Application of GIS in Determining Road Emergency Medical Service (EMS) Locations

Alireza Toran Pour and Sara Moridpour
School of Civil, Environmental and Chemical Engineering, RMIT University, Australia.
E-mail: {alireza.toranpour, Sara.moridpour}@rmit.edu.au

***Abstract*—Time is the most important factor in accidents emergency services. In general, a golden time period is defined for response to an accident and if first aid and medical assistance is accessed within this time period, victims have a greater chance of survival. The aim of this paper is to show how GIS is used to identify the best emergence system location along the road network according to accident black spots and response time. Khuzestan road network is chosen as a case study in this research and the results of Ramhormoz-Behbahan route in this province are selected to show in this paper. For this reason, the road accidents data during 2006 to 2009 in this province is analyzed. The results of this research show that the current EMS locations do not cover accident black spots even by 20 minutes response time. Therefore, new EMS locations are recommended according to accident black spots. These new EMS will decrease response time by 15 minutes and the survival chance victims will increase.**

***Index Terms*—accidents, emergency services, khuzestan, GIS, EPDO**

I. Introduction

Traffic accidents are one of the most important causes of fatalities especially in developing countries. On average, about 1.24 million people die each year in traffic accidents in the worlds and 91 per cent of road accidents fatalities occurred in low and middle income countries [1]. Khuzestan is one of the most important provinces in Iran. There are many natural resources and different industrial factories in this province. This results in increase in traffic of Khuzestan road network. Annually, more than 4,000 accidents occur in Khuzestan which result in near 800 deaths in these accidents. More than 60 per cent of these numbers were pre-hospital. Emergency response time and first aid are two crucial factors in each accident's rescue action. Many studies show that improved medical response and associated technology is an important contributory factor in decreasing the severity of long-term injuries. The chance of survival for accident victims increases by providing proper first aid in traffic accidents [2]. Beside of first aid equipment, location of emergency services and its distance to traffic accidents is one of the most effective parameters in emergency response time. Locating emergency services according to accidents black spots will decrease the response time in traffic accidents.

In recent years, Geographic Information System (GIS) has provided very useful analyzing tool to assist their users in making decision. In fact, visual and text equipment of GIS help users show the results of analyzing before and after of every changes. In addition, in GIS analysis it is possible to see achievable results with changing input data or other affecting parameters. In this paper GIS and traffic parameters are integrated to determine location of emergency services along the Khuzestan road network according to road accidents black spots in this province.

This paper is structured as follows. By reviewing the literature, the method which is used in this research to identify road black spots is introduced first. It is followed by describing shortest path algorithm that is used in GIS analysis for determining of nearest facilities and services area. After that, results of this research will be presented. The last section summarizes the outcomes of this research and provides direction for future research.

II. Identification of Road Accidents Black Spots

In safety studies, accident black spot refers to a place with a record of large number of crashes. Identifying road accident black spots assist engineers in working on these areas to decrease number of traffic accidents and severities. Different approaches exist in the literature to identify the accident black spots. However, it is important that road accident black spots must be recognized according to accident statistics, traffic data and road properties. Five significant statistical methods which are used to determine the traffic accident black spots are as follows.

A. Frequency Method

In this method, all locations are ranked according to the number of accidents occurred on that location. This method is simple, however; using the number of accidents is not a useful method as the traffic volumes are not considered in this method. Therefore, the number of accidents in a particular location may be due to high traffic volume and not due to being a black spot. In addition, severity of accidents does not consider in this method and consequently black spot points cannot show a really high risk area.

Manuscript received December 5, 2014; revised April 15, 2015.

doi: 10.12720/jtle.3.2.102-107

Although this method is not very reliable to show real high risk accident points but in some cases it use. In general, this method is used for preliminary studies to indicate the points with large number of accidents. Then other methods are used to identify black spots.

B. *Rate Method*

In this method the number of accidents and traffic volume is considered in each area or segment. The number of vehicles or vehicle miles of travel for each location are compared with other area. Then traffic accidents black spots are ranked in descending order according to accidents per million vehicles or accidents per million vehicles-miles rate. While traffic volume is considered in this method but accident intensity does not reckon in this method.

C. *Frequency-Rate Method (Matrix Method)*

To identify black spots, a matrix which consists of accident numbers on rows and accident rates on columns is prepared in this method. Each cell in this matrix represents one section of road and degree of risk in that section. While this method is appropriate to identify high risk road sections but the accident intensity is not calculated. Furthermore, it is impossible to distinguish the "accident number" and "accident rate" for each cell. For instance, accidents number is low and accidents rate is high or accidents number is high and accidents rate is low.

D. *Quality-Control Method*

In this method different accident parameters such as frequencies/rate and rate/densities for each section are compared with the predetermined average values for sites with same characteristics. According to this comparison, all sections are ranked in descending or ascending order. Black spots in this method are identified by comparing sites with similar characteristics. However, these points do not show the intensity of accidents.

E. *Number Quality Control Method*

The number quality control method uses statistical analysis to show important sites with high crash rate frequency/density and compare it with the mean crash frequency/density for similar sites. This method is usually used when the crash frequency and density have noticeable difference with other sites across the region. The equation to find the critical crash rate at a roadway location is as follows [3]:

$$F_c = F_a + k\sqrt{\frac{F_a}{M}} + \frac{1}{2M} \tag{1}$$

where:

F_c = Critical rate for a particular location,

F_a = Average crash frequency/density for all road locations of like characteristics,

k = Probability factor determined by the level of statistical significance desired for F_c, and

M = Number of vehicles traversing particular road section or number of vehicles entering a particular intersection during the analysis period.

In practice, Equation 1 can determine the critical accident rate for each particular site. Each segments or intersection with greater actual crashes is known as a black spot in this method.

F. *Rate Quality Control Method*

This method uses statistical test to compare traffic crash rates for a particular segment or intersection which has abnormally higher rate of traffic crashes compared to other locations with similar characteristics such as traffic volume and road function. The equation which is used to find the critical crash rate at a roadway section is as follows [3]:

$$R_c = R_a + k\sqrt{\frac{R_a}{M}} + \frac{1}{2M} \tag{2}$$

where:

R_c = Critical rate for particular location (crashes per million vehicles or crash per million vehicle-km),

R_a = Average crashes rate for all road locations of like characteristics (crashes per million vehicles or million vehicle-km),

k = Probability factor determined to be the level of statistical significance desired for R_c, and

M = Number of vehicles traversing particular road section (millions of vehicle-km) or number of vehicles entering particular intersection (millions of vehicles) during the analysis period.

If the actual crash rate for the selected site is greater than the critical rate, the location is considered hazardous.

G. *Crash Severity Method*

Crash severity method is useful methods when there is roadways with large number of sever crashes or when the severity of crashes is important for black spot analysis (e.g. rural road analysis). In this method, all crashes are converted to a Property Damage Only (PDO) equivalency. In this method, the most severe injury involved in the incident is considered not the number of injured people in accident. The Equivalent Property Damage Only (EPDO) index is calculated using calibrated coefficients based on crash cost data [4].

$$EDPO = C_1\,(K+A) + C_2\,(B+C) + PDO \tag{3}$$

$$SI = \frac{EPDO}{N} \tag{4}$$

where:

K= One or more people are killed at the scene or die within 30 days of the crash due to injuries received from the crash.

A = One or more people receive incapacitating injuries that prevent the individuals from performing their normal activities for 24 hours or longer.

B= One or more people receive non-incapacitating injuries that are apparent at the scene and will not prevent the individual from performing their normal activities for more than 24 hours.

C = One or more people complain of pain or momentary unconsciousness; however, the injuries are not visible or obvious at the scene of the crash.

PDO = No one is injured and only property is damaged.

C1 = EPDO constant for K and A type crashes

C2 = EPDO constant for B and C type crashes

SI = severity index

N = Number of total crashes

In practice, the number of accidents for each section or segments of road is collected to determine the EPDO. In next step, each accident is classified as K, A, B, C and PDO classified and use in Equation 3 to find EDPO. C_1 and C_2 are two constants that are determined according to severity of accidents in each study. These constants show how the crash severity is important in determination of accidents black spots. Usually these constant values are considered 3 and 2, respectively. However, fin countries with high accident severity, larger values C_1 and C_2 are used.

After determining EDPO for each segments it ranked by Equation 4 and an EDPO whit highest rank is determined as an accidents black spot.

III. Shortest Path Algorithm

One of the most important and powerful functions in GIS is network analyst. The network analyst provides network-based spatial analysis such as travel directions, closest facilities and location-allocation. The critical point in network analysis is the shortest path analysis as it does not only refer to shortest distance in general geographic sense but other parameters such as time, speed, cost and capacity are considered for each link in this analysis. In shortest path analysis, we usually need the fastest line with the lowest cost or the highest capacity. In this study emergency response time is the most important parameter. Then, shortest path is the path with minimum response time. However, arriving time in road networks is subjected to many other parameters such as network speed and traffic volume. The classical algorithm Dijkstra is foundation for solving the shortest path problem [5].

Dijkstra algorithm helps to find the shortest path between any two vertices in a weighted graph, where each edge has non-negative edge weight. Dijkstra's algorithm will assign initial distance values for each vertex, and then it will try to improve them step by step. The Dijkstra algorithm consists of the following steps:

Select starting node as base node

- Calculate the path length (distance from starting node) to all neighbour nodes of the base node which have not been base node yet.
- If the path length is shorter than the shortest path one calculated up to now, the new path and length will be stored.
- Select that node as new base node that have not been base node yet (consider all, not just neighbours) and that is closest to the starting node. Is that node the target node (for shortest path) or the very last node (for shortest tree), stop the procedure. Otherwise continue with step 2.

IV. Shortest Path Criteria

Determining the station locations is the most important issue in public transport lines (Fig. 1). The position of stations can be determined based on different parameters such as cost, time and land uses. To identify the position of emergency services, the most important criteria is arrival time. The in-vehicle travel time is less important compared to the time taken to arrive at the station or incident scene since additional stations may only add up a few minutes to the in-vehicle travel time. Thus, a good candidate location will be the one with higher degree of accessibility. In this research the aim is to identify emergency medical service stations according to travel time cost.

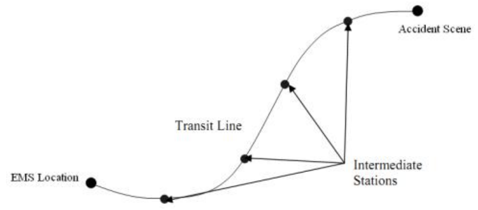

Figure 1. Station location problem

To solve this problem the optimization algorithm is integrated with network analysis extension in ArcMap GIS to calculate travel time cost. For simplify, 'Bureau of Public Roads', BPR travel time function is used in this research to find travel times in Dijkstra algorithm.

$$t = t_0\left[1+\beta\left[\frac{V}{Q}\right]^n\right] \tag{5}$$

where:

t: Travel time (min)

V: Traffic volume that in this equation equal to Daily Hour Volume (DHV) and: ADT (t is a Constance value between 12% to 16% according to road type; currently 15%)

Q: Road capacity (Vehicle per hour)

t_0: Free travel time (min)

β and n are independent parameters from road type.

Speed and traffic volume were two data which were available to determine travel time and it had limited using other functions. Although there are many other travel time function but as the BPR function needs less detail input data in this research this function selected. Traffic volume and link capacity are the two simple variables which are used in BPR function. Therefore, BPR function is still used to estimate travel time of arterial streets for planning purposes. However, it is also known that BPR functions generate erroneous estimation of travel times on arterial streets especially under congestion. Since, the accidents of rural roads are investigated in this research, traffic congestion is ignored.

V. Methodology

The proposed methodology in this study illustrates how GIS can be used to identify black spots and EMS locations. This study is based on ability of Arcmap GIS for network analysis. This study includes two main parts:

- Data collection and preparation of dataset
- Data Analysis

A. Data Collection and Dataset Preparation

This dataset which used in this paper includes two major information. Spatial data including accidents location, EMS locations and road networks, non-spatial data such as accident information and traffic characteristics (e.g. traffic speed and traffic volume). In this study accident report sheets during 2006 to 2009 are collected from Khuzestan road police office. In addition, other data such as speed, traffic volume and EMS locations are collected from Iran Road Maintenance and Transportation Office (IRMTO). These data are used in GIS dataset after modification. All of these data are collected for all Khuzestan province roads network but in this paper only the results of Ramhormoz-Behbahan road will show as a case study.

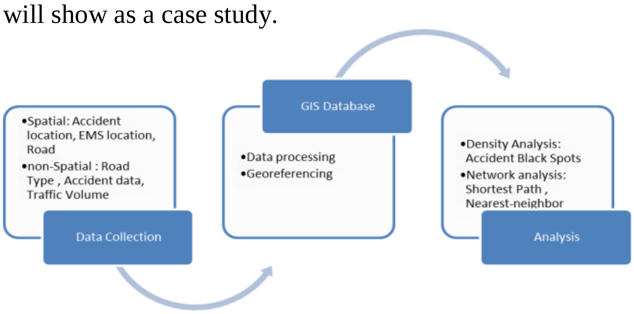

Figure 2. The overview of the methodology for system development

FID	EPDO	SPEED	DRIVETIME	MINUTES	METERS
0	16	80	0.5609	0.6462	747.869
1	8	80	0.2916	0.3359	388.77
2	17	80	0.6056	0.6976	807.453
3	9	80	0.2502	0.2882	333.539
4	4	80	1.02	1.175	1359.978
5	6	80	0.1756	0.2022	234.075
6	12	80	0.9595	1.1053	1279.323
7	3	80	0.4147	0.4778	552.961
8	4	80	0.5034	0.5799	671.188
9	4	80	0.3289	0.3789	438.486
10	5	80	0.7498	0.8637	999.679
11	4	80	0.3032	0.3493	404.294
12	6	80	1.5932	1.8354	2124.302
13	4	80	1.3832	1.5935	1844.314
14	2	80	0.4287	0.4938	571.547
15	13	80	1.3797	1.5894	1839.559
16	1	40	1.3303	1.3303	886.864
17	19	30	0.2245	0.2245	112.259
18	3	30	0.1946	0.1946	97.303
19	0	40	0.2519	0.2519	167.935
20	14	30	0.0976	0.0976	48.82
		30	1.5509	1.5509	775.457
		30	0.7817	0.7817	390.845

Figure 3. A part of GIS map data filed

B. *Data Analysing*

In second step, data are analyzed to identify accident black spots and determine best location for emergency services. The density analysis is used to identify accident black spots and to determine EMS locations the routs and service area analysis has been used in GIS tool box.

Rural road accidents are generally more severe than accidents on urban roads due to different speed limits, road geometry and functionality. As accidents severity is a more important parameter in rural road accidents, the method which is used for rural roads to show accident black spots must be sensitive to accident severity. In this research crash severity method is used to show accident black spots. This method identifies accidents black spots according to accidents intensity (Equation 3).

In other study in Khuzestan, according to the importance of accident severity in this province and the number of people whom is injured or killed in these accidents they concluded that in Equation 3 use 12 and 3 for C_1 and C_2, respectively [6]. In this research C_1 and C_2 are considered same as other safety study in this province. Density of EDPO for each segment of road is determined by using density analysis in Arcmap GIS and accident black spots are identified for road network.

Network analysis is used for determining EMS locations. In this analysis, the service area for each EMS location is determined according to travel time-volume for each segment of road. Travel time is calculated according to Equation 5. Fig. 3 shows an example of GIS dataset used in this research.

In this research service area for each available EMS is analyzed in three different response times, 10, 15 and 20 minutes. 3 different service area layers are made for each response time in network analysis. To determine the best road emergency service locations, new EMS locations are recommended according to accident black spots which are identified in the first step of this study. These new EMS locations should have the best service area to cover all accident black spots. According to golden response time, the best locations are those one that their service area covers all accident black spots in 15 minutes. In network analysis, a service area determined with 15 minutes travel time for new EMS locations. Locations which cover accident black spots in 15 minutes time are determined as best locations for EMS services.

VI. RESULTS

Results of this study include accidents black spots analysis and EMS locations analysis results. Ramhormoz-Behbahan route is one of the important roadways in Khuzestan province which connect Ramhormoz and Behbahan cities. This route is 100 kilometres long and it is a two lane, two way road. According to police accident data on average, about 100 accidents occur in this rout annually.

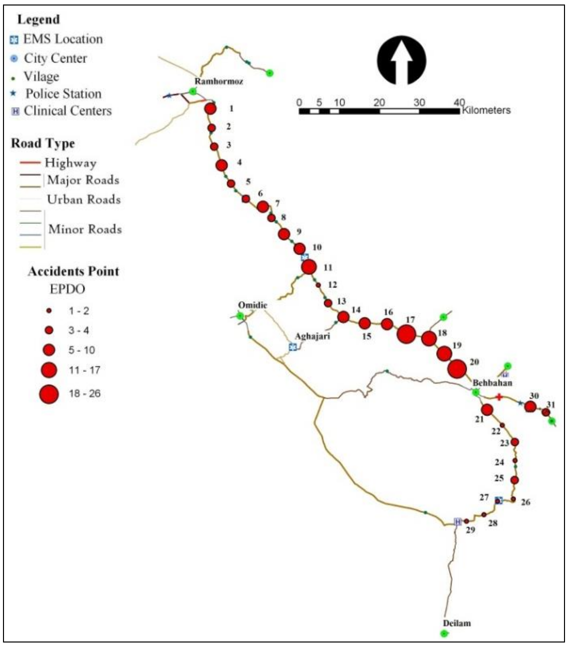

Figure 4. Accident black spots in Ramhormoz – Behbahan Road

A. *Accidents Black Spots*

Fig. 4 shows Ramhormoz - Behbahan which is divided to 5-kilometer sections. Crash severity in each section is calculated according to crash severity method and EPDO amounts are ranked in GIS database. In Figure 5 EPDO rate is illustrates for each section by points and diameter of each point shows EPDO rate for each section. According to this figure, sections 11, 17, 18, 19 and 20 (Kilometres 50-55, kilometres 80-100 from Ramhormoz) has the most crash severity and according to crash severity method these points are ranked as accidents black spot in this road.

There was 5 EMS in this road and service area analysis results show service area for these locations. The result of GIS network analysis for Ramhormoz – Behbahan roadway is shown in Fig. 5.

This figure shows emergency service area for current EMS locations along this route for three different response times, 10, 15 and 20 minute. According to Figure 5 EMS location did not cover the most of black spots even by 20 minute service time. It means that most of crash victims in these points do not have survival chance in tense accidents. In sever accidents (EPDO between 11 and 17) responses time is at least 15 minutes that is a long time for rescue aid.

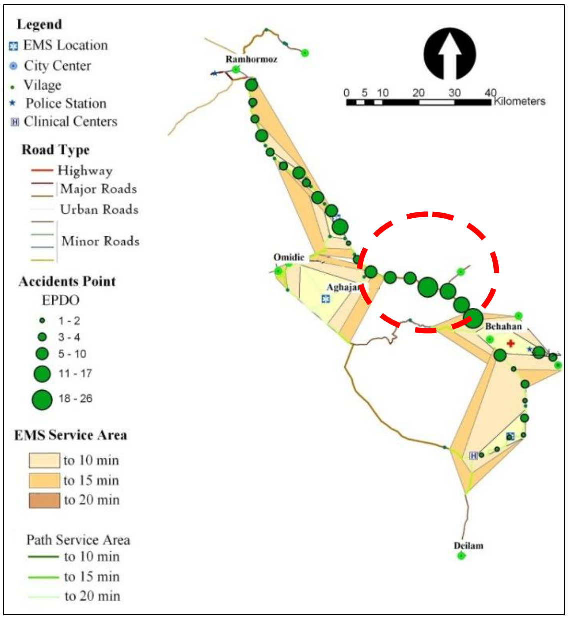

Figure 5. EMS service area with different response time in Ramhormoz – Behbahan Road

B. *Emergency Medical Services Location*

There was 5 EMS in this road and service area analysis results show service area for these locations. The result of GIS network analysis for Ramhormoz – Behbahan roadway is shown in Fig. 5. This figure shows emergency service area for current EMS locations along this route for three different response times, 10, 15 and 20 minute. According to Fig. 5 EMS location did not cover the most of black spots even by 20 minute service time. It means that most of crash victims in these points do not have survival chance in tense accidents. In sever accidents (EPDO between 11 and 17) responses time is at least 15 minutes that is a long time for rescue aid.

According to this study in most of the roads of Khuzestan province, inappropriate EMS locations cause the response time of more than 15 minutes. In addition, EMS technical weakness such as inappropriate ambulance facilities and equipment are other factors influencing the number of road accident victims in Khuzestan province.

According to EDPO results the numbers of EMS recommended in this road. After that, service area for these EMS are analysed by network analysis tools in GIS Arc tools. In the next step which EMS location that cover accidents black spots by 15 minutes is selected. Figure 6 indicates these points according to 15 minute response time (Recommended EMS locations). Service area for these points will cover all black spots for 15 minutes response time. By considering new EMS in these recommended locations, the maximum response time for emergency services will be 15 minutes and the accident victims find more chance of survival.

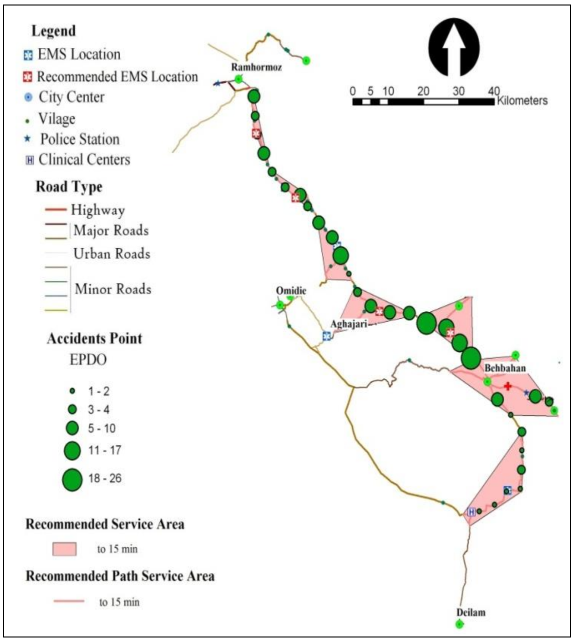

Figure 6. Recommended EMS location for 15 minute response time in Ramhormoz – Behbahan Road

VII. Conclusions and Future Research Directions

Rescue time is an important parameter in each emergency service especially in road accidents. The number of people whom killed in road accidents will be increased by increasing this time. In Khuzestan more than 60% of fatal accidents are pre hospital. This large amount shows the importance of identifying EMS locations to reduce rescue time and increase survival chance of victims.

In this research accident data was analysed in Khuzestan road networks and the accident black spot were determined by crash severity method. The reason for selecting this method is being sensitive to accident intensity which is an important factor in rural accidents. Then, each route was divided to 5 kilometre segments and EDPO was calculated for each segment. After that, they were ranked to show accidents black spots. In the second step, service area for current EMS location was analysed by network analysis tools in ArcMAP GIS for 3 different time intervals (10, 15 and 20 minutes).

The results of this study showed that current EMS locations in Khuzestan road network are not located according to accident black spots. EMS response time was more than 20 minute in many accident black spots. This is the main factor of pre-hospital death in this province road network (60 per cent of death). For decreasing crash victims in Khuzestan road network relocation of road EMS seems necessary. New EMS locations were recommended in this research by considering accident black spots and emergency response time. For this reason the 15 minutes service area was determined for new site. Every site which was covered accidents black spots in this service area is selected.

The results for Ramhormoz-Behbahan roadway illustrated 5 black spots. Kilometres 50-55 and kilometres 80-100 from Ramhormoz were identified as accidents black spots in this route. However, 5 current EMS locations can't cover these accident black spots even by 20 minutes response time. In other words, these EMS were not located according to accident black spots. The results of Service area analysis for Ramhormuz-Behbahan show 5 new EMS locations. The emergency response time for these new locations is 15 minutes. This means every accident victims will receive rescue aid by 15 minutes and their survival chance will increase.

Results of this research can use for identify accident black spots and their treatment. Furthermore, it shows relocations of EMS according to results of this research, will decrease the number of pre hospital accident death. However, this research for better results needs two other researches. In this research the time between crash and EMS notification is not considered. In other words, it is assumed that the rescue team will send instantly after accident is happened. Research about the potential for automatic collision notification system to use in this province is very useful to decrease EMS rescue time. Also, in this study, project optimisation did not considered for EMS locations and it must be defined for future research for better results.

REFERENCES

[1] World Organization of Health, "Fact sheet number 358," 2013.

[2] D. Moore, "GIS in emergency planning, a spatial analysis of ambulance services," *Spatial Planning Solutions*, Ireland, pp. 2-3, 2002.

[3] H. Ghulam Bham, U. R. R. Manepalli, and M. B. Rural Transportation Center, "Identification and analysis of high crash segments on interstate, US, and state highway systems of Arkansas," Arkansas State Highway and Transportation Department, pp. 3-6, 2009.

[4] L. A. Rodegerdts, *et al.* "Signalized intersections: An informational guide," Federal Highway Administration, United State, no. 6, pp. 120-121, 2013.

[5] F. Zhang, A. Qiu, and Q. Li, "Improve on Dijkstra shortest path algorithm for huge data," in *Proc. Sixth International Conference on Fuzzy Systems and Knowledge Discovery*, vol. 4, 2009, pp. 244-247.

[6] A. Toran Pour and S. J. Hejazi, (2012). "GIS application in ITS location in rural roads," in *Proc. 3rd International Traffic Accident Conference*, Tehran, Iran, 2012.

Alireza Toran pour received the B.Eng. in Civil Engineering from Bu-Ali Sina University, Iran. Also he earned M.Sc. degree in Transportation engineering from Shahid Chamran University of Ahwaz, Iran. Hi is currently a PhD candidate in School of Civil, Environmental and Chemical Engineering at RMIT University, Australia. His research interests are in Road safety with emphasis on the applications of Geographic Information Systems, Data Analysis, and Intelligent Transpiration Systems.

Sara Moridpour holds a Bachelor of Civil Engineering and Master's degree in Transportation Planning and Engineering from Sharif University of Technology, Iran. She received her PhD degree from Monash University. She has 9 years of work and research experience in the field of traffic and transport. Her main research interests include on driving behaviour modelling and analysis, micro simulation, transport network modelling and optimization, transport infrastructure asset management and traffic safety. She has been working in the School of Civil, Environmental and Chemical Engineering, RMIT University, from 2010.