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INFLUENCE OF DIFFERENT DISTANCE METRICS, ON EMERGENCY VEHICLES RELOCATION OPTIMIZATION PROCESS, BASED ON AUTOMATIC VEHICLE LOCATION DATA

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Abstract. *In the implementation of the emergency vehicle dwelling location optimization process, different approaches in definition of the distances between two locations are possible. The distances can be treated as Euclidian, road network routed or time distances. The main question is how the choice of different type of distances used affects the quality of the optimization solution. In this study, using the same data set and identical method, three different types of distances are used and the results are compared. For the purpose of comparison and evaluation of the quality of the obtained solutions, an innovative definition of a parameter named the saving ratio is proposed. On the basis of that parameter, quality of the obtained optimization solutions is quantified and estimated. In the previous works of the same authors, extensive algorithm to resolve the problem of p-median is designed. That algorithm, named GA-GISLAB, is used as a test bed optimization method. It performs relocation of vehicle resources in the road traffic based on the modified Genetic algorithm. Assessment of the impact of different types of distances to the quality of the optimization solution was performed using historical data from automatic vehicle location system.*

Key words: *Euclidian, routed and time distances, p-median problem, relocation of vehicles in the road traffic.*

1. PROBLEM DEFINITION

As part of comprehensive project in the field of spatial modeling based on GIS (Geographical Information System) and using the advanced AVL (Automatic Vehicle Location) component of the GPS/GPRS (Global Positioning System/General Packet Radio Service) tracking devices, emergency vehicle allocation and relocation optimization module GA-GISNIS was developed at the Department of Computer Science, Faculty of

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Electronic Engineering, University of Niš. In addition to theoretical considerations, a complete vehicle tracking solution was implemented for Emergency medical service in Niš, Serbia, as the main beneficiary.

For the purpose of resolving problems of emergency vehicles allocation and relocation, the distance between locations can be considered in three different ways. First is straight line (Euclidian distance), second is the length of the path taken along road network (routed distance) and third is the time needed to reach the one location starting from another (time distance). The aim of this paper is to evaluate impact of these different types of the distances on the quality of the optimization solution. The appropriate parameter had to be defined to assess the influence and estimate to what extent different type of used distance influences the optimal solution.

2. Mathematical Representation

The mathematical representation of the problem which is the subject of the research in this work is a classical problem of the location optimization. The problem to identify ***p***-facilities, to minimize distances, required to provide a service to ***n***-destinations, is well known as a **p-median** problem. According to the fact that this problem is classified as non-deterministic polynomial-time (NP) difficulty, required time and memory for obtaining solution is not known in advance. Contemporary meta-heuristic methods are used as a common approach to reach the semi-optimal solution. The generally adopted representation of p-median problem is given as following: find minimum of (1):

$$\sum_{i\in I}\sum_{j\in J}\omega_j d_{ij} y_{ij} \tag{1}$$

where ω_j is weighting factor of location j, while d_{ij} is an distance between location i of vehicle dwelling location and location j as one of the observed n service destinations.

This problem is well defined and probably represents one of the most often considered issues in the field of location optimization. Different approaches in solving this problem range from S. L. Hakimi [1], C. ReVelle and R. Swain [2], M. B. Teitz and P. Bart [3], P. J. Densham and G. Rushton [4], E. L. F. Senne and L. A. N. Lorena [5], P. Hansen and N. Mladenović [6], K. E. Rosing and C. S. ReVelle [7], to the contemporary meta-heuristic methods like Genetic algorithm, described in works of C. M. Hosage and M. F. Goodchild [8] and O. Alp, E. Erkut and Z. Drezner [9].

Emergency medical service and problems of the allocation and relocation of ambulances is also often considered as a domain specific application of this problem. Some of the most cited and comprehensive works are from P. Kolesar, W. Walker, J. Hausner [10], S. Budge, A. Ingolfsson, D. Zerom [11] and M. Reinthaler, B. Nowotny, F. Weichenmeier [12].

The well documented algorithm for resolving appropriate p-median problem, related to relocation of ambulance vehicles is described in details in the previous works of the authors of this paper [13], [14], [15]. The proposed algorithm is implemented in three independent phases: the first phase is extraction of vehicle destinations from the database which is an integral part of vehicle tracking system (AVL). Extraction is realized by executing series of SQL-queries defined by limited period of time in which fleet of vehicles is observed. Applied sequential analysis use several pre-defined criteria and we come to the set of ***n*** locations which represent destinations of individual ambulance vehicle interventions. We find that all these destinations are destinations of vehicle individual drives, in the observed period of the time. At the end of the first phase we construct ***n***x***n*** matrix of distances ***M(n, n)*** and introduce a weight factor. In ***i***-row and ***j***-column an individual matrix element d_{ij} is placed, and that element represents distance from the destination node ***i*** to the destination node ***j*** multiplied by ω_j **-** weight factor of node ***j***.

In the second stage of the algorithm we introduce ***p*** service locations as parking places in which we want to set ***p*** vehicles. The main goal is to shorten the total time required to handle users of service, placed into ***n*** destinations. The objective of the second phase is to get the initial solution as a starting point for the meta-heuristic procedure which will be executed in the final stage. Initial solution is obtained through direct calculations based on the 'greedy-adding-method' and 'node-substitution-procedure'. This phase is limited to 20 iterations. Between 20 candidates, we choose the best solution and move into phase three.

During phase three, modified Genetic algorithm is used and semi-optimal solution is delivered. The specific parameters of proposed Genetic algorithm ensure the rapid convergence and reduce risks of returning a local minimum as a final solution. The execution of the Genetic algorithm is limited to pre-defined number of generations, and for the purpose of this study we adopted a number of generations to be restricted to 100.

3. Practical Aspects and Method of Quality Assessment

As the result of the first phase of algorithm implemented in GA-GISLAB module, longitudinal and lateral geographical coordinates of ***n*** locations are delivered. These coordinates define locations of ambulances and users of emergency medical service during the observed time interval. Using these coordinates, it is possible to determine the distance between locations and get data required to populate the matrix of distances. The matrix can be populated in three ways:

I) Calculating the shortest distance as a straight line and it is then the Euclidian distance. Using this approach at a larger area, the curvature of the earth's surface had to be taken in consideration. But, for the area which is the subject of our interest, we can use approximate computations of Euclidian distance, between two points, defined as: ($\boldsymbol{x}_1$, $\boldsymbol{y}_1$) and ($\boldsymbol{x}_2$, $\boldsymbol{y}_2$), as follows:

```
function distance(x2, y2, x1, y1)
        Dim dlat, dlong
        dlat = Int(Abs(y2 - y1) * 0.111111)
        dlong = Int(Abs(x2 - x1) * 0.111111 * Cos(y2 * 0.000001))
        distance = Sqr((dlat * dlat) + (dlong * dlong))
end
```

where *dlat* and *dlong* represent differences of longitude and latitude components of coordinates, between two locations: ($\boldsymbol{x}_1$, $\boldsymbol{y}_1$) and ($\boldsymbol{x}_2$, $\boldsymbol{y}_2$).

II) Instead of the Euclidian distance between the two observed locations, it is possible to observe the distance as length of the path, taken along the existing road network. In this case, we are talking about routed distances, instead of Euclidian distances, between locations. For the purposes of research implemented in this work, routing is performed using the *Garmin Base Camp, Ver.4.3.4, 2008-2014 Garmin Ltd.* software, which allows tabular input of coordinates and delivers information about the route and the time. We used the road network defined in the map *City Navigator Europe NT 2014.3 Ver.17.30 NAVTEQ*. Calculating the routed distance, in practice, adds an extra step (as preprocessing phase) in preparation of input data for the second and third phase of the optimization algorithm.

III) The third method of populating the distance matrix, implies that we abandon the two dimensional plane of observing the geographical position of the locations, and shift into the time domain. Now, the distance between two points is defined as the time needed to reach assigned destination. Data related to the time distances are provided in the same manner as data obtained for purpose of the routed distances. We use the same software and the same map from *Garmin Ltd.*, as we used in case of the routed distances.

To estimate the quality of the offered allocation solution and the redeployment of the vehicles, we had to define a separate parameter to quantify the quality of the optimization solution. We need some kind of efficiency coefficient, to compare costs before and after introducing process of the optimization.

We start with the situation as there is no optimization involved, and it is our initial state. If the ambulances each time start moving from the central garage and visit all $\boldsymbol{n}$ destinations, we deal with total cost $\boldsymbol{C}_{\text{tot}}$. If we apply achieved semi optimal solution and cover all $\boldsymbol{n}$ destinations staring from the proposed optimal $\boldsymbol{p}$ parking places we lowered total distance and total cost is now $\boldsymbol{C}_{\text{opt}}$. Introduced efficiency coefficient had to exclude the direct impact of the absolute values to its size. So, we proposed following definition of "saving ratio" as relative value, described in (2):

$$\boldsymbol{S}_{\text{r}} = \boldsymbol{C}_{\text{opt}}/\boldsymbol{C}_{\text{tot}} * 100\ (\%) \tag{2}$$

The saving ratio $\boldsymbol{S}_{\text{r}}$ gives percentage in which we succeeded to decrease the cost of the initial solution. We assume that the initial solution represents 100% and $\boldsymbol{S}_{\text{r}}$ gives achieved gain in savings after introduction of the semi optimal solution. As the saving ratio is quotient of $\boldsymbol{C}_{\text{opt}}$ and $\boldsymbol{C}_{\text{tot}}$, it isn't influenced by the type of the distances used also.

4. Generated Solutions and Analysis of Obtained Results

The comparative advantage of approach applied in this work is the fact that we deal with data obtained from the archived database of AVL system, which is in use for several years. The information about destinations in the particular case discussed in this work is extracted from the database where everyday drives of medical emergency vehicles were recorded during the period from 01.09.2014 to 10.09.2014. During that period, the fleet of ambulances of the Emergency medical service in Niš (Serbia) was observed. The analysis and the algorithms which can be found in the available literature, related to similar optimization tasks, are commonly realized on artificially generated input data. The influence of different types of distances between destinations to the quality of generated solution is analyzed in the case of selected 60 destinations. We started with a situation where all vehicles travel from the central garage of Emergency medical service and after intervention, the vehicles returns, using the same route. The starting cost ($\mathbf{C}_{\mathrm{tot}}$) in the case of 60 destinations and the Euclidian distance between destinations is calculated, taking in account the geographical distribution of locations, as it is shown in Fig. 1. The amount of total cost is 255,387.00 meters.

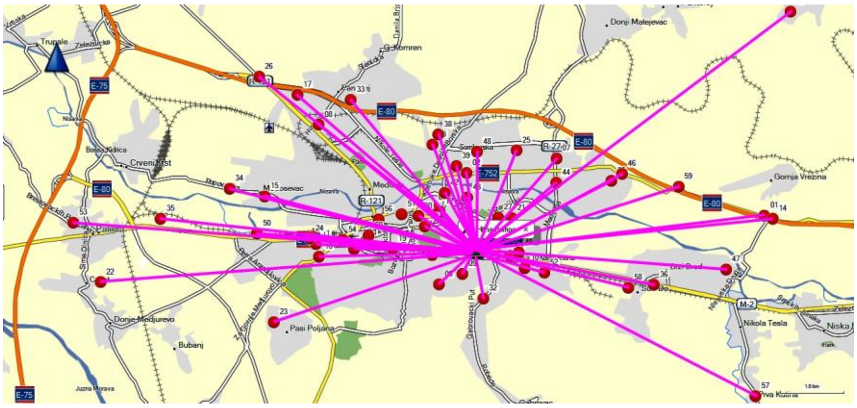

Fig. 1 The Euclidian distances to 60 destinations

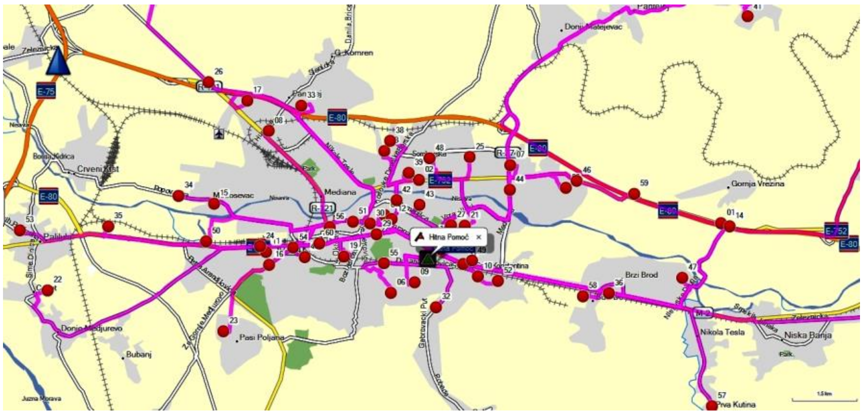

Fig. 2 The routed distances to 60 destinations

Identical 60 destinations visited from the central garage, but now with the routed distances between destinations, are shown in Fig. 2. The total initial distance or $\boldsymbol{C}_{\mathrm{tot}}$ is now: 293,155.00 meters. As we expected, this value is larger than value of $\boldsymbol{C}_{\mathrm{tot}}$, displayed in Fig. 1.

If we shift into the time domain, total starting cost is 533.00 minutes and this cost is obtained also according to the same routed paths shown in Fig. 2.

The comparative presentation of distances and corresponding costs is shown in Fig 3. It is the same group of data already presented in Fig. 1 and Fig. 2. Tabular form gives better insight in regularity, and scale of changes related to $\boldsymbol{C}_{\mathrm{tot}}$. Also, we can see changes and interdependence between all three different types of the distances. It is obvious, that the Euclidean distances are shortest and differences from corresponding routed distances vary, related to road network density, coverage and shape of the urban and suburban areas.

	Euclidian distances(m)	Routed distances(m)	Time minutes
1	8,210.00	8,319.00	12.00
2	1,740.00	2,820.00	6.00
3	11,490.00	14,872.00	16.00
4	1,479.00	1,754.00	4.00
5	4,229.00	4,900.00	10.00
6	1,296.00	2,850.00	7.00
7	3,149.00	4,010.00	9.00
8	5,200.00	5,241.00	11.00
9	689.00	1,449.00	3.00
10	1,545.00	1,802.00	5.00
11	4,360.00	4,473.00	9.00
12	1,263.00	1,472.00	3.00
13	2,655.00	3,480.00	9.00
14	8,320.00	8,554.00	13.00
15	5,210.00	6,045.00	11.00
16	3,890.00	4,391.00	9.00
17	6,127.00	7,040.00	13.00
18	426.00	549.00	1.00
19	2,288.00	2,920.00	8.00
20	12,862.00	15,170.00	17.00
21	1,292.00	2,090.00	5.00
22	10,410.00	10,628.00	19.00
23	5,931.00	5,970.00	13.00
24	4,130.00	4,643.00	9.00
25	2,573.00	2,960.00	7.00
26	7,030.00	7,264.00	12.00
27	996.00	1,174.00	3.00
28	9,430.00	9,632.00	15.00
29	1,457.00	1,511.00	3.00
30	1,655.00	1,720.00	3.00
31	1,072.00	1,573.00	3.00
32	1,226.00	2,690.00	5.00
33	4,888.00	5,660.00	11.00
34	6,010.00	7,058.00	13.00
35	7,700.00	8,921.00	15.00
36	5,217.00	5,230.00	10.00
37	456.00	678.00	2.00
38	2,806.00	3,940.00	11.00
39	1,948.00	2,750.00	7.00
40	10,793.00	11,860.00	18.00
41	10,565.00	12,470.00	20.00
42	1,501.00	1,948.00	4.00
43	1,171.00	1,773.00	5.00
44	2,802.00	3,220.00	6.00
45	3,386.00	3,580.00	8.00
46	4,570.00	4,940.00	9.00
47	6,530.00	7,218.00	10.00
48	2,229.00	3,410.00	8.00
49	1,307.00	1,915.00	4.00
50	5,690.00	6,160.00	15.00
51	2,020.00	2,175.00	4.00
52	2,112.00	2,340.00	6.00
53	9,290.00	11,391.00	18.00
54	3,260.00	3,717.00	7.00
55	1,179.00	1,292.00	3.00
56	2,763.00	3,010.00	7.00
57	8,300.00	8,745.00	14.00
58	4,515.00	4,540.00	8.00
59	6,019.00	6,260.00	11.00
60	2,730.00	2,988.00	6.00
	255,387.00	**293,155.00**	**533.00**

Fig. 3 Values of C_{tot} corresponding to the different types of used distances

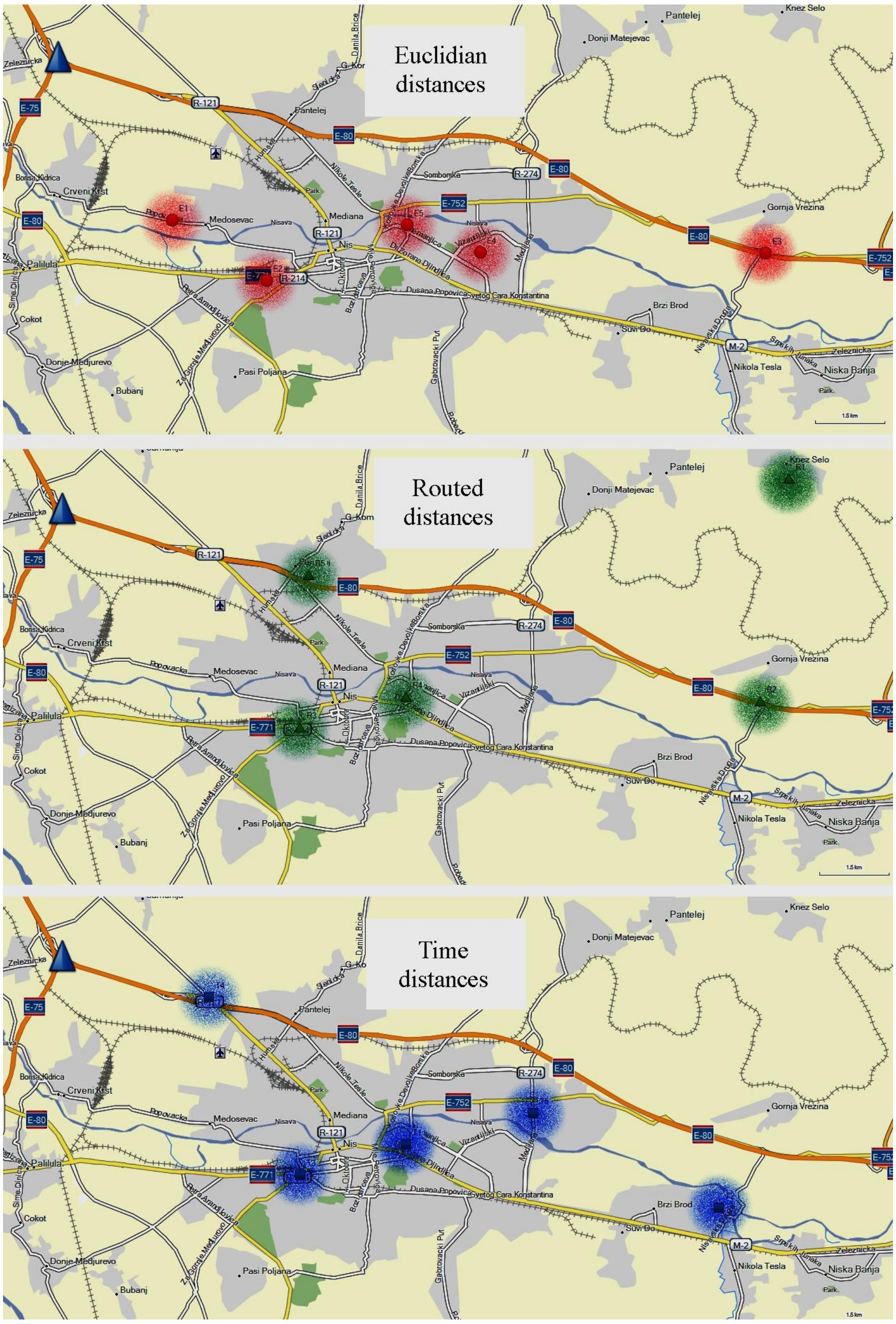

Fig. 4 Optimization solutions for three different types of the distances

In the case of Euclidian distances, total cost $\boldsymbol{C}_{\text{tot}}$ was calculated as the sum of the values of distances between each pair of the locations, while in the case of routed and time distances $\boldsymbol{C}_{\text{tot}}$ is obtained using the routing preprocessing procedure, performed on the predefined road network. The routed and time distances from the central garage to each of the 60 destinations, could be obtained from the database also. During the daily routine and monitoring of the tracks of the vehicles, in the addition to the coordinates, the time and speed tuples are recorded for the every single sampling point. Finding the total time distance between the central garage and each individual destination, based on historical information is possible, for all three different types of distances, used by the optimization process. Therefore, it is possible to calculate baseline $\boldsymbol{C}_{\text{tot}}$ using historical database information. However, for the next step of filling distance matrix $\boldsymbol{M(n, n)}$ historical database does not contain all necessary data. If we rely on the data from the history extracted from the database, we can get only information sufficient to calculate the initial cost, but we have no data which are necessary to find distance from the ***n**-th* location to all other $\boldsymbol{n-1}$ locations. As in following analysis, we compare $\boldsymbol{C}_{\text{tot}}$ and $\boldsymbol{C}_{\text{opt}}$, but it is not advisable to compare the values obtained from the uncomplimentary sources. So, for the initial solution in the case of the routed and the time distances we start with the initial costs obtained by the adopted routing procedure.

When the matrix of the distances $\boldsymbol{M(n, n)}$ is completed and populated with data, we are ready for the next processing step, performed by the module GA-GISLAB. We assume that 5 vehicles are available, during one shift, and we looking for 5 optimal locations, as a parking places. From these parking places, the time necessary to visit all 60 destinations is expected to be minimal. The Fig. 4 shows the geographical positions of proposed parking locations for all three cases: Euclidian, routed and time distances between destinations. Phase two of the algorithm was limited to 20 iterations and in phase three, Genetic algorithm was limited to 100 generations. When the last generation is examined, execution of the program module GA-GISLAB ends.

The results of all 120 steps, of the second and the third stage of the algorithm are shown in Fig. 5, for each of the three different types of distances used.

Fig. 5 shows changes of the total cost and saving ratio in every single step. For the purpose of better visibility, changes of the saving ratio are also shown in Fig. 6.

The best saving ratio is in the case of Euclidian distances and amount is approximately 44%. When routed distances are used, maximum achieved saving is 47%, whereas, when we used time distances, saving ratio is 52%. These kinds of results are expected, as use of Euclidian distances provides mathematically consistent and compact matrix elements and high efficiency of the data in same time. The inferior amount of saving ratio in the case of calculations in the time domain can be partly explained by the inherent nature of the time distances.

No.	Eucidian distances(m)	Saving ratio (%)	Routed distances(m)	Saving ratio (%)	Time minutes	Saving ratio (%)
1	255,387.00	100	293,155.00	100	533	100
2	144,372.00	57	236,469.00	81	348	65
3	174,976.00	69	206,050.00	70	340	64
4	171,054.00	67	184,171.00	63	358	67
5	180,122.00	71	253,572.00	86	388	73
6	202,576.00	79	208,390.00	71	346	65
7	189,670.00	74	206,868.00	71	326	61
8	174,065.00	68	213,297.00	73	361	68
9	141,685.00	55	192,990.00	66	334	63
10	166,984.00	65	183,789.00	63	334	63
11	117,737.00	46	206,560.00	70	391	73
12	183,422.00	72	213,374.00	73	371	70
13	188,960.00	74	217,636.00	74	385	72
14	130,075.00	51	186,500.00	64	328	62
15	149,243.00	58	158,939.00	54	342	64
16	125,191.00	49	220,975.00	75	321	60
17	205,359.00	80	246,331.00	84	342	64
18	189,034.00	74	195,518.00	67	427	80
19	205,989.00	81	232,683.00	79	407	76
20	172,121.00	67	174,730.00	60	430	81
21	154,244.00	60	184,319.00	63	389	73
22	121,019.00	47	194,187.00	66	364	68
23	117,737.00	46	158,939.00	54	321	60
24	117,737.00	46	153,940.00	53	303	57
25	117,737.00	46	153,187.00	52	303	57
26	117,737.00	46	153,187.00	52	303	57
27	117,737.00	46	139,944.00	48	295	55
28	117,737.00	46	139,944.00	48	295	55
29	117,737.00	46	139,944.00	48	295	55
30	115,756.00	45	139,944.00	48	295	55
31	115,756.00	45	139,944.00	48	295	55
32	115,756.00	45	139,944.00	48	288	54
33	115,756.00	45	139,944.00	48	288	54
34	115,756.00	45	139,944.00	48	287	54
35	115,756.00	45	139,944.00	48	287	54
36	114,265.00	45	139,944.00	48	287	54
37	114,265.00	45	139,944.00	48	287	54
38	114,265.00	45	139,944.00	48	287	54
39	114,265.00	45	139,944.00	48	287	54
40	114,265.00	45	139,944.00	48	287	54
41	114,265.00	45	139,944.00	48	287	54
42	114,265.00	45	139,944.00	48	283	53
43	114,265.00	45	139,944.00	48	283	53
44	114,265.00	45	139,944.00	48	283	53
45	114,265.00	45	139,944.00	48	283	53
46	114,265.00	45	139,944.00	48	283	53
47	114,265.00	45	139,944.00	48	283	53
48	114,265.00	45	139,944.00	48	283	53
49	114,265.00	45	139,944.00	48	283	53
50	114,265.00	45	139,944.00	48	283	53
51	114,265.00	45	139,944.00	48	283	53
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55	114,265.00	45	139,944.00	48	283	53
56	114,265.00	45	139,944.00	48	283	53
57	114,154.00	45	139,944.00	48	283	53
58	114,154.00	45	139,944.00	48	283	53
59	114,154.00	45	139,944.00	48	283	53
60	114,154.00	45	139,944.00	48	283	53
61	114,154.00	45	139,944.00	48	283	53
62	113,972.00	45	139,944.00	48	283	53
63	113,972.00	45	139,944.00	48	283	53
64	113,972.00	45	139,944.00	48	283	53
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74	113,972.00	45	139,395.00	48	278	52
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80	113,972.00	45	139,395.00	48	278	52
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93	113,165.00	44	139,395.00	48	278	52
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95	113,165.00	44	139,395.00	48	278	52
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98	113,165.00	44	139,395.00	48	278	52
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104	113,165.00	44	139,395.00	48	278	52
105	113,165.00	44	139,395.00	48	278	52
106	113,165.00	44	136,352.00	47	278	52
107	113,165.00	44	136,352.00	47	278	52
108	113,165.00	44	136,352.00	47	278	52
109	113,165.00	44	136,352.00	47	278	52
110	113,165.00	44	136,352.00	47	278	52
111	113,165.00	44	136,352.00	47	278	52
112	113,165.00	44	136,352.00	47	278	52
113	113,165.00	44	136,352.00	47	278	52
114	113,165.00	44	136,352.00	47	278	52
115	113,165.00	44	136,352.00	47	275	52
116	113,165.00	44	136,352.00	47	275	52
117	113,165.00	44	136,352.00	47	275	52
118	113,165.00	44	136,352.00	47	275	52
119	112,593.00	44	136,352.00	47	275	52
120	112,593.00	44	136,352.00	47	275	52
121	112,593.00	44	136,352.00	47	275	52
122	112,593.00	44	136,352.00	47	275	52
123	112,593.00	44	136,352.00	47	275	52

Fig. 5 The values of $\boldsymbol{C}_{\mathrm{opt}}$ and $\boldsymbol{S}_{\mathrm{r}}$ – different types of distances

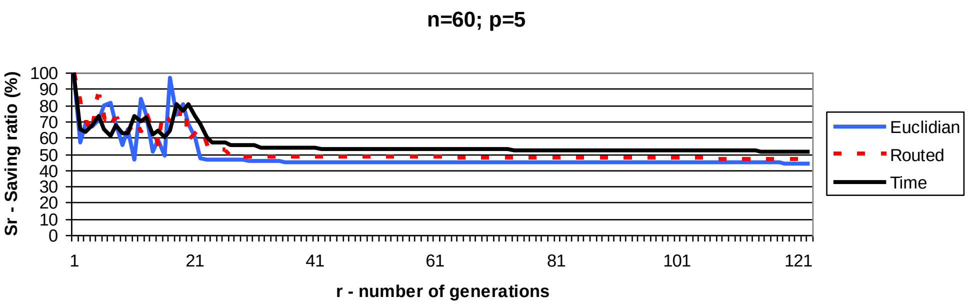

Fig. 6 The convergence of $\boldsymbol{S}_{\mathrm{r}}$ – different types of distances

If we look to the behavior and the final amount of the saving ratio, the conclusion is that the difference in amounts in the case of the Euclidian and in the case of the routed distances is not so significant, if we keep in mind contribution of both methods, to the process of decreasing amount of the initial cost. This conclusion confirms the practical usefulness of the Euclidian distances in solving problems of this type, especially if the main goal is the speed and efficiency of the whole process of finding the optimal solution. It should also be noted that the preprocessing as additional operation on the input data to find routing distances, increases the time and memory complexity of the algorithm.

The geographic locations of the solutions, obtained in all three cases of using different types of the distances, are shown simultaneously in Fig. 7.

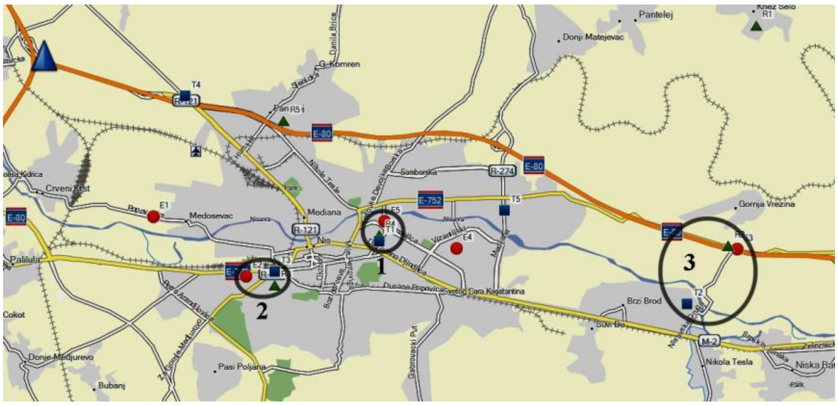

Fig. 7 Solutions related to the different types of the destinations - simultaneously

It is interesting to note that certain areas are proposed as candidate members of the final solutions in all three different cases. This is especially true for the areas in Fig. 7 marked with numbers 1 and 2, and to a lesser extent, this is also true for the area marked with number 3. It is obvious that these areas are excellent candidates for parking places of ambulance vehicles, no matter which type of the distances is used in the optimization process.

It is interesting to analyze behavior of the cost after crossing-over of the final optimization results for different types of the distances. In the matrix filled with routed distances, we will inject the final solutions obtained by using the Euclidean and the time distances. In this way, we will be able to effectively estimate in what percentage optimization ratio is corrupted by using the Euclidean distances. So, we will precisely determine in what amount, routed distances are superior to Euclidian and time distances. We will use routed distances of the semi-optimal solution, already displayed in Fig. 4 and Fig. 5, with the total cost of 136,352.00 meters and the optimization ratio of 46,51%. If solution obtained by using the Euclidian distances shown in Fig. 4 and Fig. 5 is injected into the matrix of the routed distances, we get solution of 161,915.00 meters and corresponding optimization ratio of 55,23%. We can see that the inferiority of the Euclidean approach expressed in percentage is approximately 8%, which can be addressed to the speed of the algorithm and to the simplified approach.

When solution based on the time distances is injected in the matrix of the routed distances, we obtain a total cost of 139,094.00 meters and the corresponding optimization ratio of 47,44%. Obviously, in this case the total difference from the routed solution is negligible, and we can say that the quality of the routed and the time distances types of the input data are practically identical. This is shown in Fig. 8.

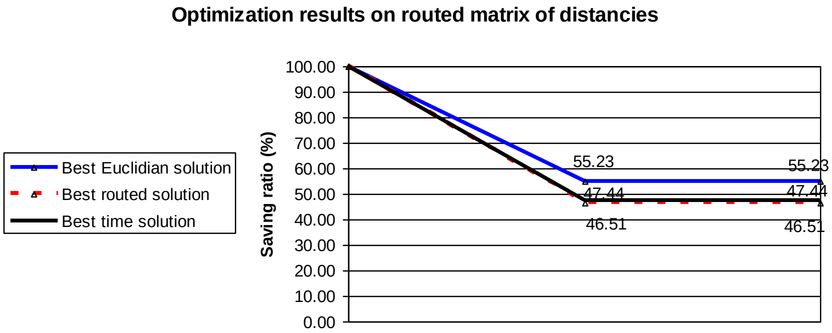

Fig. 8 S$_r$ and crossing-over of the different type solutions

5. Conclusion

If we monitor changes of the saving ratio, when different distance metrics are used in optimization process, it is apparent that there are differences in the efficiency of the solutions, generated by differences in types of data. But, the differences are not so significant in magnitude, and important in scale, to reject in advance any particular type of the input data. The routed distances reflect the realistic properties of the problem being solved; introducing influence of the road network, but this approach requires additional processing and additional computing resources. The inferiority of the Euclidian type of distances is evident, but backlog of the solution efficiency is not significant enough to dismiss this approach. The Euclidean distances justified its usage in practice, especially when speed and simplicity of the algorithm are imperative. The time distances approach gives results that practically coincide with the results obtained using the routed distances. This is a very interesting consequence, since time distance data can be directly calculated from AVL historical database, thus eliminating possibly computationally expensive step of routing over road network.

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