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COMPARATIVE ANALYSIS OF ALGORITHMS FOR CALCULATING ARRIVAL TIMES OF EMERGENCY VEHICLES

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Abstract

The problem discussed in this article covers the issue of the generation and computational complexity of an arrival time map of emergency vehicles (ambulances). Finding the optimal (fastest) route between two points is a complex and time-consuming task. Moreover, the discussed issues are identical to the problems faced by dispatchers from Malopolska Medical Emergency. Therefore, the aim was to develop algorithms to reduce time calculations, based on the reduction of their number only to the points where ambulances are able to reach within the specified time. There were compared three types of algorithms, taking into account their time and computational complexity. The result of the research was to identify algorithms, which depending on the adopted criteria allow to achieve optimal results.

ANALIZA PORÓWNAWCZA ALGORYTMÓW WYZNACZANIA CZASÓW DOJAZDÓW POJAZDÓW RATUNKOWYCH

Słowa kluczowe: GIS, analizy sieciowe, optymalizacja, obliczanie czasów dojazdu

Abstrakt

Problemem poruszanym w niniejszym artykule jest czas, w jakim obliczana jest kompletna mapa czasów dojazdów pojazdów ratunkowych (ambulansów) dla zadanej siatki. Znalezienie optymalnej (najszybszej) trasy między dwoma punktami jest problemem złożonym i czasochłonnym. Co więcej, poruszane zagadnienia wynikają z potrzeb i problemów, z którymi zmagają się dyspozytorzy Małopolskiego Ratownictwa Medycznego. Wobec tego, intencją autorów było opracowanie metod pozwalających na skrócenie czasu wykonywania obliczeń, bazując na redukcji ich liczby wyłącznie do punktów, do których ambulans jest w stanie dotrzeć w zadanym czasie. Porównano trzy typy algorytmów, uwzględniając ich złożoność czasową i obliczeniową. W rezultacie wskazano metody, które – w zależności od przyjętego kryterium – pozwalają osiągnąć optymalne wyniki.

1. INTRODUCTION

Geographic Information Systems (GIS) with network data structures are one of the most significant application areas of research in geographic information science. As is mentioned by Curtin (2007), a large network's analysis capabilities are the result of their strong theoretical basis in graph theory. Moreover, Fischer (2003) as well as (Bell, et al., 1997) proved that we might talk about a fully functional network model if the topology and connection between the subsequent feature elements is maintained. As additional elements of the model, he indicates the so-called flow characteristics of the network, expressed in the form of capacity constraints, choosing the right path, or cost function.

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So far, these network models are widely used in logistics, with particular emphasis on the problem of routing vehicles (ang. VRP – Vehicle Routing Problem) (Simić, 2012; Bernas et al., 2013). Transport accessibility maps (time accessibility maps) for selected locations are also worth mentioning, as has been shown in the literature (Cichocinski et al., 2012; Bielecka, 2010; Diller et al., 2014).

The issue raised in this article largely concerns the issue of network analysis, which allows the unambiguous and rapid calculation of a complete map of ambulance arrival times for an assumed grid. It should be noted that the authors developed the ambulance speed model using real data (Łukasik et al, 2016), so this work is a natural continuation of our research.

The primary problem is to find the optimal (fastest) route between two points. An additional criterion is to minimize the computational complexity and overhead time. This issue is known as the shortest path: instead of the length of the chosen route, the criterion is the travel time from the starting point to the end point. Of the algorithms that designate the route between two points (Aho et al., 2012; Kozieł, 2014), the most frequently used are those by Dijkstra (1959), Bellman-Ford (1958) and A* (Hart et al., 1986). The basic principle of the created system is a time map consisting of grid nodes, for which transit times are determined. The procedure for finding the shortest travel time is performed for each pair of grid points, taking into account the passage in both directions. This gives more than 250 million complex calculations, and thus, the same amount of stored values. The aim of this study was to optimize the calculations by only including points that the ambulance is able to reach within 60 minutes. Arrival times over 60 minutes are useless from the perspective of a medical emergency.

2. USED TOOLS

Transit time between start and end points was calculated using commercial GIS software (MapPoint 2013). The proposed network model allows points to be defined for which the time and cost of travel can be determined and the speed of each type of road can be defined. However, due to the huge number of calculations and dozens of machines available (cluster), it was decided that it would be necessary to implement an authorial system for mass calculations in a distributed environment. This system makes it possible to automate and scatter calculations and provides the ability to modify the velocity values used to calculate arrival times. The optimization algorithms are implemented in C # language.

3. THE COMPUTATION ALGORITHMS AND ITS OPTIMIZATION

The process of preparing for the calculations started with the design of grid nodes for which transit times were determined. To maintain sufficient accuracy of calculations, it was decided to use two types of density (250 m and 1 km) grids:

- for Małopolskie Voivodeship, except urban areas of more than 10 thousand residents,
- for cities with more than 10 thousand residents.

Locations containing hospital emergency departments (ED) were also added.

Based on historical data of Krakow Rescue Service, the average ambulance speeds for each type of road were calculated (Łukasik et al., 2016). These speeds were uploaded to the system, taking into account the mechanisms of calculation automation. These speeds were introduced to the system that calculates the route.

Initially, without considering the mechanisms of optimization, calculation of arrival times was performed between all points in the grid. Thus, the number of calculations was equal to the Cartesian product of the number of grid nodes. This method of calculation is extremely time-consuming and generates a large amount of mostly unnecessary data.

3.1. Description of optimization algorithms

To reduce the number of calculations, algorithms were implemented that could iteratively expand area calculations, while checking whether the obtained results are within the set time interval (60 minutes). Three approaches to expanding the area of calculations were used:

- the use of rings,
- the use of square areas,
- developing areas around only points that meet the time criterion.

In the first case, it is necessary to convert the distance in a straight line from the specified point to all the others, using the Haversine model (Robusto, 1957; Mwemezi et al., 2011). This gives the ability to see quickly which points are in the area of a circle with a radius of a predetermined size. With this information, it is easy to determine the initial calculation zone. Then, in each subsequent iteration, rings are formed with a stable center at the point for which the arrival time calculations are performed. In subsequent iterations, the external and internal radiuses are increased, but the difference between them is fixed at 1 km.

If the given number of iterations does not return a point that can be reached within a specified time interval, the algorithm check randomly selects points located on three consecutive calculation rings. If there are points that meet the time criterion, the calculation is continued.

In the second method, the rings were replaced by squares. This approach is very similar, but the algorithm operates solely on the coordinates of the grid points, rather than the distance between them in a straight line. The algorithm begins with a calculation of arrival time from the set of points that falls within a square with designated side length.

In subsequent iterations, further square areas are developed whose sides are increased by a constant step (2 kilometers). Calculations are carried out for the unprocessed points of the new, larger area. Moreover, similar to the ring method, if five consecutive iterations do not return a single point that meets the time criterion, randomly selected points of three consecutive potential areas are checked. If the results do not return locations achievable in a given time, calculations are halted; otherwise, they are continued.

The third approach is based on developing square areas only around locations that meet the time criterion. The algorithm used an adjacency matrix that holds indexes of points surrounding the relevant point of the grid. The first step of the algorithm calculates the arrival time for the initial square area and the identification of points forming its perimeter. The result of the first step is also an input for the next iteration, in which the points with a high probability of achieving positive results (travel time between a given starting point and a specified range of 60 minutes) are selected. For such selected positions, neighborhood areas are developed from which the repeated and previously calculated points are rejected. The table of designated points and arrival times are the basis for the next iteration. Subsequent iterations are performed until there are new locations that meet the time criterion.

4. RESULTS

For the randomly selected point, there is a graphically depicted output of each of the algorithms. In the following figures, various types of points are represented by colors:

- yellow – a point for which computations were performed,
- green – locations where travel time from the point subjected to calculations is less than or equal to 60 minutes (relevant calculations),
- red – locations where travel time from the point subjected to calculations is greater than 60 minutes (necessary calculations).

Figure 1 presents the method of expanding the calculation area with rings (Fig. 1).

Figure 2 contains the method of expanding the calculation area with squares (Fig. 2).

The figure 3 (Fig. 3) shows the method of expanding the calculation area only around promising points.

Statistics were prepared to check the effectiveness and correctness of the implemented algorithms. The experiments were conducted by setting arrival times for the province of Malopolska. The calculations were carried out in real time, and the attempt consists of 500 randomly selected points on the map. Efficiency is given in table 1. It is understood as reducing the number of unnecessary calculations and can be assessed based on the values in table 1.

Assuming an average number of calculations for a grid containing 15,867 points, the estimated number of calculations required to calculate a map were collected and are presented in Table 2.

Table 3 presents the average time for determining the points for which route calculation should be performed. However, this does not include the time taken to calculate the route itself.

In the case of the adopted optimization algorithms, the established margin for searching for successive points might be inappropriate. Therefore, a risk arises that some points will be completely ignored in the calculations and the result times will be incomplete. The optimization algorithm error, understood for each of the algorithms as

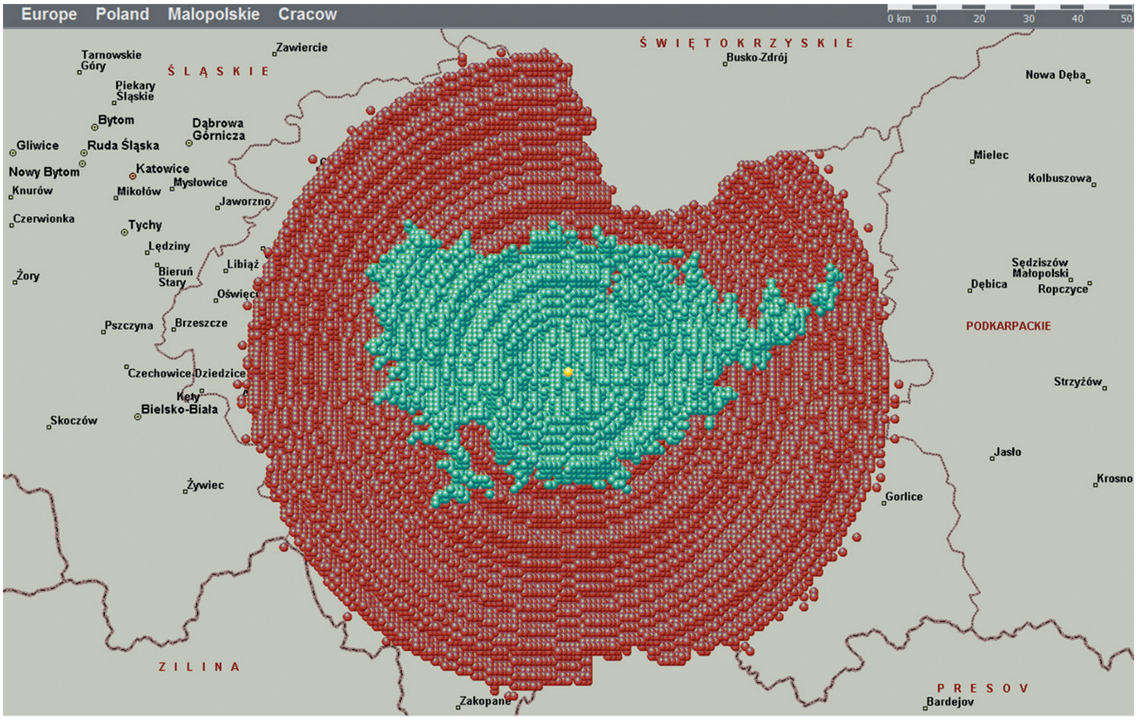

Fig. 1. The result of the method of expanding the calculation area with rings
Rys. 1. Wynik działania metody rozszerzającej obszar obliczeń pierścieniami

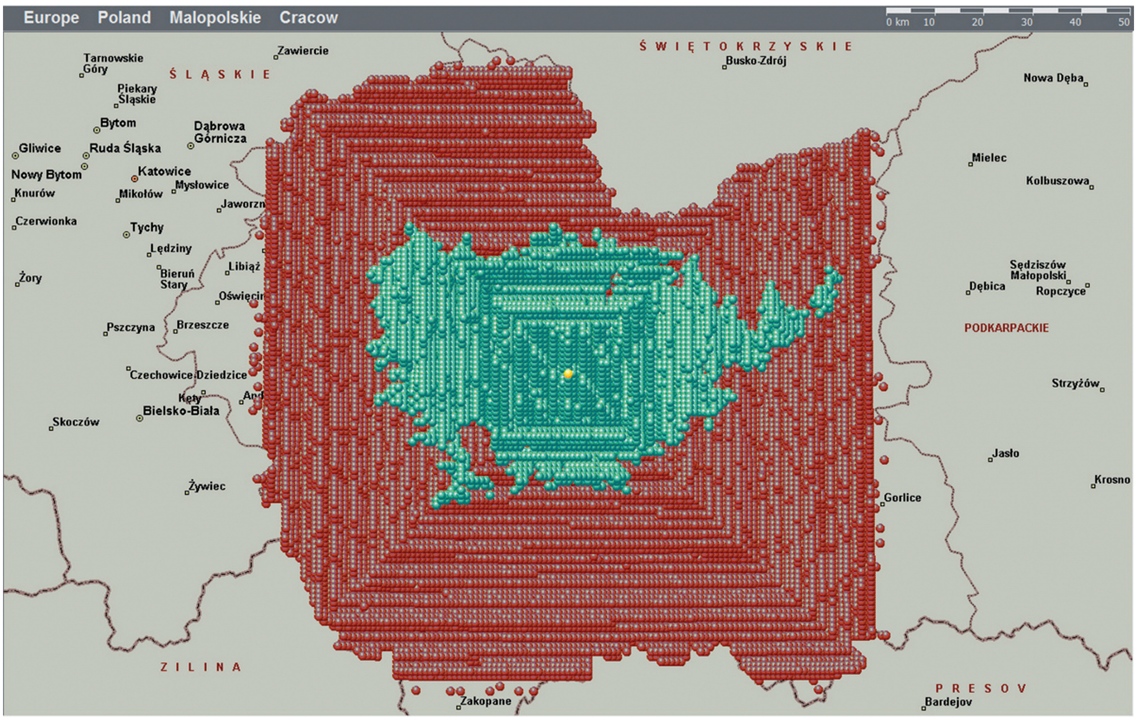

Fig. 2. The result of the method of expanding the calculation area with squares
Rys. 2. Wynik działania metody rozszerzającej obszar obliczeń obszarami kwadratowymi

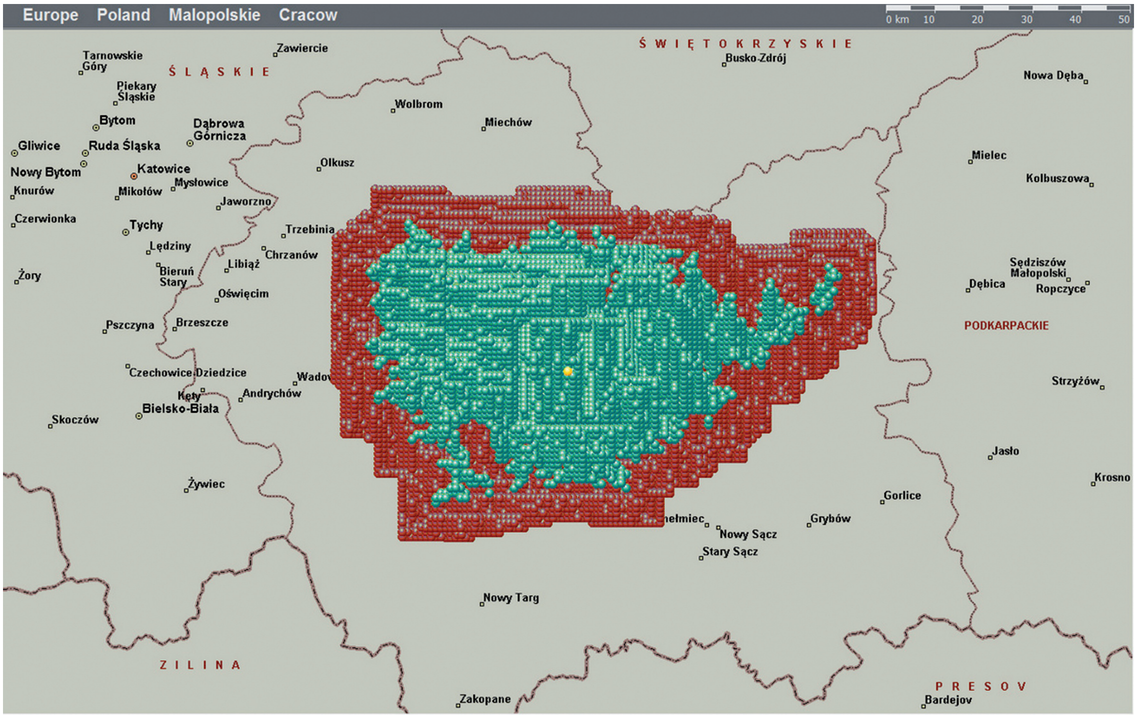

Fig. 3. The result of the method of expanding the calculation area only around promising points
Rys. 3. Wynik działania metody rozszerzającej obszar obliczeń tylko wokół rokujących punktów

Table 1. The effectiveness of optimization algorithms
Tabela 1. Skuteczność metod optymalizacji

	Rings method	Squares method	Promising points method
The avg. number of calculations	6,785	7,464	4,631
The avg. percentage of relevant calculations	38.70%	35.10%	53.80%
The avg. percentage of unnecessary calculations	61.30%	64.90%	46.20%

Table 2. The estimated total number of operations required to generate the arrival times map
Tabela 2. Szacowana liczba wszystkich operacji wymaganych do wyznaczenia mapy czasów dojazdów

	Without optimization	Rings method	Squares method	Promising points method
The number of calculations	251,761,689	107,657,595	118,431,288	73,480,077
The percentage of primary calculations		42.76%	47.04%	29.19%

Table 3. The average execution time of optimization algorithm for one point
Tabela 3. Średni czas wykonywania algorytmu optymalizacji dla jednego punktu

	Rings method	Squares method	Promising points method
Average time (sec.)	0.03	5.33	3.65

the ratio of the number of all relevant missed points to all the relevant points that should be designated, is less than one promil. The exact values are presented in table 4.

The results of these statistics depend primarily on the assumed calculations margin. Experiments were performed for all optimization algorithms based on the same test sample, assuming the calculation margin was 3, 5, and 7 km. The results of the rings method, squares method, and promising points method are shown in Tables 5, 6 and 7.

Table 4. The correctness of optimization algorithms
Tabela 4. Poprawność działania metod optymalizacji

	Rings method	Squares method	Promising points method
The percentage of points for which all relevant locations were found	93.61%	92.81%	89.82%
The ratio of missed relevant points to all relevant points	0.071‰	0.071‰	0.168‰

Table 5. The results of the rings method for different calculation margins
Tabela 5. Wyniki metody rozwijania obszarów obliczeń pierścieniami dla różnych marginesów obliczeń

	3 km margin	5 km margin	7 km margin
The average number of calculations	6,069	6,785	6,974
The percentage of relevant calculations	41.40%	38.70%	35.90%
The percentage of irrelevant calculations	58.60%	61.30%	64.10%
Error	0.3932‰	0.071‰	0‰

Table 6. The results of the squares method for different calculation margins
Tabela 6. Wyniki metody rozwijania obszarów obliczeń obszarami kwadratowymi dla różnych marginesów obliczeń

	3 km margin	5 km margin	7 km margin
The average number of calculations	6,687	7,464	7,665
The percentage of relevant calculations	38%	35,10%	32,70%
The percentage of irrelevant calculations	62%	64.90%	67.30%
Error	0.12‰	0.071‰	0‰

Table 7. The results of the promising points method for different calculation margins
Tabela 7. Wyniki metody rozwijania obszarów obliczeń tylko wokół rokujących punktów dla różnych marginesów obliczeń

	3 km margin	5 km margin	7 km margin
The average number of calculations	3,494	4,141	4,631
The percentage of relevant calculations	68.50%	60.30%	53.80%
The percentage of relevant calculations	31.50%	39.70%	46.20%
Error	1.049‰	0.544‰	0.168‰

5. SUMMARY

Based on the presented statistics, it can be seen that the promising points method reduces the number of unnecessary calculations of routes to the greatest extent. Nonetheless, it is not the best method if we consider as a key criterion the efficiency of finding all the relevant nodes, thus creating a complete map of arrival times. In this case, the best method that we could adopt is the rings method, for which the error of the algorithm is the smallest at only 0.071 ‰. The algorithm that expands the calculation area with the shape of a square is characterized by the worst result in terms of effectiveness and hence optimization. Taking into account that it has the same degree of error as the method using rings, the algorithm is unlikely to be used in practice.

An analysis of the two algorithms, i.e. the rings method (best for correctness of results) and the promising points method (most effective in reducing unnecessary routing calculations), we can compare them in terms of computation time. In terms of time, the rings method is definitely fastest. However, if we consider that (using the machines on which the calculations are performed) 1,000 routing operations between two points takes about two minutes, and the difference between the average route calculations for these two algorithms is 2,154, it turns out that the time taken to determine arrival time maps for each point will increase by circa 4 minutes and 20 seconds. In total, for 15,867 points, this will lengthen the calculation time by more than 38 hours, assuming continuous operation of the available computers. If the key criterion for a project is the correctness and accuracy of maps, the best choice of method is be the rings method. If, however, the time of map creation is crucial and acceptable accuracy error of the algorithm is greater than 0.168 ‰, then the algorithm that expands areas of computations only around promising points using an adjacency matrix should be used.

It is also worth considering modifying the margin calculations. According to tables 5 and 6, the rings and squares algorithms for a 7 km margin are not affected by any mistake. Additionally, for all points of the test sample, all relevant points on the map were found. Nonetheless, this unfortunately involves a large amount of route calculations, of which more than 65% are unnecessary.

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