globally available Open Street Map (OSM) dataset. However, the data quality is inhomogeneous and depends on the geographic region. Even for European countries, the public service infrastructures are often not completely contained in OSM. Therefore, it is more advisable to use official datasets of public authorities as input for service infrastructure planning. In Germany, for instance, such data is increasingly made available by the authorities and published as open data [7][8]. The general availability of such authoritative geodata has been reviewed in [30].

A more detailed analysis, as required by the planning practitioners, includes not only the location information of the service infrastructures. Often, they require combined information about the detailed types of service and service capacities (e.g., yearly student capacity of schools, capacity utilization of medical practices, and service times). Depending on the data topic, some countries might consider such infrastructure information sensitive and restrict access.

4.2 Population Data

The service consumers are ideally represented by population data of the census. Again, the availability differs depending on the geographic region. Detailed analyses certainly require high-resolution population data provided as gridded data with a resolution between 100m and 500m. In addition to population numbers, detailed analyses for more specific planning purposes additionally require information about age, sex, income, etc.

International efforts are ongoing to conduct regular population censuses to count the population in terms of number and spatial density. At the national level, there are different quality characteristics regarding the census's temporal frequency and spatial accuracy. The United Nations plays an important role in promoting and standardizing censuses. Its Department of Economic and Social Affairs Statistics Division publishes guidelines for collecting census data [31]. These recommendations cover topics such as data collection, processing, and publication. However, in practice, the spatial resolution is often limited² and the collection frequencies are not harmonized between the countries.

For the European Union, for example, population data is available with a 100m grid resolution, and the member states are required to collect and publish data every 10 years [32]. However, the latest update frequency has been longer than 10 years

²<https://unstats.un.org/unsd/demographic-social/products/dyb/index.cshtml/#censusdataset>

in some countries. The data is made available by EuroStat³. For the USA, the U.S. Bureau of the Census⁴ is a reliable data source. For Africa, the African Information Highway (AIH)⁵ can serve as a starting point to find open population data of the individual countries.

Worldwide population data, including population density and partial socioeconomic information, is made available by the Socioeconomic Data and Applications Center (SEDAC)[33]. The gridded data has a relatively high resolution with grid cells of 30 arcseconds (approximately 1 km) and provides a time series since the year 2000. Therefore, it is well suited for use in multi-criteria analyses or accessibility applications. However, depending on the region, official regional statistics may provide more accurate and detailed information than the interpolated data from SEDAC [33].

Less detailed applications can also refer to derived data, for example from land cover data (e.g. CORINE land cover⁶) or the Nighttime Light Dataset of the World Bank⁷.

4.3 Routing and Accessibility

Web applications providing routing and, based on that, accessibility analysis functions require topologically consistent transport network data. Ideally, the data distinguishes different modes of transport modes, such as walking, cycling, individual motor car traffic, and public transport. Whether classic road network analyses with one mode (e.g., exclusively on foot, by car, or public transport) or public multimodal networks (e.g., starting at the bus stop with a transfer point to a subway and a connecting waiting time and then continuing with the express train): To determine travel times or distances in a transport network, the streets (edges) and intersections (nodes) are modeled as a graph or transferred to a distance matrix in a database. To determine one of the possible routes between two nodes, search algorithms are used that successively search all connected nodes of a graph (e.g., Breath-First Search (BFS), Depth-First Search, single-source shortest-path/Dijkstra algorithm) [34].

OpenStreetMap (OSM), administrative data, or commercial offers are data sources for building such graphs. Multimodal graphs of public transport can be generated using General Transit Feed Specification (GTFS).

Table 1 provides an overview of selected software libraries and tools for routing and accessibility analysis. These software libraries can be used to calculate routes and catchment areas. They facilitate the development of advanced methods and services based on E2SFCA or other analysis methods for calculating accessibility measures.

5 Examples of Planning Applications

In the following, the advantages that geospatial Web applications provide for public service planning are illustrated with three prototypical implementations. The targeted

³<https://ec.europa.eu/eurostat/web/main/home>

⁴<https://catalog.data.gov/dataset/census-data>

⁵<https://aih.opendataforafrica.org/>

⁶<https://land.copernicus.eu/en/products/corine-land-cover/clc2018>

⁷<https://registry.opendata.aws/wb-light-every-night/>

Table 1 Overview of selected software libraries and tools for routing and accessibility analysis

Name	Description
ArcGIS Pro	offers routing and accessibility analyses with the Network Analyst extension
GraphHopper	Java-based routing engine, several plugins integrate GraphHopper into QGIS https://www.grhaphopper.com
Open Route Service	OSM-based routing API https://openrouteservice.org/
R ⁵	multimodal routing engine developed by Conveyal https://conveyal.com/
R5R	uses R ⁵ for routing on multimodal transport networks [35], supporting many-to-many queries for public transport networks
R ⁵ py	Python library for routing on multimodal transport networks based on R ⁵ https://r5py.readthedocs.io/
pgRouting	extends the PostGIS / PostgreSQL geospatial databases with routing functionality https://pgrouting.org/

user groups, provided functionalities, applied technologies, relevant data, architectures, and services are discussed.

5.1 Accessibility Analysis of Central Places

In Germany, the Central Places Theory [21] is implemented as a hierarchical system that includes three different categories: lower-order centers, middle-order centers, and higher-order centers. Lower-order centers offer services for daily needs like supermarkets and childcare facilities. Middle-order centers and higher-order centers offer more specialized services like specialized medical practices or education infrastructures like universities. Changes in demographics, settlement structures, and traffic infrastructures require monitoring of the defined centers and their accessibility, as this usually involves financial subsidization.

The application showcased here provides a simple overview of the multimode accessibility of central places. The tool has been developed in a student project at the Technical University of Dresden for the district Saxon Switzerland-Eastern Ore Mountains in Saxony, Germany, as a study area⁸. The central places for this area are defined in the corresponding federal state and regional development plans^{9,10}. As shown in figure 2, the central places do not necessarily have to be within the district.

The application’s main goal is to evaluate and compare the accessibility of the central places from the populated areas within the study area. The supported transport modes are cycling, individual motor car traffic, and public transport. A 500m grid was intersected with ‘built-up and urban’ areas from the 2018 CORINE land cover data set to represent the settled areas. The route calculation for cycling and car traffic was done using the Open Route Service. For public transport routing, the station information system of the Deutsche Bahn (German national train service) has been queried. Therefore, the closest public transport stop or railway station to

⁸<https://storymaps.arcgis.com/collections/e4b934a7b30b46dfbf8464e22f468ea5?item=6>

⁹<https://www.landesentwicklung.sachsen.de/landesentwicklungsplan-2013-4794.html>

¹⁰<https://rpv-elbtalostorz.de/regionalplanung/regionalplan-2020>

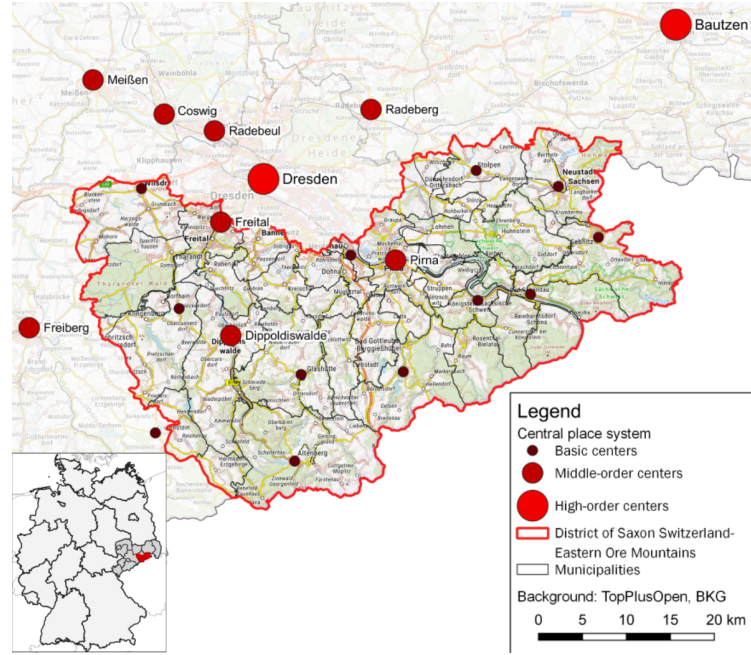


Fig. 2 Overview map of the study region: the Saxon Switzerland-Eastern Ore Mountains district with its central places

each grid center has been used to calculate the connection. The accessibility score is calculated for grid centers and their respective fastest accessible central place. Based on the relative weighting of the transport modes and the expected ideal and maximum acceptable traveling times for each mode, an accessibility score between 0 and 100 is calculated and visualized in the map (figure 3). The accessibility scores can also be calculated for municipality regions and exported for further processing and use.

The application allows to compare the accessibility of different parts of the region or the effectiveness of the transport modes. As shown in figure 3, the user can select layers for the accessibility score of the transport modes and center types separately or get summarizing scores calculated based on the weighting of the transport modes. With this functionality, the application can serve as an information tool for the wider public or as a decision-support tool for regional and urban planners.

The single-page browser application is implemented based on Angular and LeafletJS. The navigation is kept simple to provide all functionalities in the same view component. The route calculations have been preprocessed and internally stored to simplify the architectural requirements and improve the performance. The data is stored with GeoJSON. Potential extensions could include real-time traffic information in the route calculation or consideration of the different service types offered in the central places.

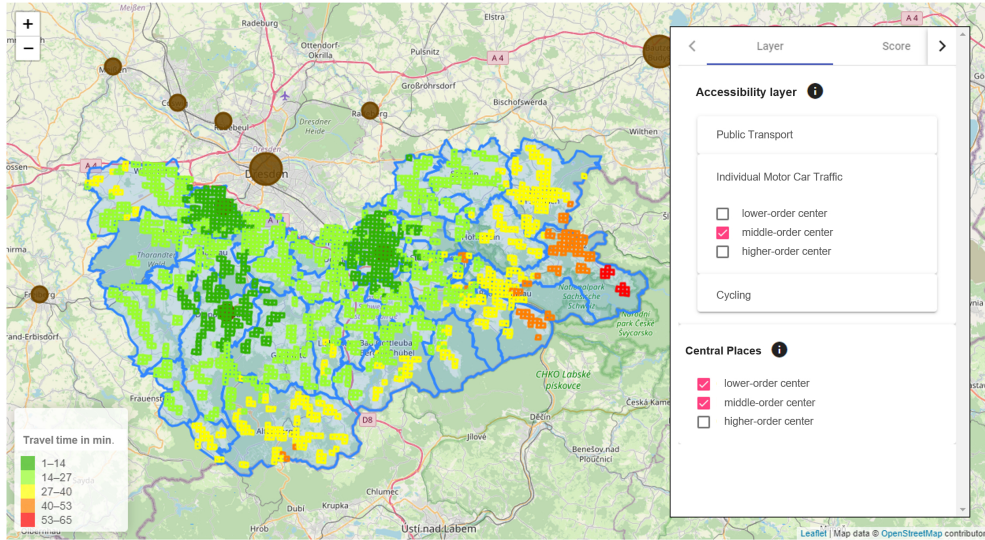


Fig. 3 Web application for the accessibility analysis of central places (user interface labels translated)

5.2 A Multi-Criteria Analysis Web Planning Tool for 15-Minute Cities

Development concepts such as smart cities aim to make cities more liveable, efficient, technologically advanced, ecologically sustainable, and socially inclusive. Therefore, they are obliged to combine different information to form a fundamental statement about the overall situation of community infrastructure provision. Multi-criteria analyses, which can summarize various information in one information layer, are particularly suitable for answering questions about the accessibility of infrastructures, for example, for 15- or 30-minute cities. Other assessments of the supply situation of public service infrastructures can also support smart city planners.

Here, the Atlas of Infrastructure Provision for state, regional, and urban planners of the federal state of Lower Saxony, Germany, is used to demonstrate such a Web application. It is a map viewer application that serves as a central access point to infrastructure data as well as accessibility and other analyses [36][37]. The application provides access to all necessary data and methods:

- **Service Infrastructure Data:** State-wide and complete location data for local supply (supermarkets, discount stores, other grocery stores), health (clinics and hospitals, specialists in general practitioner and general specialist care as well as pharmacies), and education (daycare centers, primary schools and educational institutions offering secondary level 1 and/or secondary level 2 education)
- **Population Data:** High-resolution population data in a 100m x 100m grid with current and historical data including various age classifications (relevant for specific issues relating to the accessibility or supply of a certain urban clientele such as preschoolers or pensioners)

- **Routing & Accessibility Calculations:** Using OpenStreetMap street network data and the OpenRouteService, it is possible to determine time and distance values between supply and demand locations and to calculate catchment areas.

With the help of a multi-criteria analysis, various urban infrastructures can be used to analyze the residential population supply situation. People responsible for planning, evaluating, or improving services of general interest infrastructures in a residential area might, for example, be interested in whether a desired set of infrastructures can be reached within a reasonable travel time (i.e. the individual travel time thresholds for each infrastructure type set by the planner). The analysis allows the planner to investigate the cause of a potential poor service coverage. The planner receives an adequate tool to evaluate the supply situation and derive measures for action. The following practical example shall illustrate the details of the supply analysis and its parameterization:

Assuming the role of a planner who has the task of evaluating the geographical proximity between residential locations and supply facilities in the state capital of Hannover, which has a population of around 550.000. In particular, the aim is to find out if there are any deficits in terms of the 15-minute city concept. The investigation should indicate the locations of the deficits and potential reasons (e.g. lack of infrastructure capacity or insufficient accessibility).

The planning application is designed to be easy to use and requires little or no prerequisite knowledge of GIS. [22] provide more details about the user interface and interactions. The user first defines the analysis area using a bounding box. The application automatically creates a buffer of 20 kilometers around the analysis area. This is necessary to consider infrastructure and population as well as the interaction of co-supply effects for the surrounding area of the bounding box.

The next step is to specify the service infrastructures to be analyzed. For example, the planner is assumed to want to analyze general practitioners, pharmacies, discount stores and supermarkets, nurseries, and elementary schools. He selects these from a list of infrastructures in the application using checkboxes. Further, he selects the relevant age groups of the population for the analysis.

For all selected infrastructures, the next step is to define the threshold values for the accessibility minutes. The user specifies the transportation mode and can choose between walking, car, and public transport. In the context of the 15-minute city, it is assumed that essential urban services should be available within a distance of 500 to 800 m from the place of residence [38]. Adults can reach these distances under normal conditions at a speed of 5,15 km per hour in about 10 minutes [39].

In this planning scenario, we assume that accessibility on foot can be considered very good in less than 5 minutes, good in 10 minutes, sufficient in 15 minutes, and still acceptable without a deficiency in 20 minutes. This also covers accessibility for older people [39].

In the last step, the planner starts the calculation. Figure 4 shows a screenshot of the application with the calculation result. A language switcher makes the application available in German and English. The interface on the right-hand side navigates through the analysis process and guides the user in the parameter adjustment. The analysis result is visible in the map window as a criteria map. It is possible to switch

between the supply of individual services and the overall supply situation. Areas presented in red indicate a deficiency regarding the parameters set.

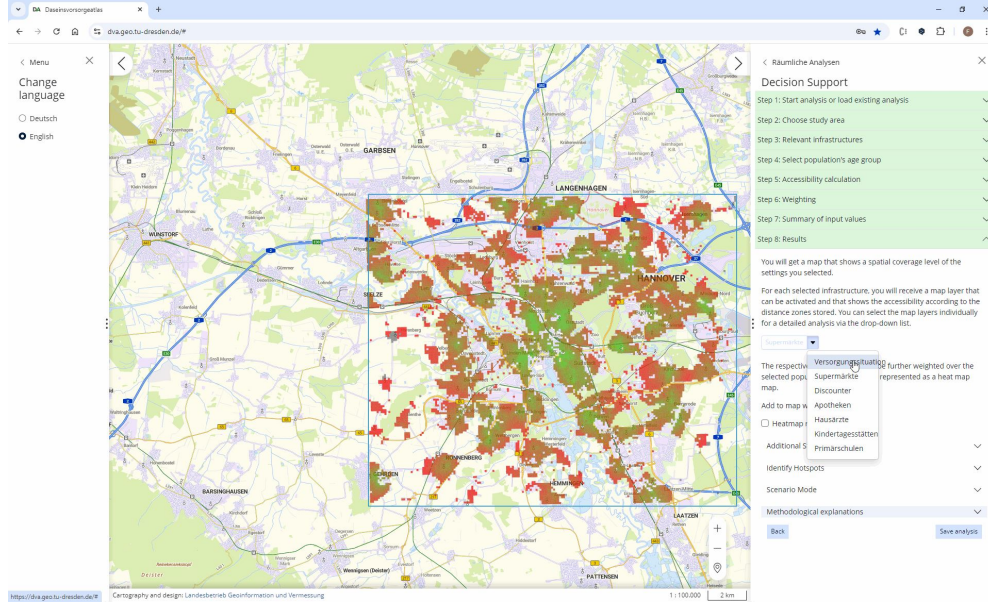


Fig. 4 Screenshot of the application with a multi-criteria analysis result to check the accessibility of selected infrastructures.

For the described use case, two further functions are useful. First, for each public service type and the overall supply situation, additional statistics and diagram visualizations are offered to represent the population numbers with an insufficient supply situation, for example. Therefore, it is possible to generate information about the service quality per infrastructure for each 100m x 100m (Figure 5 top right). In this example, the pharmacies layer has been selected for a more detailed view. To support the interpretation of the results, the coverage values relative to the population density can be viewed and interactively selected in a diagram (Figure 5 bottom right). The diagram shows a point cloud in which each point represents a grid cell drawn at its supply and accessibility situation and its number of inhabitants, correspondingly. The planner can select cells in the diagram by drawing a box. In the example shown in Figure 5, the population cells with at least 100 inhabitants and comparatively low accessibility to pharmacies are selected (selection in the diagram bottom left). After the selection, the corresponding cells are highlighted on the map (red cells). This allows the planner to improve the understanding of the study area. Thereby, deficient settlement structures can be quickly recognized and planning initiatives derived.

The second function is the scenario mode, which allows users to explore the various action options. Infrastructures can be relocated or deleted, and new ones can be added.

The effects of the changes are immediately visible on the map, and the accessibility values are adjusted.

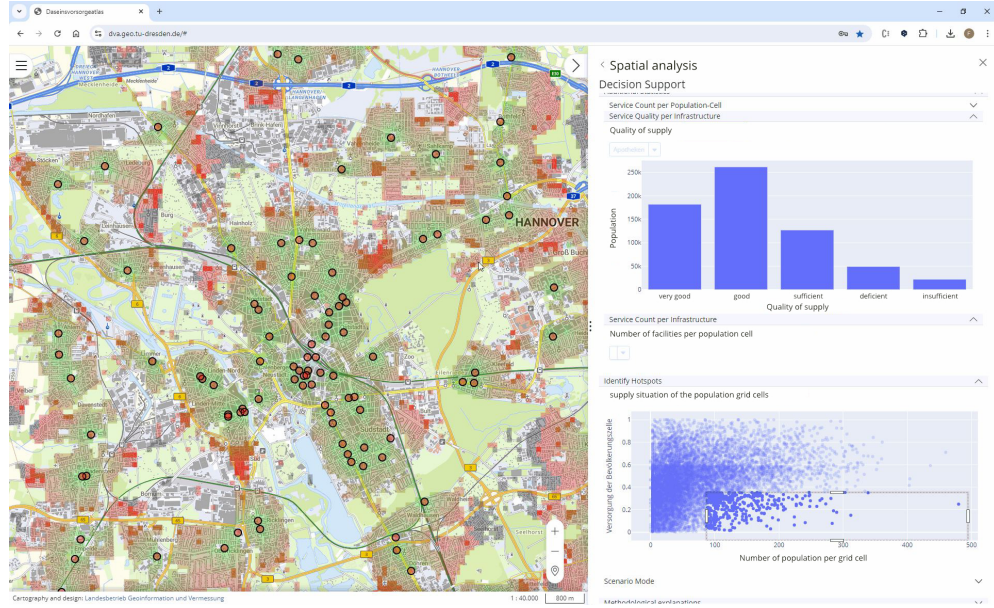


Fig. 5 Interactive diagrams in the statistical view for the pharmacy supply situation

The advantage of the application is the low threshold for planners with limited GIS knowledge. The user interface provides broad but not overwhelming options for parameter adjustment and allows for analyses that may be required in the planning context of smart cities. We have illustrated the use case of the 15-minute city. However, other analyses are also possible, such as assessing the accessibility of central locations or non-urban areas or identifying undeveloped settlement areas with particularly high accessibility values for service infrastructures.

The application focuses on the user group of public service planners. Under certain circumstances, it may also be suitable for policymakers who want to get a more precise picture of the situation in certain urban areas. However, the application is unsuitable for informing citizens due to its complexity.

The initial effort required to prepare the data and to develop the application is very high. Therefore, providing such a tool for more than just one city or region is advisable. In this case, the application was developed for the federal state of Lower Saxony, with an area of almost 50.000 km² and over 8 million inhabitants.

The presented application evaluates accessibility in terms of simple accessibility (without capacity measurements). Not taking capacity characteristics into account is a general point of critique, also for the 15-minute city concept. The capacity analysis can only be meaningful if it is done separately for each service infrastructure type, such as education, health, or local supply, rather than referring to multiple service

types in a multi-criteria analysis. Such spatial accessibility analysis can be done with another tool presented in the next subchapter.

5.3 Spatial Accessibility of Health Infrastructures

In the previous chapter, accessibility measurements were investigated without considering capacity. This chapter will present a second tool from the Lower Saxony Atlas of Infrastructure Provision. This tool can be used after the previous one has identified deficient coverage of a specific supply type; in the following example, this is healthcare. The E2SFCA methods are used to calculate spatial accessibility measures. This allows for precisely modeling the supply situation, including accessibility and availability.

The methods require the adjustment of numerous model parameters. Incorrect basic assumptions can reduce the validity of the results [40]. Therefore, setting up such tools requires intensive requirement analysis and coordination with expert planners to provide a correct user interface for functionalities and parameterization. In this context, defining parameters that indicate capacity utilization is important. These can be completely different in retail (e.g., sales area) than in education (e.g., student capacity) or medical care (e.g., the number of possible doctor-patient contacts depending on weekly consultation hours at the location). This also applies to the type and characteristics of the catchment areas and the underlying distance decay function used to map the population's demand behavior.

As [12] point out, implementing such tools is often complex, requires a wide range of software libraries, and the calculations are computationally intensive. Therefore, it is hardly feasible for planners and analysts to integrate the development and operation of such analysis tools into professional desktop GIS systems during their daily work. A centrally provided application can be a solution here. In the following, we present two options: a web application and an ArcGIS toolbox that accesses the data and analyses of centrally provided services. These solutions significantly increase the freedom and flexibility of the planner or analyst.

In the following example, we will examine the city of Wilhelmshaven in terms of its spatial accessibility to primary care physicians. Wilhelmshaven, as part of the German metropolitan region of Northwest, is a relatively small settlement with a population of about 75.000.

- **Service Infrastructure Data:** Location and capacity information for primary care physicians. This includes the number of physicians working at the location. Depending on the data availability and the healthcare system's organization, the accuracy of the analysis can be increased if the capacity information on the workload or even the number of potentially possible treatment cases at the locations is known.
- **Population Data:** High-resolution population data in a 100m x 100m grid with current and historical data including various age classifications (relevant for specific issues relating to the accessibility of elderly or infants).
- **Routing & Accessibility Calculations:** Using OpenStreetMap street network data and the OpenRouteService, it is possible to determine time and distance values between supply and demand locations and to calculate catchment areas.

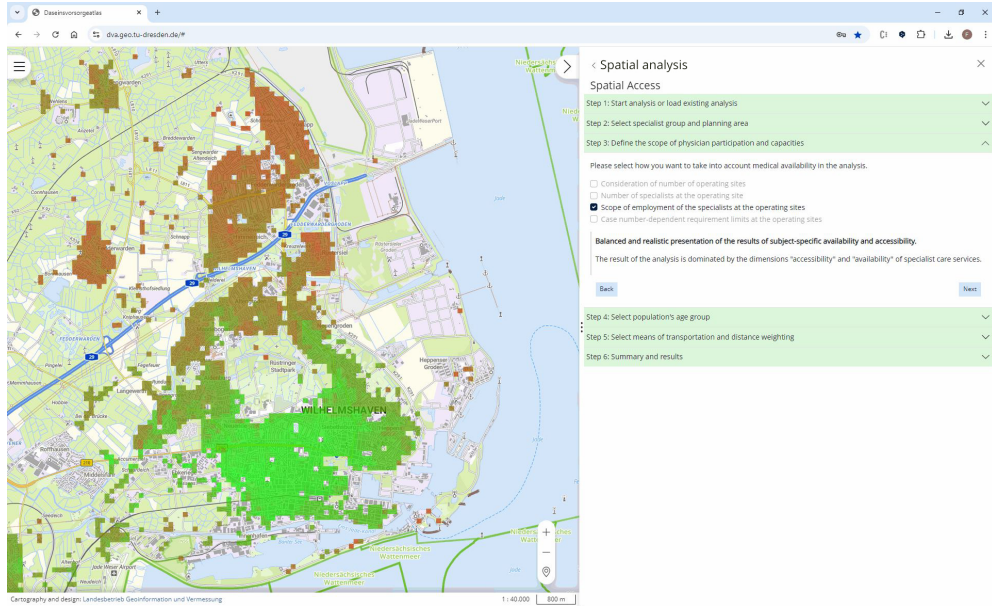


Fig. 6 Screenshot of the application with calculation results of a spatial accessibility analysis in primary healthcare.

The planner is supported in selecting parameters in the interface (Figure 6). Particular attention is paid to steps three and five when applying the 2SFCA method (on the right of the user interface). Here, the planner specifies how locations and the capacity weighting are included in the analysis:

- using a purely location-dependent approach,
- including the number of primary care physicians at a location,
- including the scope of employment (e.g., in weekly working hours) of the staff at the location,
- using patient case numbers at the location (according to the central accounting system, if available).

In addition to the essential component of the capacity weighting of the suppliers, it is possible to define relevant population groups (demand) and the distance decay function in the last step. Here, the planner has the option of choosing from various established functions. The map window in Figure 6 shows the analysis results in a 100m x 100m grid. Green values represent comparably high spatial accessibility values, while red values represent low ones.

The ease of use for non-GIS-affine users is a clear advantage of this tool. Despite the complex parameter adjustments the method requires, realistic results can be achieved within a few minutes. However, this requires intensive development work and requirements analysis. The invested effort can only be sustained if many users access the Web application and the underlying data is kept up to date.

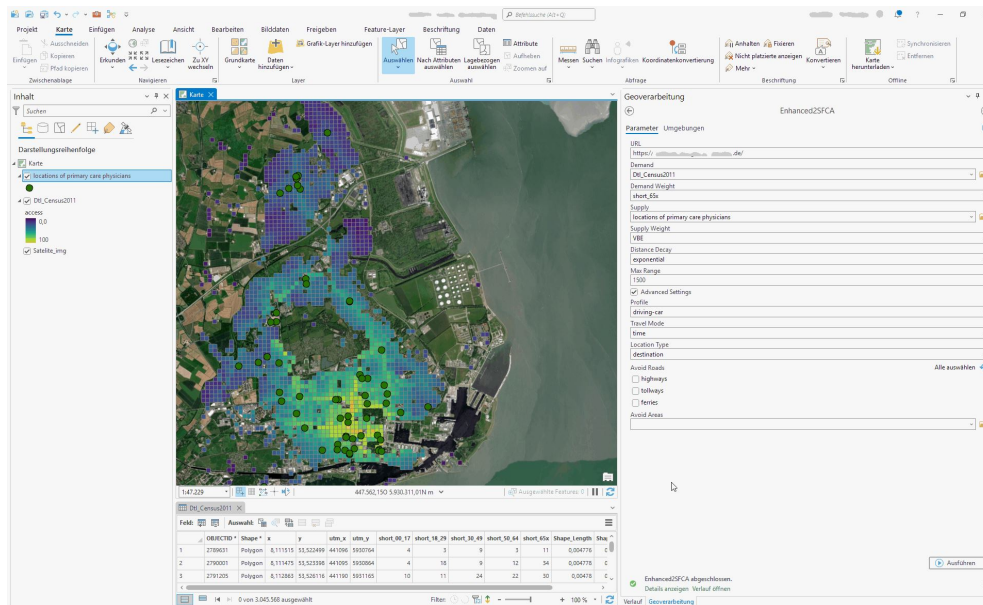


Fig. 7 Screenshot of ArcGIS with the calculation result of a spatial accessibility analysis in primary healthcare and a toolbox to access the accessibility calculation service and define the parametrization.

Another solution is to provide a toolbox for expert GIS, such as ArcGIS or Q-GIS. Figure 7 shows an example tool from ArcGIS for Desktop for the study area. The advantage of this solution is that no complex Web application with a sophisticated user interface needs to be developed. At the same time, the user has full control over the input data of the service infrastructure data and the population data. In addition, the parameter adjustment, layout, and study field can be set much more flexibly, as shown in the example. Once the planner has made all the entries, the request is sent to a centrally provided server, which performs the calculations via the Open Route Service and a service for calculating spatial accessibility and returns the calculation results to the desktop GIS. The planner does not have to worry about the routing algorithms or performing the E2SFC calculation. However, the disadvantage is that using GIS systems often requires specialized knowledge. Unfortunately, experts with extensive GIS knowledge and the specialist context of the planning view (in our example, healthcare) are relatively rare. In addition, the high (license) costs of some GIS software can make this variant an isolated solution that is only available to a small group of users.

However, the two proposed ways of evaluating spatial accessibility, with their highlighted strengths and weaknesses, will be suitable for the variety of analysis requirements of public service planners and export analysts in smart cities.

6 Summary and Conclusion

This chapter illustrated the potential of geospatial Web applications to support public service planning in smart cities. Planning public services heavily relies on measuring access to service infrastructures. Therefore, the literature increasingly acknowledges the importance of spatial accessibility in urban planning and sustainable urban development.

The chapter discussed the concepts of access, spatial accessibility, and central places to provide the foundation for the presented work. It distinguished three central user groups with different levels of information, which are addressed by the Web applications: political decision-makers, planning practitioners, and citizens. This classification is also valid for many other smart city applications and services. Further, the required data foundation and available analysis tools and software libraries have been elucidated.

The implemented Web applications, illustrated in the chapter, offer several advantages to the users. Without such tools, using comparable analysis functionalities requires GIS expertise. Before starting an analysis, experts must harmonize, integrate, and later update the input data. This is time-consuming, particularly if the population and public services data are used from different sources (e.g., different administrations). Another considerable effort is the setup and parameterization of the analysis in the GIS.

The initial effort to set up such specialized Web applications is high. However, the centralized workload can save a lot of time if provided to a wide range of users. For the presented use cases, an analysis that would take several working days to prepare and execute in an expert system can be carried out in a few minutes by users with limited GIS knowledge. Therefore, Web applications should focus on a limited set of functions and be intuitively usable. They should be made available to a wide range of users who regularly need to use such analyses. In the context of smart cities, typical use cases involve regular tracking of access and spatial accessibility.

Many other use cases or extensions of the presented application or similar tools are conceivable. So far, the tools support the planning and evaluation of the public service infrastructure. Changes or optimizations of the transport network are not included, although this could also be a significant topic for smart cities. Further, most of the existing spatial accessibility measures do not incorporate the environmental and ecological impacts of accessibility, i.e., the environmental costs of access. Therefore, future accessibility research should consider environmental and social sustainability goals, as suggested by [41]. In the future, such applications might help to close the gap between smart cities and sustainable cities, as claimed by [4].

The implemented multicriteria analysis and spatial accessibility planning tools are available online for interested users¹¹. The website also provides descriptions of other usage scenarios as well as extensive tutorials and documentation.

¹¹<https://dva.geo.tu-dresden.de/info/>

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