Summary. Conducting analyses with the use of GIS tools in geography of transport enables to cut costs, optimize variants of new route solution (e.g. bypassing terrain barriers), create road traffic control systems, crisis management, work out the optimum travel route in terms of money or time.

The aim of this article is to present possibilities of using the functions of the Network Analyst tool in geography of transport.

Keywords: GIS, network analysis, geography of transport

ANALIZY SIECIOWE W GEOGRAFII TRANSPORTU

1. Introduction

Geography of communication is a part of economic geography which, in conjunction with the general and regional distribution of production against the background of the natural environment, deals with:
• development and distribution of the network as well as other elements of transport and communications infrastructure;
• development, distribution and range of activity of different communications branches.

The notion of transportation consists of two elements: transport and communications. Transport is part of the production process in which cargo and passengers are moved from one place to another [3]. It is, therefore a field closely connected with space and the core of its activity consists in covering it. This is why the geographic approach to the topic of transport is particularly purposeful [22].

Geographic Information Systems (GIS) allow not only to collect and share spatial data and attributes connected with them but also, most importantly, to process them [19, 24]. Due to analysis of collected information one may understand some regularities in the spatial distribution of different phenomena and their correlations, which facilitates decision-making processes. Using them one may not only follow events and human activity but also their spatial distribution [19].

Network analyzes allow you to conduct research that is of interest to traffic engineering. Examples include the choice of public transport [2], the impact of local bandwidth constraints on availability [14], use of traffic analysis in marketing analysis of transport projects [16], identification of areas of the lowest level of public transport [4], the influence of the factories of the functionality of the city on the shipment of transportation in the travel [15].

GIS systems may be used in geography of transport for instance to monitor the development of transport on a regional and global scale as well as to assess conflicts which accompany the process of modelling its network. Examples of its use in the discussed research include: impact of construction of new roads and railways on the increase in accessibility, delineating isochrones surface in travel cost models, analysis of carriage and travels, planning of the course of roads and distribution of nodes, registration of car accidents [25, 29, 30, 31]. Conducting analyses with the use of GIS tools enables to cut costs, optimize variants of new route solution (e.g. bypassing terrain barriers), create road traffic control systems, crisis management [8], work out the optimum travel route in terms of money or time [19].

In turn network is a set of interrelated objects: lines (edges) representing axes of roads and streets as well as points (nodes) representing towns on a smaller scale and junctions on a larger one. Traffic takes place along edges (roads, streets) whereas nodes, which allow traffic flow between different edges, can be found on the junction of two or more roads. Naturally, to be able to conduct analysis along the network it is necessary to have an appropriately constructed database which includes information about costs (resistance) of traffic along the network sections, whether the section is two-way or one-way as well as some appropriate tools [10, 11].
OpenStreetMap is one of the most popular free databases which may be used to conduct research into geography of transport in GIS (with the use of Network Analyst). This is a community project aimed at creating an editable map of the world available to everyone [11, 17]. It was launched in 2004 by Steve Coast from the University College of London. From the very beginning of its existence, emphasis has been laid on the road network. Roads were introduced into the database in the linear form. Besides this, the database gives access to information on road category, permissible speed, bridges, tunnels, etc. Additionally, more information may be attached in the form of tags which include information on the type and quality of road surface, the number of lanes, etc. [13].

Only on the basis of this type of data does the Network Analyst work in the GIS software. These analyses may be conducted in a number of ways. The function of finding the optimum route between two points is most commonly used. Apart from this, one may also use other options: New Service Area or MakeODCostsMatrix. New Service Area marks zones consisting of sections of streets which are closer to the selected point than any other point as far as the distance, time or costs are concerned in accordance with the Dijkstra’s algorithm. In this way a set of all lines (or a polygon comprising these lines) is established and it forms paths emerging from the central point, whose aggregate resistance measured from the central point along these paths will not exceed the adopted value. In turn, MakeODCostsMatrix searches for a path along the network from many origins to many destinations simultaneously [12].

Besides that, Network Analysis also offers the following functions: New Vehicle Routing Problem, Make Location Allocation Analysis Layer or New Closest Facility.

The aim of this article is to present possibilities of using the functions of the Network Analyst tool in geography of transport.

2. Selected possibilities of using network analysis

2.1. New Vehicle Routing Problem as urban public transport optimization tool

In order to conduct research aimed at boosting the effectiveness of public transport the researcher should have access to data on the distribution of the given region’s population (together with its such basic features as age), the course of individual elements of the area’s transport network and the distribution of stops. In this case the first step of the analysis consists in constructing a set of network data on the basis of the linear layer which will illustrate the area’s transport network. It is necessary to configure all transport modes if it is assumed that transport is intermodal and combines, for instance, footpaths, bus transport and tram...
network. Each of them points to the way in which displacement takes place within this transport mode using numerical attributes expressing length (physical, temporal) of the section and logical attributes, i.e. one-way roads or exclusion from traffic. Combining many networks into one network will allow to conduct door to door analyses. Target analysis of public transport courses should be preceded by analysis of stop distribution validity and their potential load. New target research is possible upon establishing the final list of points and giving them attributes specifying the number of potential passengers (fig. 1).

![Fig. 1. ArcMap programme with running New Vehicle Routing Problem tool][9]

Rys. 1. Program ArcMap z uruchomionym narzędziem New Vehicle Ruting Problem

Its first stage consists in loading all the necessary analysis elements. As Vehicle Routing Problem is dedicated to analysis of logistics operations which tend to be based on management of a fleet of vehicles in order to handle services, the terminology used in the analysis fails, at first glance, to conform to public transport management. Yet when individual categories of facilities are translated into those functioning in the public transport system, they seem to exhaust the list of necessary facilities. Therefore Orders should be identified with stops. Each of them may became characterized by many properties which differentiate the effectiveness of servicing individual points. One example of this may be time of servicing the stop, which the transport mode stays in the given point so that passengers can get on or off the vehicle. It may assume a constant value or be a function of the number of potential passengers.
Network analyses in geography of transport

Load Stop Wizard also enables to show the time scope in which the given stop must be serviced by the means of transport. This allows to account for changes in the demand for transport and include e.g. rush hours. Spatial differentiation of individual time scopes may correspond to daily changes in the load in the directions of passenger transport from places of work and education to their places of residence. Loading locations of stops makes it also possible to determine the acceptable transport mode delay time to the given point. Among about a dozen of available characteristics of each loaded stop it is worth paying attention to variables describing the number of potential passengers which should be serviced on the given stop by means of public transport.

Depots, in turn, should be identified with transfer nodes in which modal displacements take place. Each of these may also be defined by the time scope in which means of transport should reach it. While planning the service of concrete traffic generators (e.g. public utility facilities, mass events) Depots may be treated as these objects. Routes reflect individual public transport lines. It is an element of analysis which is definitely the most extended one as far as attributes are concerned. For each line one should determine both the starting point and the destination between which public transport modes will travel. The choice should be made from a set of previously defined nodes.

While designing the transfer system it is most precious to be able to define the waiting time scope of vehicles of the given line in the concrete transfer node. Analysis, therefore, accounts for the time between arrival of the means of transport and its departure to the subsequent terminus. The following two variables refer to the time scope within which the first and last service of the given line may take place. This function seems particularly useful when there is more than one organization form of public transport on the given area. A good example is a system based on may transfer nodes during the day and the night where all lines meet in one central transfer node. Smooth transition from one system to another excludes drops in accessibility levels in the time scope when the two systems overlap.

Characteristics of individual lines also takes into account the capacity of public transport vehicles. This allows to differentiate vehicles moving in the network considering the time of day and consequent changes in traffic intensity and demand for transport services or the functional and spatial structure of the area which is serviced by the given line. Different transport needs can be found on areas dominated by detached houses and different ones on areas of dense downtown development or districts with blocks of flats. Determining the vehicle’s capacity will translate directly into the frequency of connections if servicing potential passengers becomes the system’s priority.

Vehicle Routing Problem also allows to account for the cost analysis. Movement of vehicles on the given line may be encumbered with two types of costs just as it happens in the
economic reality: fixed and variable costs depending on the time of work and/or covered distance by the given vehicle. Naturally cost may be understood directly in the economic sense but also as any variable whose increment accompanying accomplishment of services may be of interest for the researcher. Examples include different types of environmental costs connected with mobility [9].

Border values to which continuous work is allowed on the given line comprise the last group of important variables which refer to the functioning of individual lines. These variables allow to account for, among other things, safety principles connected with operation of vehicles or maximum time of work of drivers. The first variable permits to reduce the number of stopping places of public transport vehicles. The following three allow to establish the value of time or distance not to be exceeded while planning operation work of transport modes [21].

The aforementioned facilities represent essential elements for conducting VRP analysis. Network analyses determining vehicle routes allow, however, to account for a considerably larger range of variables. As drivers of public transport vehicles may work only for a strictly defined amount of time without an adequately long break, it is advisable to define Breaks while optimizing the functioning of public transport with the use of Vehicle Routing Problem. Besides the breaks which vehicle drivers are eligible for, it is also possible to determine, among other things, the maximum working time between breaks and the non-extendable accumulated amount of time which the given driver has spent at work, after which there must be a break. The tool makes it possible to determine in a logical way (true/false) either the time spent on a break at work is to be included in the driver’s paid hours or not. If the designed public transport system assumes the zone variant where individual lines are dedicated to the given areas (districts, suburbs) isolated from a larger area, then Route Zones should be used. They allow to determine the boundaries of an area within which the given line will operate. The programme’s other optional settings also include Route Seed Points, Route Renewals, Specialties and Order Pairs yet they are variables which do not need to be accounted for in the research into public transport.

Depot Visits are the last element present in Network Analyst Window which is characteristic of the VRP tool. This element, however, tends to gain in value only after some simulations are conducted. It is, therefore, one of the properties characterizing the obtained solution to public transport vehicle routing problem (fig. 2). The variable provides information on the frequency of connections on the given line which, depending on the parameters adopted, is necessary to cater for the potential passengers or possible to be accomplished with time restrictions of the driver’s working hours or with the length of the concrete line [9].
Fig. 2. Analysis results of Vehicle Routing Problem for night public transport system in Łódź

Rys. 2. Wyniki analizy Vehicle Routing Problem dla łódzkiego systemu zbiorowego transportu nocnego

After determining all the variables which are to be included in public transport modelling on the given area it is also necessary to define the properties of the thematic layer. Only two tabs require special attention in the case of the VRP tool. These are Analysis Settings and Advanced Settings. In the first one it must be indicated which time and distance units will be used in all analyses, whether the designed solutions are to refer to the given time moment during the day or week and what type of restrictions in traffic organization concern drivers of public transport vehicles.

It is also worth mentioning Capacity Count, which deals with the number of elements to be treated as the subject of transport in the analysis. Taking into account that public transport focuses exclusively on passenger transport, the default value should remain 1. In advanced settings it is necessary to determine the weight (low/medium/high) for violating time window and exceeding transit time. The higher the preference for visit time windows, the greater priority will be given to solutions which minimize violating time windows at the expense of increasing the result’s total cost. In turn, the higher the preference for minimizing violation of transit time windows, the greater priority will be given to solutions with shorter transit time between a pair or orders at the expense of increasing the result’s total cost.
Dispatchers in charge of traffic operations tend to use their own experience and intuition while allocating the available means of transport to the scheduled lines. Dispatchers are often unable to specify the optimum or close to optimum solution as a result of the combinatorial nature of the problem. The main aim of public transport operators should be, therefore, to increase the number of passengers who trust public transport. The proposed method of allocating available transport modes on bus routes ensures minimization of the total waiting time, bearing in mind at the same time the number of passengers who used the service.

2.2. New Service Area as a tool to assess the effectiveness of fire brigade units

Tasks of volunteer fire departments (OSP) result from the Act as of 24 August 1991 on fire protection [32]. They accomplish tasks for the benefit of civil protection, fire protection and rescue services, but they also take preventive action on a broad scale aimed mainly at young people. The main aims and tasks of volunteer fire departments resulting from their charters include activities aimed at fire prevention, participation in rescue missions conducted in the event of fires, other dangerous events and natural disasters as well as notification of the population about the existing hazards [27].

The State Fire Service and its volunteer department are the core of the National Fire and Rescue System (KSRG). Its aim is to standardize rescue activities undertaken in situations which pose a threat to life, health, property or the natural environment [34]. Arrival time of fire service units to the place of incident has a direct impact on rescuing human health and life as well as the effectiveness of rescue operations [20]. In accordance with the Minister of Internal Affairs and Administration Regulation as of 18 February 2011 all entities located in the town, commune or district included in the National Fire and Rescue System (KSRG) accomplish basic rescue operations within their area defined by arrival time from 8 to 15 minutes [5, 6]. This is why it is so important to conduct adequate analyses so as to localize fire service units and choose the “shortest” (in terms of time) access roads to the place of incident. Only then is it possible to provide casualties with assistance.

In order to conduct analyses property with Network Analyst firstly fire service units should be identified on the given area and they will serve as input facilities. In addition, it is necessary to have access to the road network for the given area which may be obtained from the OSM resources. If isochrones of 0-8 and 8-15 minutes are to be generated, first a database must be appropriately prepared. In the case of a database obtained from the OSM resources, it is also necessary to fill in the missing tags. Columns should be added in the attribute table, i.e. length (in metres), speed (calculated from km/hour to m/minute) and time (in minutes), (fig. 3).
Network analyses in geography of transport

All necessary calculations should be made on this basis. Subsequently, one has to construct a network consisting of nodes and segments (fig. 4).

Fig. 3. Adequately prepared in ArcMap attribute table for road layer to be used in Network Analyst

Rys. 3. Odpowiednio zbudowana w ArcMap tabela atrybutów dla warstwy drogi – do wykorzystania w Network Analyst

Fig. 4. A network composed of nodes and segments for the commune of Zapolice with the use of OSM database [7]

Rys. 4. Sieć złożona z węzłów i segmentów dla gminy Zapolice przy wykorzystaniu bazy OSM
In the subsequent stage it is necessary to select New Service Area, a tool for network analysis, and load the location of fire service units. After meeting these conditions it is necessary to specify the properties of the thematic layer. Only two tabs require special attention in the case of the New Service Area tool. These include Analysis Settings and Polygon Generation. In the first one it is necessary to specify in which time units all analyses are to be conducted (in this case these should be the brackets of 0-8 and 8-15 minutes), whether the designed solution is supposed to concern any concrete time moment during the day or week and what type of restrictions in traffic organization concern drivers of public transport vehicles. As for settings in reference to ”generating polygons” it must be determined if isochrones should be in the form of discs or rings (here rings should be selected) and how they should be constructed (there are three options available: overlapping, non-overlapping and connected according to their border value – the right option should be selected depending if these analyses are to refer to individual fire service units or to their total service area). In the end, after selecting the Solve option available on the Network Analyst toolbar, we obtain generated isochrones of 0-8 minutes and 8-15 minutes from fire service units. Knowing place of potential interventions of these units on the given area it is possible to specify in what time they are capable of reaching the place of the incident and, consequently, if they are appropriately located (fig. 5).

Conducting this type of research is of utmost importance as it may contribute to better management of fire service units (or the police) but also to appropriate location of new facilities so as to ensure access to places of potential intervention in the time which allows to save human life [5, 6, 33].

2.3. New Service Area as a tool for optimum distribution of Łódź Agglomeration Railway (ŁKA) stops with regard to accessibility to places of residence of potential passengers and the Local Public Transport stops

The function New Service Area may be also used to determine theoretical stop locations, in this case of the Łódź Agglomeration Railway (ŁKA), so that they meet the optimum accessibility requirements for potential passengers. It must be explained here that this is not a concept on the basis of which real location of stops could be considered (fig. 6).
A list of factors which should be taken into account while localizing new point railway infrastructure is so vast and diversified (including technical, technological and demand factors) that considering the indicated proposals to be binding would be downright irresponsible. They
M. Borowska-Stefańska, S. Wiśniewski

Illustrate to what extent the existing distribution compares to the optimum one considering the demand for transport services. To achieve some results in this respect it is necessary first to draw points at a distance of 50 metres from one another along the whole course of the railway network within the boundaries of Łódź, illustrating the potential distribution of Łódź Agglomeration Railway stops. This distance was established arbitrarily so that it allows, on the one hand, to conduct a detailed analysis and, on the other, makes the analysis possible with regard to the computing power of the tools used. Subsequently, access time on foot, by individual car transport and local public transport should be specified for every generated point (fig. 7).

Accumulating the obtained results will allow to select these 12 locations which are characterized by the lowest costs in the form of total access time by each form of transport.

To define accessibility to Łódź stops of Agglomeration Railway it was necessary to include into research data which refer to the distribution of stops of Łódź Agglomeration Railway, distribution of stops serviced by local public transport, timetables of local public
Network analyses in geography of transport

transport vehicles, distribution of the population and the course of the city’s transport infrastructure network.

Fig. 7. Time competitiveness of local public transport in Łódź as compared to theoretical travel time by individual car transport
Rys. 7. Konkurencyjność czasowa lokalnego transportu zbiorowego w Łodzi względem teoretycznego czasu przejazdu indywidualnym transportem samochodowym

From the moment of launching Łódź Agglomeration Railway public transport connections have been provided on the area of Łódź by three main means of transport: bus, tram and train. After drawing lines connecting points of identical access time to Łódź Agglomeration Railway stops it was possible to construct polygons corresponding to the city’s areas characterized by different time accessibility levels. Then the surface of the city’s development was calculated in each polygon and it was determined what surface of Łódź is covered by different accessibility levels. This part of the analysis is aimed at showing how well the distribution of Łódź Agglomeration Railway stops matches the distribution of places of residence, work or education of potential passengers.

Also stops of local public transport were calculated in individual polygons of access time to Łódź Agglomeration Railway stops. Naturally, in this approach travel time between a
Łódź Agglomeration Railway stop and a Local Public Transport was adopted in accordance with the timetable of local carriers.

2.4. New Closest Facility as a tool to search for the closest evacuation places from flood-prone areas

Evacuation consists in displacing of people outside a (potentially) flood-prone area before there is direct contact of man with “water” and remaining in “safe” locations until necessary [18, 23]. Its success depends on many factors, such as warning time, reaction time, dissemination of information and instruction on how to act during the evacuation, escape routes, possibility of travelling on roads etc. [1, 26]. Using one function available in Network Analysis, namely New Closest Facility, it is possible to delineate the closest public utility facilities to which people should evacuate.

The first stage of the analysis consists in preparing the database in an appropriate way: in this case both the information on facilities located within flood-prone areas from which evacuation is necessary as well as public utility buildings where people may stay in the event of a flood hazard. Subsequently, as in other cases it is necessary to have an adequately developed network which includes both nodes and segments and possesses all necessary attributes, i.e. speed, time and length. In the following stage one should select the tool for Network Analysis, New Closest Facility, and load both the location of buildings (their centroids) from which evacuation takes place and those to which people may go to. After meeting the aforementioned criteria it is necessary to determine the properties of the thematic layer. In this case only one tag requires special attention, namely Analysis Settings. One should define in it which units will be used for all analyses (length or time), whether the designed solution should concern the given time moment during the day or week, what restrictions in traffic organization concern vehicle drivers, how many places of evacuation should be searched (whether only one facility closest in terms of time or distance, or a larger number of facilities). In the end it must be checked if all facilities are properly located in the network and analyses can be launched. Their effect is presented in Fig. 8.

Using this tool enables to indicate the closest evacuation facilities, which has a huge impact in flood protection for those who organize evacuation. Furthermore, searching a number of facilities to which access time is the shortest will allow to take into consideration also their potential load. Due to this it is possible to avoid a situation when one facility is excessively “overloaded” whereas another one is not used at all.
Fig. 8. The use of New Closest Facilities to search the closest evacuation places from flood-prone areas

Rys. 8. Wykorzystanie narzędzia New Closest Facilities do wyszukiwania najbliższych miejsc ewakuacji z obiektów zagrożonych powodziami

3. Conclusions

As it is shown by the above examples, functions available in the Network Analyst tag may be widely used in transport research or any other research where space plays an important role. These tools, on the one hand, allow to manage, e.g. public transport in towns and cities in more effectively way, but also adjust transport capacities in units responsible for saving human life. This is why these solutions should be implemented in all institutions which deal with transport issues. Naturally, it would not be possible to use these functions if there were no (also free as it happens more and more often) databases. In these concrete examples OpenStreetMap turned out to be the most important one. Even though it does not have all the at-
tributes necessary to transform it into an adequate network of attributes, it can be easily adopted for this purpose.

A very wide tool set of GIS programmes allows to analyze each element comprising transport systems. This can be achieved both with use of universal tools to conduct spatial analyses and those dedicated to transport. The vector image of reality in which individual elements are presented by means of point, linear or surface elements is ideal for transferring individual real transport system elements to the analytical space of GIS programmes.

The presented tool obviously has a strong competitive edge in the software market. One example of competitive software is PTV Visum. In the field of transport network modeling, it can be used both for the analysis of individual transport systems as well as for collective transport and in integrated form. Despite the numerous add-ons in which the application is available, it is in the field of transport analysis, but geographically, it is a less intuitive tool. It is difficult to find classical tools in spatial analysis. ArcMap is a complete tool in this case.

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Omówienie

Systemy informacji geograficznej pozwalają nie tylko gromadzić i udostępniać dane przestrzenne oraz związane z nimi atrybuty, ale przede wszystkim je przetwarzać i wykorzystywać przy podejmowaniu decyzji, w tym o charakterze przestrzennym. Narzędzia GIS mogą zostać wykorzystane w geografii komunikacji, m.in. do monitorowania rozwoju transportu w skali regionalnej i globalnej, a także do oceny konfliktów towarzyszących modelowaniu jego sieci. Wykonywanie analiz przy użyciu narzędzi GIS w geografii transportu umożliwia obniżenie kosztów, optymalizację wariantów rozwiązań (np. ominięcie barier terenowych) nowych tras, tworzenie systemów kontroli ruchu drogowego, zarządzanie w sytuacjach kryzysowych, wyliczenie optymalnej trasy przejazdu pod względem finansowym czy czasowym. W tym celu przydatna jest znajomość narzędzia Network Analyst (oraz jego funkcji), a także umiejętność stworzenia, czy uzupełnienia bazy danych niezbędnej do budowy zestawu danych sieciowych. Za cel niniejszego artykułu przyjęto przedstawienie możliwości wykorzystania funkcji narzędzia Network Analyst w geografii transportu.

Adreses

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