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A GIS BASED NETWORK ANALYSIS FOR THE IDENTIFICATION OF SHORTEST ROUTE ACCESS TO EMERGENCY MEDICAL FACILITIES

Paul-Silviu NICOARĂ¹, Ionel HAIDU²

ABSTRACT:

Traffic emergencies represent events that pose a great threat for the life of individuals and the development of human societies. The frequency of road accidents is related to the behavior of people, density of people, behavior of the machines as well as the arrangement of the infrastructure. At any accident three different types of vehicles can respond: ordinary vehicles, ambulances and police or fire fighters. There is a great need for the response time to be as low as possible. This response time depends on the condition of the emergency response vehicle and the possible obstructions or prohibition along the road network. The present study is an attempt to model shortest path and closest facility problems in order for an ambulance to travel through a road network, by creating a system based on GIS technology and application on the city of Cluj-Napoca, Romania.

Key-words: Network analysis, Traffic emergencies, Dijkstra algorithm, Cluj-Napoca

1. INTRODUCTION

Emergencies due to road accidents are one of the types of anthropic problems that are represented by various situations: vehicle-vehicle collision, vehicle-pedestrian collision, vehicle-object collision. Other types of emergencies that can be represented on the network include sudden human health problems, like strokes, heart failure or people injured within inter-personal conflicts. The rate of occurrence is directly proportional to population density, the density of traffic, road conditions and drivers responsibility. Prior to the digital age finding the shortest path was done by the ambulance driver. He had to rely on a printed map as well as various situations like one-way streets, streets under repair, or other possible blockings along the network.

The present article refers to the city of Cluj-Napoca, located in central Transylvania at the coordinates 46°46' N, 23°36' E. The population is at 350 000 inhabitants, but it grows with 100 000 students and tourists, many of them having their own car, during the 10 month of the university year, so the streets are over crowded. In this city, the relief and hidrography have been the main features in the development of the transportation network. Along the river Someșul Mic, on the est-west direction, the main transportation axes are developed, for a length of approximately 15 km, doubled or tripled by secondary streets in the central area of the city.

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From the two lateral hills, 80 m taller than the Someșul Mic's stream bed, the one on the right having much clearer terraces, perpendicular roads travel down to the longitudinal axis of the city. The one-way street characteristic is highly important for Cluj-Napoca with a high number of currently assigned one-way streets, and a high number of one-way streets assigned in the last 6 years. A total number of 27 streets have had their entire, or part of their length, turned into one-way street. This measure was taken in order to make the traffic more fluid. The heavy traffic that a busy city like Cluj-Napoca has to endure, means that the road condition keeps deteriorating. This increases the chance of many light and serious accidents. The large number of students within the city, means a lot of young, inexperienced drivers, who are more prone to driving at a high speed, therefore being a greater threat.

A recent study consacrated to Cluj (Ivan and Haidu, 2012) has shown the fact that most road accidents have been produced during spring and autumn, at the intersection of main arteries and secondary streets. No matter where the accident happens, the ambulance must reach that place within a certain time period in order to save the life or to improve the situations of the injured. There is no standard minimum time to do this, but a maximum of 8 minutes is regarded as optimum response time. This is achievable in the city, given a medium speed of 40 km/h, but may not be, depending on the traffic. Traffic was not taken into consideration for the purpose of this paper. In Cluj-Napoca, the ambulance response vehicles are spread around the city, but at the same time are in quite a low number (**Fig. 1**).

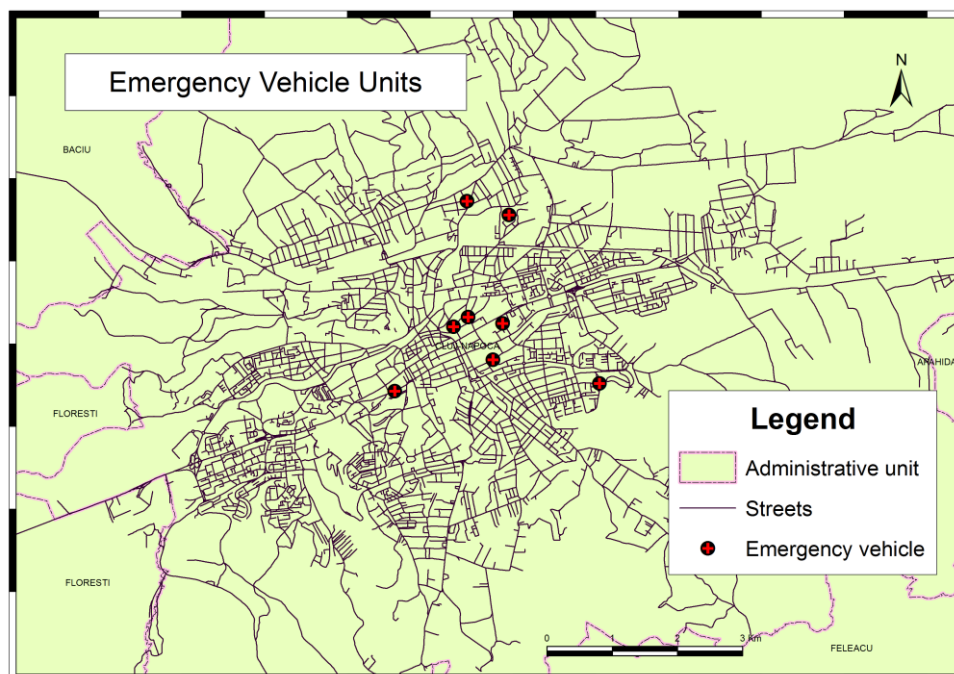


Fig.1 Medical Emergency Units in Cluj-Napoca.

The central emergency receiving hospital is localized near the city center. The road network is generally represented by small streets, therefore the one way prohibition can cause problems for new drivers and delays for the ambulance route. The architecture of the streets is made up of many streets that are not wide enough and many one-way streets. A unique feature is one two-way street that passes through the center, but where on one of the two ways only busses can go. This is where ambulance has a better chance of reaching a high speed. Another feature of the city is represented by the many pedestrian crossings and light stops, determining the ambulance to reduce speed.

A digital system is required that would offer the ambulance driver's as well to the emergency central office the optimal shortest route in order for fast and easy access to the site of the victim. During the last years, digital systems and spatial statistics applications are proven of great importance in public health system's management (Haidu et al. 2009). GIS products are becoming more solicited by the stake holders who regard phenomena, processes and actions in deployment at the earth spatial level.

2. METHODOLOGY AND WORKING STEPS

Today, in any busy city, the euclidian distance between two destinations is impossible to drive with the help of vehicles. Ever since the early years of pioneering of GIS, specific applications have been developed dedicated to oriented graphs and to the problem of search of minimal route through a city (Haidu I. and Haidu C., 1998). A wide search dedicated to this problem, like Lindeskov (2002) did, who created a system which correlates demographic data with the street network to generate an optimal positioning of the ambulances within a city. Hong and Ghani (2006) have created a statistical model for minimizing ambulance travel time in Penang Island. Pasha (2006) did an ambulance management system using GIS and GPS technology, on the city of Hyderabad (India). Ateş et al. (2011) have determined the optimal placement of ambulances within Istanbul, using statistic data regarding the density of accidents correlated with the number of people. Neis and Zielstra (2014) created an algorithm in order to represent a routing graph with cartographic application dedicated to people with disabilities.

There are multiple ways to calculate the shortest path from point A to point B. The one used by ArcGIS software is Dijkstra algorithm (ESRI, 2014; Magyari-Sáska, 2013; Kai et al, 2014). The algorithm searches for the distance from the starting point to every other vertex until it reaches the destination point and gives the shortest path possible. This makes possible for the rapid calculation of the most appropriate route as well as other functions like closest facility. The model is based on vector data. Vector lines are used to describe spatially distributed streets and points to represent locations along the network (hospitals, accidents, junctions). The object of the study is to model shortest paths along the street network as well as closest facility for ambulances to reach with the injured person. The coordinate system used in the analysis is Stereo 70, the national coordinate system of Romania.

The data used for this application are: the road network, digitized from topological maps; the location of the hospitals, recorded with a GPS device; and some locations of accidents, in order to test the feasibility of the network for shortest path and closest facility. One way streets have been assigned from news collected on the internet in the local

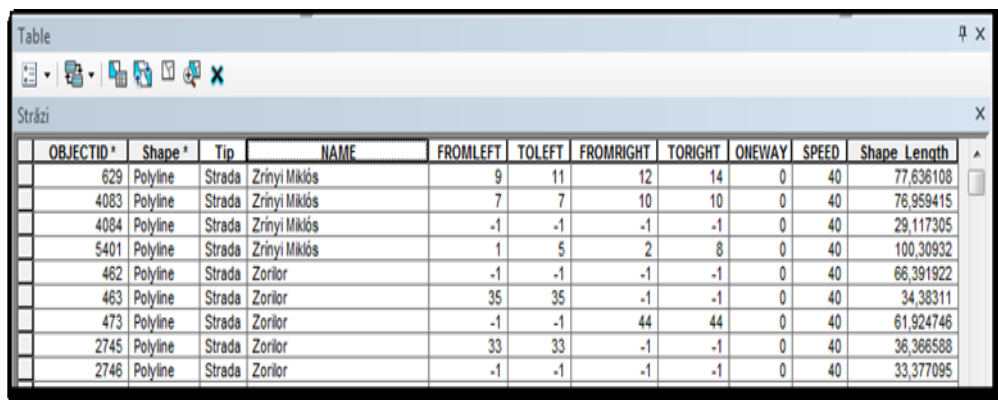
publications. A number of 695 one-way street segments from a total of 5420 street segments have been found and allocated with a proper value. A geodatabase within ArcGIS software was used for the storage of data. All the files were within one single dataset which ensured all had the same coordinate system, which was a vital condition for the operation to be correct.

The database allows for the modification of the layers by the users as a response to real life changes. The network dataset can then be rebuilt with the up-to-date information. The advantages of using a database include: centralized data, all within the same place; high speed for access and manipulation of data; high security, with measures to ensure the data is not damaged or corrupted; only one user can have the role of administrator of the database.

The data is managed using a database management system that allows description, manipulation, use, coherence and administration of data. The geodatabase (GDB) is specifically designed for spatial (geographical) information, which provides the ability to set topological rules, such as connectivity, to set a spatial domain of the attributes and to import and export from the geodatabase using a vector format. The advantage of using a file GDB are: operating system versatility (the files can be ported to Linux); creates encrypted files; allows a high quantity of data (up to 1 TB); uses more spatial index levels, making a search faster.

The vector data representing the streets had some important attributes (**Fig. 2**), like: name of the street, number on the street (from – to left side of the street, from – to right side of the street), oneway and shape length. The GPS points had the following attributes: name, latitude coordinate and longitude coordinate. The points taken with the GPS were initially in a geographic coordinate system and had to be converted to the working coordinate system (Stereo 70).

Setting one-way code was done with Visual Basic script that took into consideration the value of the one-way column as well as the digitization direction.



OBJECTID*	Shape*	Tip	NAME	FROMLEFT	TOLEFT	FROMRIGHT	TORIGHT	ONEWAY	SPEED	Shape Length
629	Polyline	Strada	Zrinyi Miklós	9	11	12	14	0	40	77,636108
4083	Polyline	Strada	Zrinyi Miklós	7	7	10	10	0	40	76,959415
4084	Polyline	Strada	Zrinyi Miklós	-1	-1	-1	-1	0	40	29,117305
5401	Polyline	Strada	Zrinyi Miklós	1	5	2	8	0	40	100,30932
462	Polyline	Strada	Zorilor	-1	-1	-1	-1	0	40	66,391922
463	Polyline	Strada	Zorilor	35	35	-1	-1	0	40	34,38311
473	Polyline	Strada	Zorilor	-1	-1	44	44	0	40	61,924746
2745	Polyline	Strada	Zorilor	33	33	-1	-1	0	40	36,366588
2746	Polyline	Strada	Zorilor	-1	-1	-1	-1	0	40	33,377095

Fig.2 Street layer attributes

3. RESULTS

Two analysis were done, one for finding the closest ambulance from the place of the accident and one for finding the shortest path to the Emergency Receiving Unit, which in Cluj-Napoca is the County Clinical Emergency Hospital. For the first analysis the locations of the ambulances were necessary as well as the location of the accident. The function used is Closest Facility from Network Analyst, which is an extension of the ArcGIS software. It is necessary to set the attributes of the analysis (**Fig. 3**) of the facilities, incidents and barriers, as well as travel type: from incident to facility or from facility to incident, allowed U-Turns at Junctions, restrictions (one way travel), distance units, number of facilities to find and attribute parameters: curb approach, cut-off length.

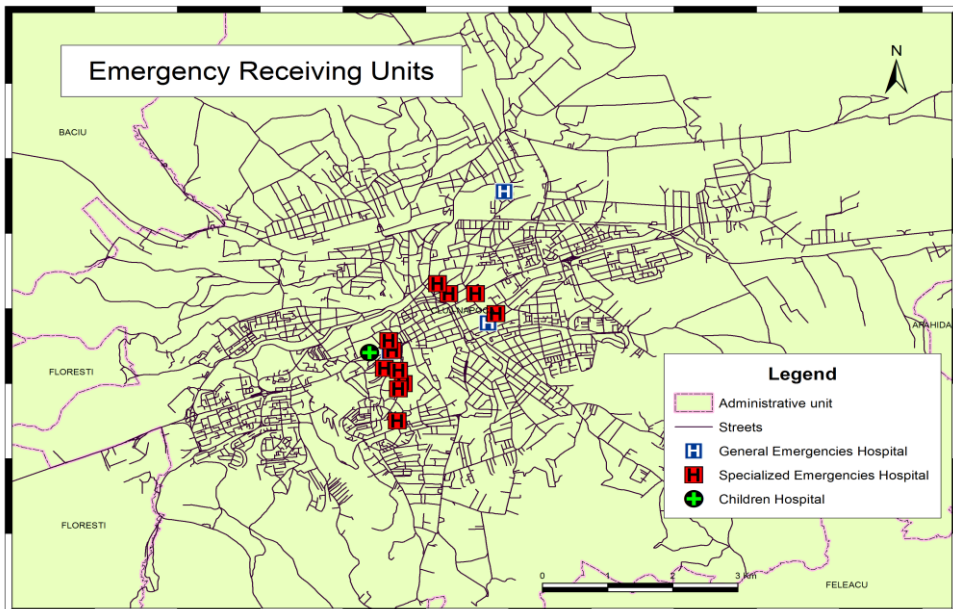


Fig. 3 Emergency Receiving Units in Cluj-Napoca.

The analysis is done by loading the location of the hospital taken with the GPS at the Facilities class of objects and by loading/placing the location of the accident at the Incidents class of object. By hitting the solve command on the Network Analyst Window, the shortest path to the closest hospital is generated (**Fig. 4**). After finding the closest ambulance and showing the shortest route to the accident a new closest facility should be made, to search for the nearest hospital. In the case of Cluj-Napoca, there is only one receiving emergency unit, so a shortest route is done, from the accident site to the County Clinical Emergency Hospital (**Fig. 5**). The injured person is then sent to the proper Emergency Receiving Unit, depending on the medical diagnosis. A new shortest route was done to fulfill this task.

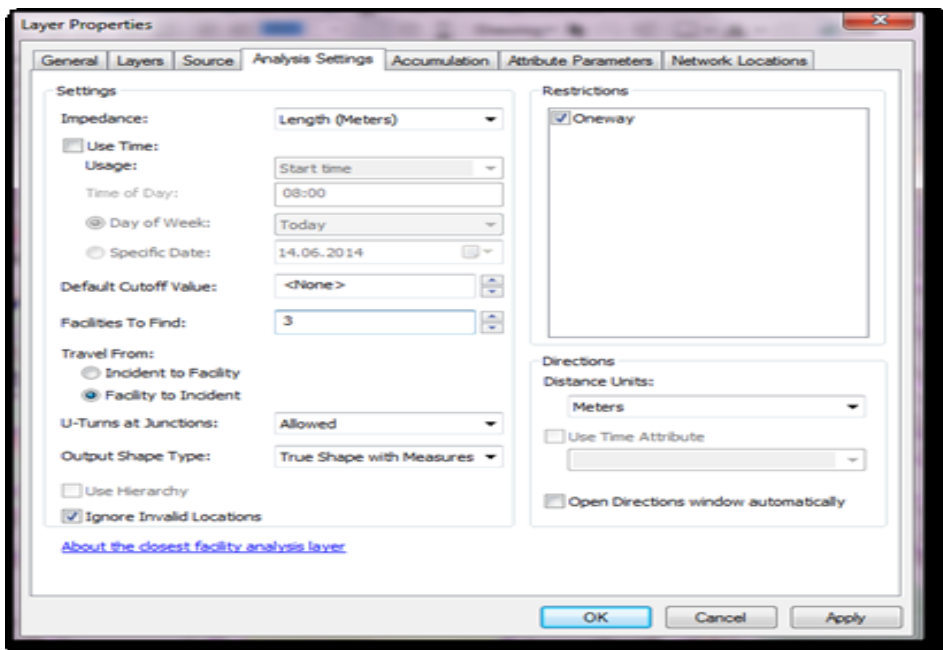


Fig. 4 Analysis Settings (Closest facility)

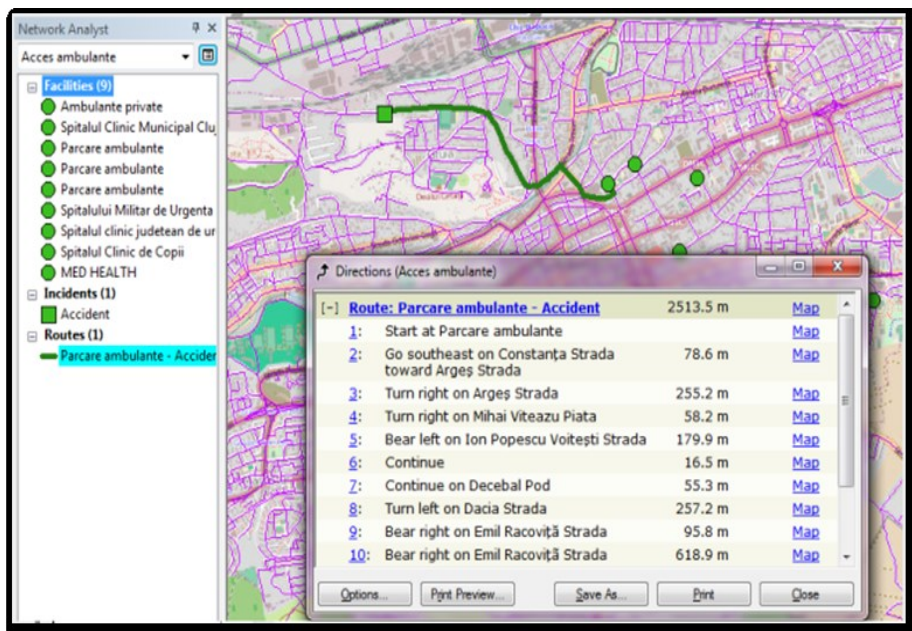


Fig. 5 Closest Facility to the accident with directions

4. CONCLUSIONS

This centralized system is the optimal solution to solving emergency vehicles through the city. It makes the job of the drivers much easier, and makes sure they get to the accident in less time than previous. The system could be improved by managing the position of ambulances in real time, using GPS. It can also be improved by taking into consideration the traffic flow. Data about traffic can be taken from the Romanian National Road and Highways Company. Another improvement can be the setting of road importance or road width. The system will therefore be forced to choose a different path, in order to maintain a certain road width.

A strict communication and information received from the city council about planned road modifications will mean that the system will always be up-to-date and the time to get to the accident will be minimal. The same system can be used for less important medical conditions, for the police department in order to fight crime as well as for fire fighters in case of fire emergencies.

The Dijkstra algorithm used in this paper by using the functions of ArcGIS software's Network Analyst extension have produced very good results. The closest facility function has shown the correct closest facility to the proposed accident site. The proposed accident site is found on the 127 Romulus Vuia street, at the following coordinates: 46° 46' 48.7554"N, 23° 34' 15.312" E. The closest facility found is an ambulance location on 7 Constanța street, found at the following coordinates: 46° 46' 29.1066" N, 23° 35' 42.147" E. The route proposed for the ambulance starts on Constanța street towards Argeș street, taking a right turn after 78,6 m. It continues on Argeș street up to the intersection with Mihai Viteazu square (255,2 m), where it takes a right turn. It then continues through the square and up on Ion Popescu Voinești street (179,9 m). After crossing the Decebal Bridge, it takes a left turn on Dacia street and after 257,2 m it reaches a intersection. It is necessary to cross this intersection and to take a slight right turn on Emil Racoviță street. After 714 m the ambulance reaches the famous 7 street intersection. It is now necessary to cross the intersection and to take a slight left turn on Romulus Vuia street and after 885 m on this street the ambulance will reach the accident point. The total distance is 2514,3 m and the total time it would take the ambulance to reach destination point is approximately 5 min, travelling at an average speed of 50 km/h. This is the same route as the route proposed by Google Maps.

This is an obvious solution for anyone who knows the current street configuration in the city. The alternative facility location (a private ambulance location on Karl Liebknecht square, at 46° 47' 30.012" N, 23° 35' 57.1596" E) would require a distance with 730 m longer. The third option means that an ambulance would start from 5 Paris street (46° 46' 29.7228" N, 23° 35' 55.9602" E) and travels along main street (21 Decembrie 1989), than takes a right turn on Ferdinand street and follows until it reaches the same intersection, on Horea street, as the first option, and takes a left turn on Emil Racovita.

This option means travelling 800 m more than the first, but it has the advantage of only following main streets on the route. This solution can be used with confidence by the emergency department from the County Emergency Hospital Cluj.

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