ISSN 1816-6075 (Print), 1818-0523 (Online)
Journal of System and Management Sciences
Vol. 1 (2011) No. 5, pp. 81-92

Estimation of response time for ground ambulance transport

Bruno Jezek[1], Jan Vanek[1], Miroslav Prochazka[1]
[1] Faculty of Military Health Sciences, University of Defence, Trebesska 1575, 50002 Hradec Kralove, Czech Republic
jezek@pmfhk.cz, vanek.conf@gmail.com, prochazka@pmfhk.cz

Abstract: Response time is a key factor to determine the quality of pre-hospital emergency medical service. We propose a method to estimate the response times based on a classified road network. The method takes into account different attributes that depend on road type, category, surface and class. Comparison of measured times and calculated values shows that the estimated response times are optimistically inclined and situations in a real traffic would probably be worse. The results can thus safely be used to identify areas where emergency system is likely to be insufficient.

Keywords: Emergency Medical Service, Response Time, Ground Ambulance Transport, Shortest Path, Routing, Fastest Path, Geographic Information System

1. Introduction

Response time is a key factor to determine the quality of a pre-hospital emergency medical service (EMS). Many authors mention the term “golden hour”, which is commonly used to characterize the urgent need for the care of trauma patients (Carr, 2009) (Lerner, 2001) (McNicholl, 1994) (Newgard, 2010). Correctly estimated travel times are crucial not only for optimal deployment of all resources within the analyzed region, but also for the evaluation of the readiness of the emergency medical system for a response (Blackwell, 2002) (Cunningham, 1997) (Henderson, 2005) (Sheu, 2007) (Özdamar, 2004).

Methods focused on the estimation of the travel time are used in applications for EMS simulation (Su, 2003) (Clark, 1994) (Haghani, 2004) and geographic information systems (Lerner, 1999) (He, 2003) (Peleg, 2004) (Zaki, 1997) (Thill,

J. 2000) (Wang, 2005). Besides special continuous models that work on raster data, the usual methods for travel time calculation are based on graph theory (Xu, 2008).

This paper focuses on the accurate estimation of ground ambulance travel times from an emergency station to the site of an accident defined in a real road network. The designed method uses a classification of the road network to assign weights to all edges. The fastest path is found by routing procedure using weighted edges. Computed results of response times were compared with measured times and visualized in GIS.

Design and implementation a method of accurate response time estimation is motivated by a bill draft law, which proposes more restrictive policy for responding time. Service areas computed and visualized using the designed method supports arguments of the regional EMS management. In actual conditions, especially a density of the road network and the number of ambulance stations, it is impossible meet government's requirements of response times for any area of the region.

2. Methodology

The estimation of the response time is based on the computation of travel time measured from an emergency station to an incident location. The simplest method of travel time calculation is to use the air distance and the mean velocity of a transport vehicle. This method is acceptable for helicopter ambulance, but it is inaccurate for ground ambulance transport and a real road network must be used. The road network is a collection of all roads and junctions that can be used for vehicle movement.

2.1 Routing in Road Network

A structure of the road network is represented by a graph G = (N, E) comprising a set N of nodes, together with a set E of edges. The nodes model the real junctions located in a geographical situation and the edges model roads connecting them. The edges are weighted by a distance between the nodes, which can be calculated in several ways. Routing in the graph is based on finding the shortest path from the start to the final node, for example by Dijkstra's algorithm.

The response time of EMS is travel time along the shortest path found by routing algorithm. We used two approaches, the shortest path method and the fastest path method.

In the first case all edges are simply weighted by true geographical distance calculated along a road connecting two neighboring nodes. The path found by routing method in the graph corresponds to the shortest path in the real road network.

The second method is much more complicated. Using real distance and mean velocity the travel time for every edge is calculated. This travel time is used as the weight to find the shortest path. In the real network mean velocity depends on many attributes, such as vehicle type, road classification, time of day, weather or actual traffic density. Because some of the attributes, such as the weather or the traffic density, cannot be easily predicted, our method estimates travel time in ideal conditions. The response time in a real situation is likely to be worse.

2.2 Road Network Classification

As a road network data source a commercial collection of vector maps prepared for processing in geographical information systems (GIS) was used. This collection stored in Esri shape file format contains point, polyline and polygon layers, which represent geometrical information of real geographical objects. The most important part of the collection is the polyline layer with road network used for navigation in GIS. Besides real distance, the direction of one way roads is also assigned to all edges (Figure 1). In some cases edges have different velocity for forward (from-to) and backward (to-from) direction. For example, ambulances can travel one-way roads in both directions, but with much lower velocity in the wrong one. In addition, all edges of the road network are categorized by several attributes such as road type, surface, category and class.

The following tables (Tables 1-4) show typical ground ambulance vehicle mean velocities in kilometers per hour and their dependency on values of attributes. The velocities were estimated on the base of discussion with drivers of ground ambulances. Besides the direction of one way roads, the mean velocities also depend on area type. In an urban area the table values are decreased due to traffic limitations.

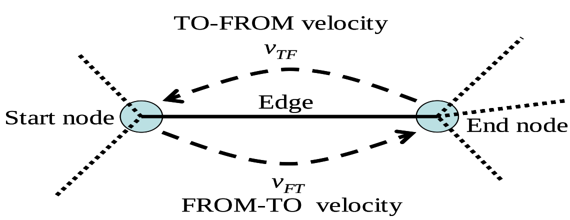


Figure 1: The velocity assigned to road network edge, vFT and vTF are the same for both direction roads and different for one-way roads.

Table 1: Estimated mean traffic velocity vFW for different road types in dependence on road direction FT (From-To), TF (To-From), NT (No Through) [km/h].

Road type (FW)	FT	TF	NT
Highway, Motorway	160	1	5
Multi-lane	130	1	5
Single flow	120	1	5
Ring-road	40	1	5
Parking place, parking house	20	15	5
Highway entrance, exit	90	1	5
Service road	60	5	5
Parking exit, entrance	15	5	5
Pedestrian zone	5	5	5
Side-walk	5	5	5
Others	5	5	5
Stairs	0.1	0.1	0.1

Table 2: Estimated mean traffic velocity vDS for different road surfaces [km/h].

Road Surface Category (DS)	Velocity [km/h]
Paved	140
Unpaved	40
Bad conditions	20

Table 3: Estimated mean traffic velocity vFC for different road categories in dependence on road direction and area type [km/h].

Road category	Out of urban area		In urban area	
(FC)	FT	TF	FT	TF
Highway	160	1	140	1
International road	130	1	120	1
Main road	100	1	100	1
Main city road	90	5	90	5
Regional road	70	5	70	5
Local road	60	5	60	5
Others	30	15	5	5

Table 4: Estimated mean traffic velocity vNC for different road classes [km/h].

Road Class (NC)	Velocity [km/h]
Highway	160
1st class	130
2nd class	100
3rd class	80
Others	60

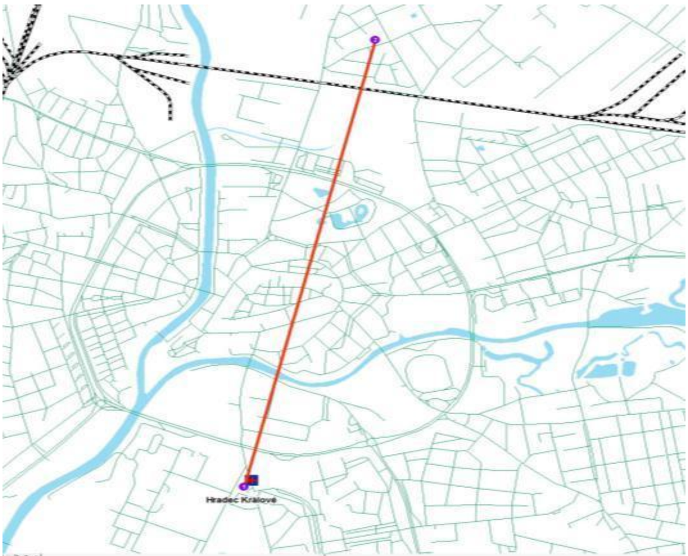
2.3 Response Time Calculation

During the classification the estimated mean velocities are assigned to all edges of the road network. Using the following procedure the travel time for every edge will be calculated and consequently the response time for the found path will be aggregated.

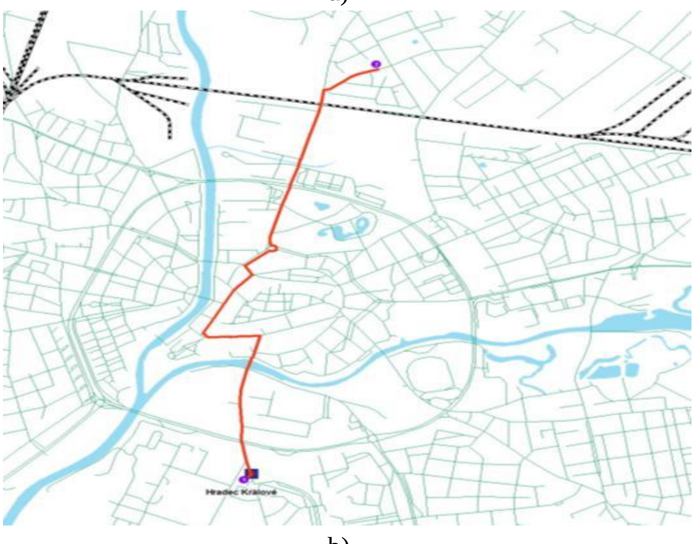
In the first step, the edge velocity for both directions (from-to and to-from) is calculated as a minimum of all assigned values (Equation 1). The minimum function enables to involve all factors limiting mean velocity of the certain edge.

$$v_{FT} = \min\left(v_{FW\_FT}, v_{DS}, v_{FC\_FT}, v_{NC}\right) \quad (1)$$

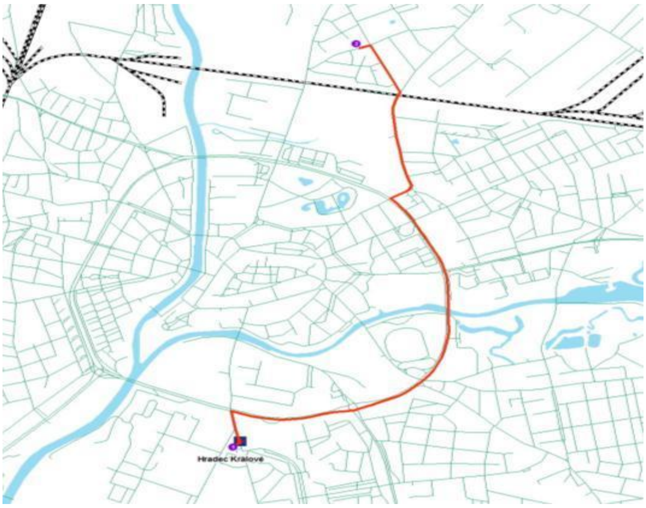
In Equation 1 vFT is mean velocity in from-to direction and vFW_FT, vDS, vFC_FT and vNC are estimated velocities dependent on classification. The velocity vTF in the to-from direction is calculated in a similar way.



a)



b)



c)

Figure 2: Routed path calculated in real road network: a) the air distance (2.9 km ~ 2.9 min), b) the shortest path (3.6 km ~ 3.6 min), c) the fastest path (4.1 km ~ 2.7 min).

The second step calculates travel time as the rate of length over velocity (Equation 2):

$$t_{FT} = \frac{l_E}{v_{FT}} \tag{2}$$

Where tFT is travel time of the edge in one direction and lE is the edge length. Both travel times tFT and tTF are assigned to the edge as an edge weight and stored in shape-file format. This polyline layer will be used in the routing algorithm.

ArcGIS Network Analyst was used for routing calculation. The edge assigned travel time was used as the minimizing criterion to find the shortest, in this case the fastest, path. Figure 2 shows three examples of found path between to nodes in the real road network. Shortest air distance (Figure 1a) does not reflect real network structure and the shortest network path (Figure 2b) takes more time than the fastest path, which is the longest (Figure 2c).

Finally the response time is given as accumulated value along the found path (Equation 3):

$$t_R = \sum_i t_{FTi} \tag{3}$$

Where tR is response time calculated along the routed path and tFTi is the travel time of one edge.

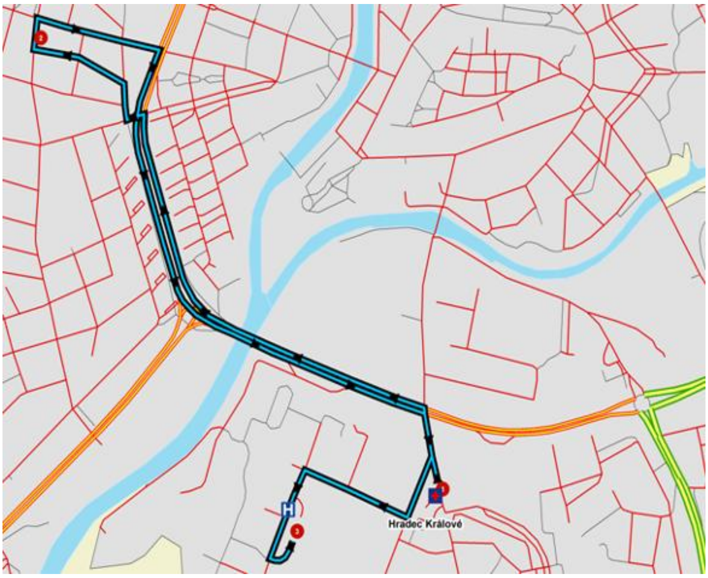


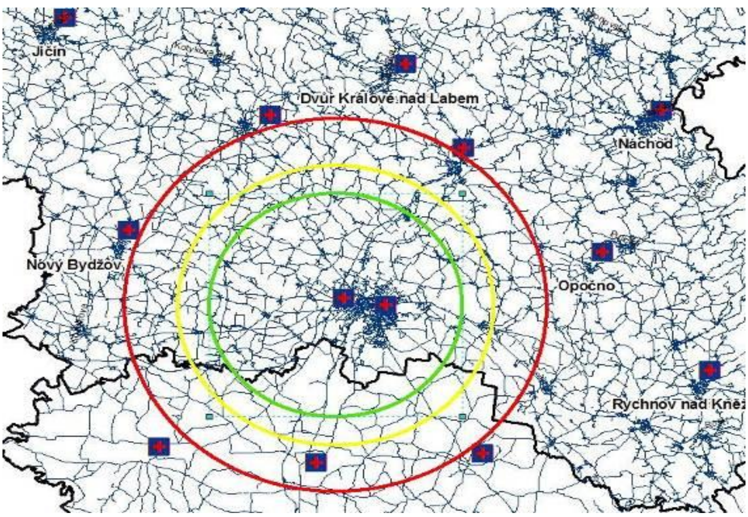
Figure 3: The path found by the fastest path method. A ground ambulance vehicle is routed from the emergency station to the site of an accident location and from the site to the hospital. Velocities and one way direction are accepted in routing algorithm.

3. Results

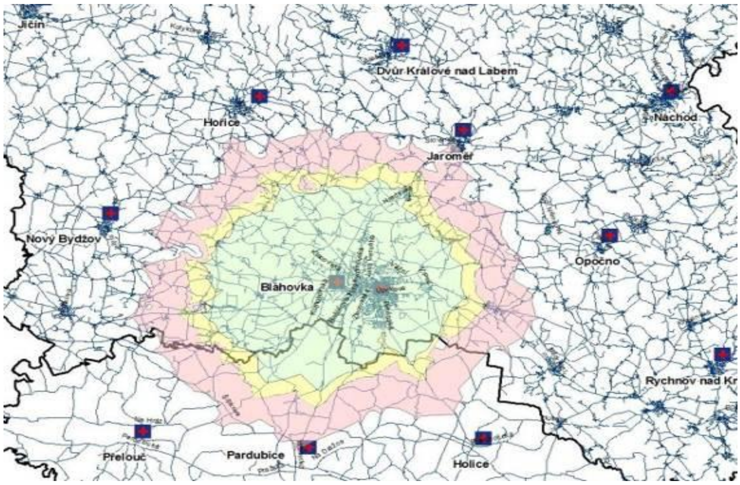
The fastest path method was tested on real data source. Figure 3 shows the routed path of a ground ambulance vehicle going from an emergency station to an accident location and back to a hospital. Comparison of the found path with real road network validated that correct velocities and directions of one way roads were properly applied in routing algorithm.

Table 5: Response time comparisons for selected paths of actual emergency responses. The last column presents difference between the real and estimated response time [minutes:seconds]. In nearly all cases the response times estimated by the fastest path method are shorter. Big differences are especially in urban areas.

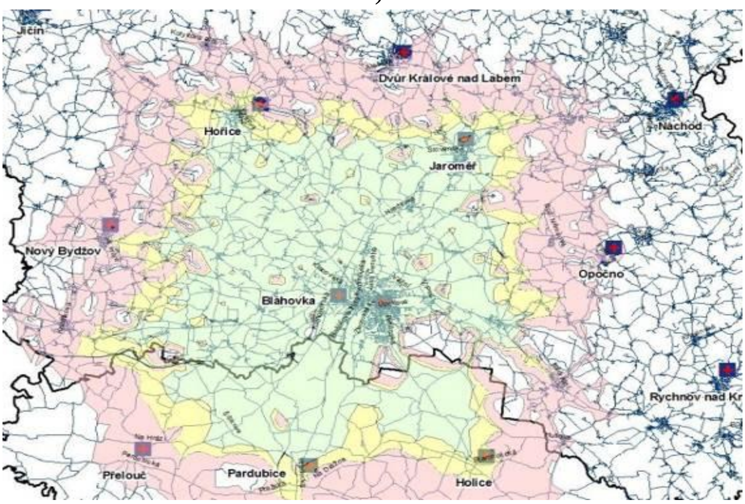
Path number of actual emergency response	Real response time [m:s]	Estimated response time [m:s]	Urban area [Y/N]	Time difference [m:s]
1	08:26	08:03		0:23
2	17:00	16:44		0:15
3	12:00	08:30		3:30
4	07:48	01:41	Y	6:07
5	16:00	11:03		4:57
6	03:02	01:19	Y	1:43
7	04:09	00:56	Y	3:13
8	12:08	12:38		-0:30
9	06:00	04:07		1:53
10	09:01	08:30		0:29
11	10:34	09:10		1:24
12	08:08	04:38		3:30
13	14:00	10:38		3:22
14	02:40	00:54	Y	1:46
15	07:32	05:42		1:50
16	10:53	10:35		0:18
17	07:06	02:02	Y	5:03
18	11:00	08:20		2:40
19	10:30	10:19		0:11
20	05:30	03:15	Y	2:15
21	04:57	02:03	Y	2:54
22	11:19	09:02		2:17



a)



b)



c)

Figure 4: Service area maps calculated by three methods: a) the air distance method, b) the shortest path method and c) the fastest path method. Colors show the borders for 13 (green), 15 (yellow) and 20 (red) minute limits.

Estimated response times were compared with real response times of 22 selected paths of ground ambulance responses (Table 5). In nearly all cases the response times estimated by the fastest path method were shorter than real times measured during the response. It means that estimated response times are optimistic and situations in real traffic would probably be worse. Big differences in times occurred especially in urban areas. To rectify that the estimated mean velocities for roads within an urban area will be decreased. The described method was used in ArcGIS to analyze the readiness of the emergency medical service within selected regions of the Czech Republic. The Network Analyst extension created polygons of service area representing the calculated distance that can be reached from an emergency station in specified time (Figure 4 b and c). Topology of polygons calculated by the shortest path (Figure 4b) is very similar to air distance circles (Figure 4a). Real density and quality of the road network manifests itself in the service area map calculated by the fastest path method (Figure 4c)

4. Conclusions

The contribution has described suitable method of response time estimation and its application for a ground ambulance transport. Designed method for routing along the fastest path was implemented, tested and applied to the real road network of analyzed region. The comparison of real-world times and calculated values shows that the estimated response times are optimistic.

A combination of routing and visualization features of GIS and using classified road network brings the possibility to evaluate readiness of a region/country EMS system. Service areas maps of all emergency stations computed and visualized using the fastest path method show that in the analyzed region, which are unavailable in the respond time proposed by bill draft law.

The future work will be focused on precision improvements of mean velocities for the classified road network to get more accurate estimation of response times. The method can be also extended to include attributes such as traffic density, weather and time of day, which decrease mean velocity of ambulances.

Acknowledgements

This work was supported by the Ministry of Defence research project MO0 FVZ0000604 and Central European Data Agency, as (www.ceda.cz) that provided Street-Net data of the Czech Republic. The authors also wish to thank the Regional Emergency Service of Hradec Kralove.

References

Blackwell T. H, & Kaufman, J. S. (2002). Response time effectiveness: comparison of response time and survival in an urban emergency medical services system. *Academic Emergency Medicine*, 9(4), 288-95.

Carr, B. G., Caplan, J. M., Pryor J. P., & Branas, C. C. (2009). A Meta-Analysis of Prehospital Care Times for Trauma. *Prehosp Emerg Care*, Apr-Jun, 10(2), 198-206.

Clark, D. E., Hahn, D. R., Hall, R. W., & Quaker, R. E. (1994). Optimal location for a helicopter in a rural trauma system: prediction using discrete-event computer simulation. *Proc Annu Symp Comput Appl Med Care*, 888–892.

Cunningham, P., Rutledge, R., Baker, C. C., & Clancy, T. V. (1997). A comparison of the association of helicopter and ground ambulance transport with the outcome of injury in trauma patients transported from the scene. *J Trauma*, Dec, 43(6), 940-6.

Haghani, A., Tian, Q., & Hu, H. (2004). Simulation Model for Real-Time Emergency Vehicle Dispatching and Routing. *Transportation Research Record*, 1882(1), 176-183.

He, C. (2003). Integration of geographic information systems and simulation model for watershed management. *Environmental Modeling & Software*, 18(8-9), 809-813.

Henderson, S., & Mason, A. (2005). Ambulance Service Planning: Simulation and Data Visualization. Operations Research and Health Care. *International Series in Operations Research & Management Science*, 70(2), 77-102.

Lerner, E, & Moscati, R. (2001). The golden hour: Scientific fact or medical "Urban Legend"? *Acad Emerg Med*, 8, 758–60.

Lerner, E. B., Billittier, A. J., Sikora, J., & Moscati, R. M. (1999). Use of a Geographic Information System to Determine Appropriate Means of Trauma Patient Transport. *Academic Emergency Medicine*, 6(11), 1127-1133.

McNicholl, B. (1994). The golden hour and prehospital trauma care. *Injury*, 25(4), 251-254.

Newgard, C. D., et al. (2010). Emergency Medical Services Intervals and Survival in Trauma: Assessment of the Golden Hour in a North American Prospective Cohort. *Ann Emerg Med*, Mar, 55(3), 235-246.

Özdamar, L., Ekinci, E., & Küçükyazici, B. (2004). Emergency Logistics Planning in Natural Disasters. *Annals of Operations Research*, 129(1-4), 217-245.

Peleg, K., & Pliskin, J. S. (2004). A geographic information system simulation model of EMS: reducing ambulance response time. *The American Journal of Emergency Medicine*, 22(3), 164-170.

Sheu, J. (2007). An emergency logistics distribution approach for quick response to urgent relief demand in disasters. *Transportation Research Part E: Logistics and Transportation Review*, 43(6), 687-709.

Su, S., Shihb, & C. L. (2003). Modeling an emergency medical using computer simulation. *International Journal of Medical Informatics*, 72, 57—72.

Thill, J. (2000). Geographic information systems for transportation in perspective. *Transportation Research Part C: Emerging Technologies*, 8(1-6), 3-12.

Wang, X. (2005). Integrating GIS, simulation models, and visualization in traffic impact analysis. *Computers, Environment and Urban Systems*, 29(4), 471-496.

Xu, T., Wang, L., Zhang, D., & Gao, L. (2008). Estimation of Travel Times in the Context of Intermodal Transportation. Proceedings of the 8th *International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences*, Shanghai, P. R. China, June 25-27, 376-382.

Zaki, A. S., Cheng, H. K., & Parker, B. R. (1997). A Simulation Model for the Analysis and Management of an Emergency Service System. *Socio-Economic Planning Sciences*, 31(3), 173-189.