THE APPLICABILITY OF ACCESSIBILITY ANALYSES IN SPATIAL PLANNING

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Abstract
Accessibility is a popular concept in many research areas, including spatial planning, where it denotes the possibility of reaching a specific location. Accessibility is not a characteristic feature of a single location: it is always measured between at least two locations (places), and it is strictly determined by the mode of transport. Subject to the evaluated parameter, accessibility falls into different categories, including physical accessibility which is defined by distance (meters, kilometers), temporal accessibility which is expressed in minutes and hours, and economic accessibility which is denoted by cost. In highly urbanized areas and their rural outskirts, spatial policies need to be coordinated to guarantee the effective distribution of functions and services. The optimization of accessibility should be the key goal of spatial policies adopted at both local and metropolitan level. The aim of this study was to analyze the applicability of public data sources and GIS tools for analyzing and improving spatial accessibility. A wide range of tools and data supports detailed evaluations of the spatial coverage and effectiveness of services (public and commercial), multi-objective optimization of planned locations and determination of the optimal service areas (with the use of gravitation and potential methods).
Spatial planning is a process of selecting the optimal and rational functions for the existing space. A very wide variety of analytical tools can be deployed to acquire and process public data and research data. The results of multi-objective analyses can be support the planning proces.
Key words: spatial planning, accessibility analysis, territorial cohesion, urbanization

Introduction

Economic and social activities take place in space and are localized in space. Space is a limited commodity, and the management of space in accordance with a specific set of rules relies on the principle of economic efficiency which states that the existing spatial resources have to be optimally allocated to maximize the desired outputs, and that costs have to be minimized to achieve the anticipated goal (Domański, 2006). The concept of space is used in many fields of research (Olenderek, 2009), and it has numerous definitions. Spatial planning focuses on geographic space, namely the surface of the Earth which constitutes the natural environment and differs in physical, biological and geochemical attributes (Meyer, 1998). These attributes are modified by infinite combinations of economic and social activities which are responsible for the unique natural and anthropogenic features of space (Kupiec, 1997). The fourth dimension, time, is an essential element of geographic space which supports analyses of past activities as well as forecasts of future events and socioeconomic needs in the future. The distribution of objects and various types of human activities in space is determined by numerous factors, including environmental conditions (Kurowska et al., 2014), social needs, economic possibilities, type of object and its parameters (Cymerman, 2011). Real space is characterized by various parameters, such as resistance, variation, limitedness, continuity, saturation, structure, accessibility, value, variability and function (Chmielewski, 2001, Parysek, 2007, Olenderek, 2008 Cymerman, 2011). Accessibility is one of the most important features of space, in particular in relation to public space, and it is defined as public access to space and its resources. Resistance is also a key characteristic of space, and it is expressed by the cost of traveling in space.
In geography, the term "accessibility" has been used in a variety of contexts without a clear definition, therefore, it is regarded as a fuzzy concept (Moseley, 1979). According to Ratajczak (1992), accessibility cannot be unambiguously defined due to a high number of mutually exchangeable synonyms. Accessibility has different meanings in various fields of science. In geography, it denotes proximity and spatial interactions between objects. In sociology, it is analyzed in the context of social limitations, whereas in economics, the definition of accessibility is linked with cost. Koźlak argued that accessibility is a relative and context-dependent concept, therefore, its definition is largely determined by the scope and context of research. The same location can be regarded as accessible in one field of research, but inaccessible in another when different considerations, such as the time or cost or travel, are taken into account (Koźlak, 2009).

Spatial accessibility has to be defined for the needs of this study. According to the most popular definition, spatial accessibility is the ease of reaching a specific location from a different location or locations (Guzik, 2013). Spatial accessibility cannot be construed as a characteristic feature of only one location – it is always measured between at least two locations, and it is strictly determined by the mode of transport. Subject to the evaluated parameter, accessibility falls into different categories, including physical, temporal and economic. A distinction is also made between relative and integral accessibility. Relative accessibility denotes the linkage (distance) between two locations or points in space (the greater the distance, the lower the accessibility), whereas integral accessibility describes the distance between the point of origin and the remaining locations in the analyzed system. Unlike relative accessibility, integral accessibility is not a reciprocal relationship (Ingram, 1971).

In practice, the accessibility of map systems for multiple users is analyzed by mapping a route between two indicated points. Regardless of the implemented algorithm, its main objective is to optimize the length, cost or time of travel. The most popular optimization solutions include an algorithm for finding the shortest paths between two nodes, which was conceived by Dutch scientist Edsger Dijkstra in 1959 (Dijkstra, 1959), as well as the more generalized A* algorithm which searches among all possible paths to the solution for the one that is characterized by the smallest total distance. The A* algorithm analyzes a smaller number of nodes and is generally much faster than other solutions (De Smith et al., 2007).

The above algorithms are also applied to develop other tools. The most popular solutions are used to determine the zones and sectors of interactions between locations. In accessibility studies, a zone is a polygon covering all road and street sections whose combined resistance, measured from a central point (along the streets), will not exceed a preset value. A sector is composed of road and street sections which are situated closer to a selected point than to any other point in the grid (De Smith et al., 2007).

Accessibility analyses are frequently undertaken in geographical research and, as of recently, also in spatial planning. The first isochrone map plotting out travel distances between locations in London was developed by Francis Galton in 1881 (Galton, 1881). In Poland, the isochrone method was first used by Włodzimierz Kubijowicz (Kubijowicz, 1923) to map parallel isochrones from the cities of Lvov and Kraków. The progress in accessibility analyses was stimulated by the need for effective spatial planning methods and the rapid development of cartography, in particular for military applications.

Isochrones are relatively easy to plot, but in the past, this process was highly laborious and time-consuming because the distances between points and the interpolation of isolines between road sections had to be calculated manually. The introduction of computer-aided methods, in particular GIS tools, significantly increased the speed and quality of isochrone generation. At present, these functions are available in numerous commercial applications as stand-alone tools or as add-ons or plug-ins in complex software systems. The existing functions support automatic isochrone plotting based on the preset criteria. License costs vary subject to the number of functions and computing power.

In accessibility studies, computer-aided methods require digital topographic maps displaying road networks. These resources are used in grid-based analyses in geographic information systems (GIS) which evaluate various travel options along different elements of the grid. A grid is defined as a set of mutually linked objects – lines representing road and street axes and points (nodes) denoting intersections (Curtin, 2007). The course and extent of a road section provide basic information about its length and location in space, however, these data are not sufficient for optimization. The second vital element is travel time, which is calculated based on the length and speed allocated to every road section.

A grid analysis is a process of formulating and solving problems that are expressed by grid structures and are generally represented by graphs. Graph theory provides abstract methods of graph analysis. Graph theory is a field of mathematics and computer science that deals with graphs – spatial structures that model the associations between data (Lange, 2012). A graph is a set of vertices (referred to as nodes in computer science in GIS) that can be connected by any number of edges or lines representing the associations between vertices (Narsingh, 2004).

Simple grid analysis does not always fully reflect the complexity of the evaluated phenomena. In simple grid analysis, a resident is unambiguously assigned to the nearest, specific location (center). The resulting monopoly is a simplified approach, whereas an evaluation of a given location's real potential and coverage requires the identification of competitive sites and their influence on the population in a given area.

The simplest and most popular method of analyzing the potential of a location is Reilly's law of retail gravitation (Reilly, 1929, 1931). Reilly's law has many variations and extensions, the most popular being the generalized Huff model which accounts for the differences in the attractiveness of other sites (Huff, 1963). The Huff model had been originally designed for retail analyses, but it is also applied in urban planning and transport. The model is used to determine the attractiveness of a trade area and the number of potential customers. In strategic planning, such as the selection of the optimal location for a new site, the Huff model is used to simulate the effectiveness of the available options.
Spatial accessibility is a key consideration which determines the extent to which the local market is accessible to outsiders and external institutions as well as the extent to which local residents have access to external markets. The above applies particularly to external labor markets and the availability of public and administrative services that are not available at the municipal level. Continuous growth is needed in the production sector, the consumer goods market, infrastructure, construction, transport and communications to improve the standard of living and increase the profitability of investments in both urban and rural areas.
The aim of this study was to analyze selected methods and tools for evaluating accessibility in spatial planning. The results of accessibility analyses provide vital information for spatial planning and decision making. The applicability of accessibility analyses for spatial planning was evaluated to justify the choice of selected analytical methods.

Methodology of research and materials
The selection of the most relevant data is one of the most important tasks before analysis. The data describing units of administrative division (Warsaw districts) and address points were used, subject to the type and scale of the analysis and the size of the analyzed area. The purpose of spatial accessibility analyses was to determine the possible development scenarios for the capital city of Warsaw and their implications for the adjacent rural areas. Rural areas provide urban residents with recreational options, therefore, their accessibility is an important consideration for city dwellers. The analyses were carried out based on public data generated by the Central Statistical Office (GUS) with the use of GIS tools.
There is a wide selection of commercial and freeware applications for the visualization and analysis of spatial data. In this study, the ArcGIS (Esri) program was used to visualize the distribution of Warsaw residents. MapInfo Professional analytical software with dedicated add-ons extending the program's functionality were used in accessibility analysis. The Vertical Mapper application supports raster data analysis. In this study, Vertical Mapper was used to generate a Huff model for shopping centers in the Warsaw metropolitan area. The ChronoMap optimization tool was applied in accessibility analyses to identify multi-objective access zones and distances for the Huff model. The results were visualized in thematic maps with the use of MapInfo Professional software.

Discussions and results
Rural areas situated in the direct vicinity of large cities undergo progressive urbanization. Urban sprawl is intensified, and metropolises exert a growing influence on the adjacent territories, mostly rural, which are part of the functional urban area. Residential construction is on the rise in rural outskirts, and rural residents spend increasingly more time commuting to work in the city. The number and size of areas that are dependent on and functionally linked with the urban core continue to increase, and the traditional model of urban-rural dichotomy is gradually disappearing. The agricultural role of rural areas is limited by their functional diversification.

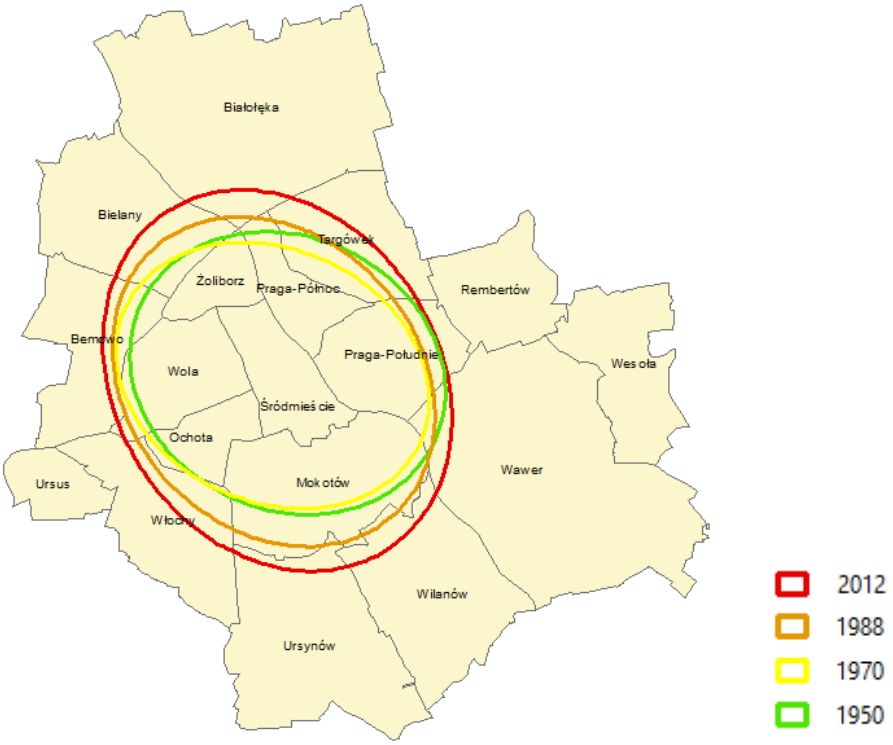

Fig. 1. Urbanization processes in Warsaw in 1950-2012.

Urbanization processes in Warsaw and the accompanying urban sprawl are presented in Figure 1. In a cluster analysis, demographic statistics for Warsaw's districts in 1950-2012 were used to analyze the growth, density and distribution of population in the Polish capital. The analysis was conducted in intervals in view of spatial changes over time. The results indicate that the urban area was significantly expanded over the years at the expense of its rural outskirts.

Until 1970, Warsaw's population was concentrated in pre-war districts where the majority of new development projects had been undertaken (Mokotów, Ochota, Wola). This trend began to disappear in the early 1970s which witnessed the construction of high-rise apartment buildings and the development of large residential estates in the remote districts of Ursynów, Wilanów, Bemowo and Białołęka.

In urban areas, new development projects are inspired by the local residents' activities and needs. They include residential estates, offices, recreational centers, shopping centers and other forms of non-agricultural land use. Most of these projects are localized in the proximity of cities, and they significantly decrease farmland area.

Despite legal regulations, urban development often proceeds in an uncontrolled manner, and it leads to dispersed development that encroaches upon open and protected landscapes. Badly planned and arbitrary expansion causes many functional problems in rural areas, including higher demand for new roads and traffic routes, higher transportation costs, deforestation and environmental pollution. These factors increase the cost of and decrease the quality and access to technical, social, commercial and transport infrastructure.

Spatial Accessibility

The time of travel between two points in space is determined by many factors which are influenced by the specific features of space, mode of transport and transport users. Optimization functions are available in a wide range of commercial applications. The appropriate database (pedestrian traffic, public transport, bicycle transport) has to be implemented in optimization software together with a set of attributes required for performing a given task.

The results of accessibility analyses are generally presented in map format (Bielecka, Filipczak, 2010). Temporal accessibility is plotted with the use of isolines which are lines connecting points with identical values on a map. The results are also presented with the use of isochrones, which are lines representing distances that can be traveled in a given timespan, and isodistance lines connecting points which are separated by the same distance from a point or a set of points.

Accessibility is measured by distance (and isochrones) to determine the maximum time of travel to a given location for the needs transport policy making. In spatial planning, accessibility should be analyzed based on various criteria. One of them is the availability of local transport between peripheral locations and a central location or other important locations, which indicates whether a given distance can be traveled within a reasonable timeframe and at acceptable cost. Such locations include urban areas with larger job markets, schools, universities, shopping centers, transport hubs or airports.

Fig. 2. Range of locations that can be accessed by car within 5, 10 and 15 minutes from the city center – road sections that are accessible within the anticipated travel time.

Infrastructure is indispensable for economic growth. The Region of Mazowsze is characterized by the greatest disparities in economic growth and infrastructure development in Poland. The high concentration of transport infrastructure in Mazowsze is linked with the economic significance of Warsaw, the capital city of Poland. The majority of heavy-traffic roads and railway lines intersect in Warsaw.

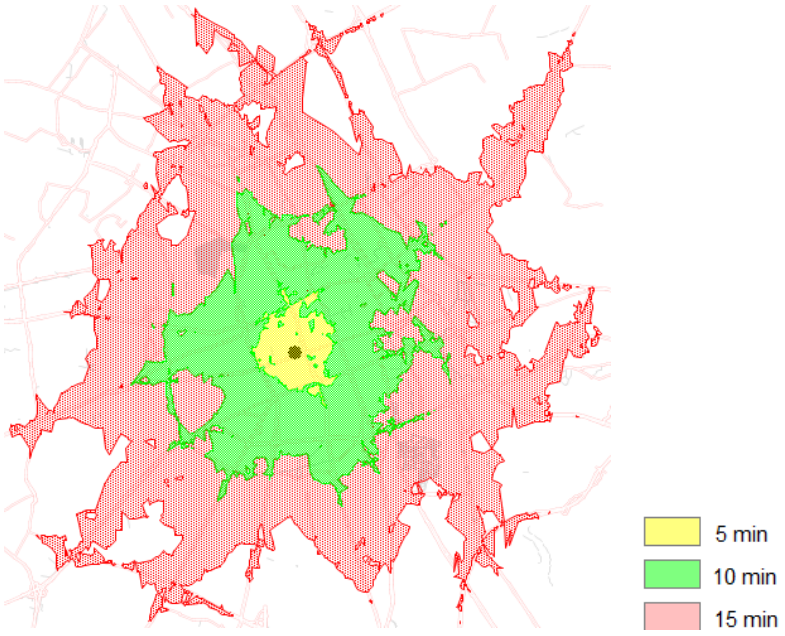

Fig. 3. Range of locations that can be accessed by car within 5, 10 and 15 minutes from the city center – visualization of successive time intervals.

Accessibility analyses are also indispensable for planning the location of new development projects. They are carried out by businesses searching for attractive locations for new service outlets, as well as institutions in the process of planning new hospitals or schools.
In the process of generating zones for new locations, the travel time required to reach service outlets in the vicinity of the planned project has to be minimized. A specific location cannot be identified during the search for attractive locations, but the criteria that will contribute to the location's attractiveness for future users can be established. For example, the criteria that are likely to increase the attractiveness of a residential project include the proximity of a health care facility, post office, bank or bus stop.
When zones have been mapped in view of the specified criteria, their applicability can be evaluated based on the information found in land use maps and other sources. This approach guarantees that the planned project will be consistent with planning requirements, and it will facilitate the selection of locations that cater to the developer's needs.

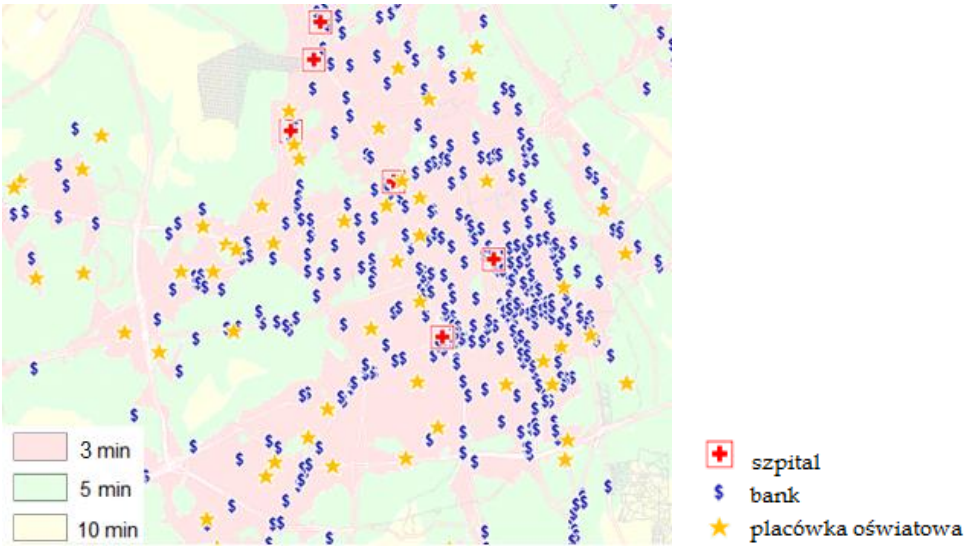

Fig. 4. Range of locations that can be accessed by car within 5, 10 and 15 minutes from the city center – visualization of successive time intervals.

The analysis was carried out based on information about the location of educational facilities, banks and hospitals in Warsaw. The analysis was performed in the MapInfo program with the ChronoMap add-on for optimizing transport routes. The applied tools support multi-objective optimization and the selection of individual weights for all criteria included in the analysis.
The above map presents the results of a multi-objective analysis, namely a zone in which specific service outlets can be reached within the timeframe defined by the user. The optimal location of a planned project is selected based on the defined and weighted variables as well as the defined localization criteria in urban and rural areas. It should be noted that large projects localized in cities strongly influence the functional urban area.
The boundaries of the analyzed area have to be correctly defined in the process of generating coverage zones for various types of projects. If the analyzed area is limited to its administrative boundaries, the results of the analysis could be highly unreliable or incorrect. For this reason, the analyzed area should be expanded to include the neighboring territories with a high growth potential. The above approach can be used to generate coverage zones of Warsaw-based shopping centers with the use of gravitation models.
The generalized Huff model is most frequently used in accessibility analyses. The Huff model had been originally designed for retail analyses, but it is also applied in urban planning and transport. The coverage of shopping centers can be determined based on their attractiveness and the distance (calculated along roads) between every residential building and every shopping center.
The results of the analysis indicate that the territorial coverage of shopping centers in the city includes mostly locations in their immediate vicinity. However, due to the absence of large retail facilities in suburban areas, the coverage of city centers extends well beyond the city's administrative boundaries.

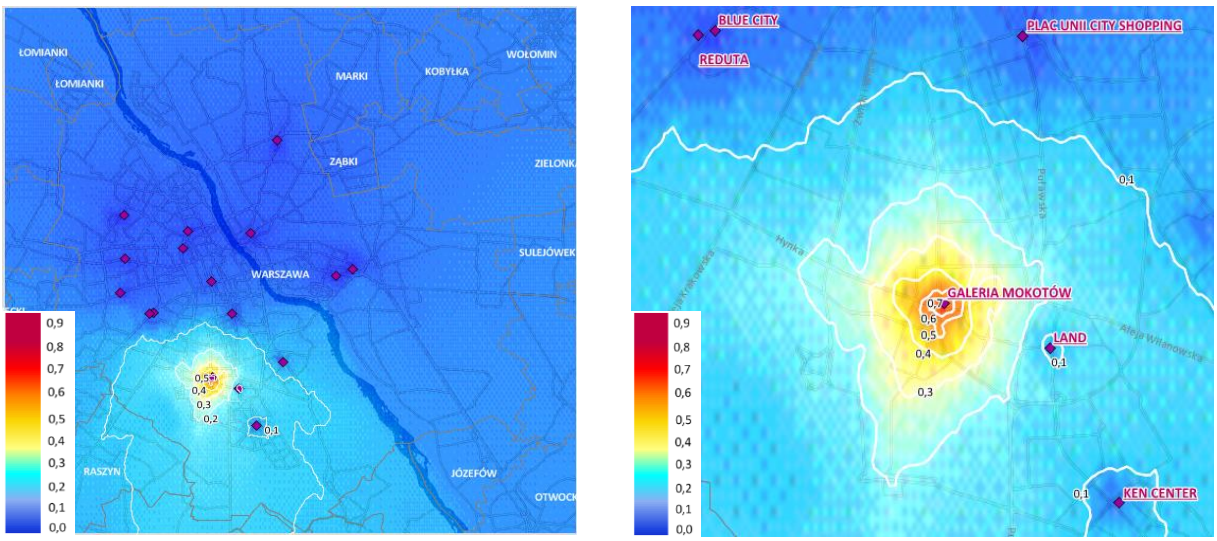

Fig. 5. Territorial coverage of Galeria Mokotów shopping center in Warsaw.

Conclusions and proposals

Spatial planning in urban and rural areas should contribute to economic growth. When spatial development in one area occurs at the expense of the neighboring municipalities, usually rural, the affected areas should also experience an improvement in the standard of living. Measures aiming to improve the standard of living in rural areas should also preserve the characteristic features of rural life, namely low population density, low economic activity rate and lower anthropogenic pressure.

Space is characterized by unique attributes, including resistance, limitedness and variation, therefore, spatial planning has to be rational and based on the principles of sustainable development. Spatial planning is a process of selecting the optimal functions for the existing space. Socioeconomic growth in urbanized space increases the demand for auxiliary services, which implies that new services have to be optimally localized in space. Local conditions have to be surveyed, and the most appropriate solutions have to be proposed in planning documents. Economic growth often leads to uncontrolled urban sprawl, both in metropolitan areas and in peripheral regions. The aim of spatial planning is to coordinate all types of activities, including economic, infrastructure development, services and the job market. In this context, spatial accessibility, which often denotes transport accessibility, is a very important criterion. Rational planning measures should also forecast changes and the demand for social infrastructure, housing and services to guarantee that the needs of the local community are adequately met. Multi-objective analyses deliver valuable information for spatial planning. A wide variety of analytical tools can be deployed to acquire and process public data and research data. The results of multi-objective analyses support the selection of the optimal planning variants.

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