The Role of Geographic Information Systems (GIS) in Road Emergency Services Location and Black Spot Studies

Alireza Toran Pour [1], Dr. Wen Long Yue[2]

[1] Jahad-e Daneshgahi University of Ahwaz, Iran

[2] University of South Australia, Adelaide, Australia

Email: art_turanpoor@yahoo.com

Abstract

Each year more than 200,000 road accidents occur in Iran and road traffic crashes kill nearly 25,000 people, and injure or disabled 300,000 more. Studies show that near 60 to 70 per cent of all road accident deaths occur within the first few minutes at the scene or during transfer to hospital after road accidents. There is a considerable weakness in ambulance crew, equipment and especially in the location of emergency services along the roads. Studies indicate that the locations of emergency services are not appropriate positioned relating to black spots and this problem causes very high pre-hospital deaths in Iran. There is a wealth of medical evidence to suggest a ‘golden hour’ for minimizing casualties after accidents. Within this time frame, victims stand a greater chance of survival and a reduction in the severity of their injuries, if first aid and medical (paramedic or ambulance) assistance can be immediately accessed. Khuzestan province is the most important economic and geopolitical area in Iran. Annually, more than 4000 accidents occur in Khuzestan and near 800 deaths result in these accidents that more than 60 per cent of these numbers were pre-hospital. The purpose of this paper is to describe the use of geographic information system (GIS) in emergency management to determine the best emergency services location along the roads according to black spot information in Khuzestan province as a case study. The results from this study could find a way to best utilize of public resources to minimize social costs.

1. Introduction

Today, road accidents are a serious problem in the words especially in developing countries. According to Word Health Organization (WHO) nearly 3,500 people die on the world's roads every day and tens of millions of people are injured or disabled every year (World Health Organization Fact Sheet, September 2011). One of very important factors in road accidents is medical time response. The benefit of rapid response and treatment of road accident victims is increasingly being recognized in research in road safety strategies. Recent studies indicate that improved medical response and associated technology is an important contributory factor to decreases in the severity of long-term injuries. It is recognized that time is a crucial factor in dealing with medical emergencies resulting from road traffic accidents. The first hour after the trauma is called the ‘golden hour’. If proper first aid is given, road accident victims have a greater chance of survival and a reduction in the severity of their injuries (Moore .D, 2002). The location of emergency medical services (EMS) in roads is very important to decreasing response time. Each year more than 200,000 road accidents occur in Iran and road traffic crashes kill nearly 25,000 people, and injure or disabled 300,000 more. Studies show that near 60 to 70 per cent of all road accident deaths occur within the first few minutes at the scene or during transfer to hospital after road accidents. Khuzestan province is the most important economic and geopolitical area in Iran. Annually, more than 4000 accidents occur in Khuzestan and near 800 deaths result in these accidents that more than 60 per cent of these numbers were pre-hospital (S.J. Hejazi, A. Toranpour, April 2009).

Geographic Information Systems (GISs) have been presented as a powerful analysing tool for civil engineers to help their decision-making processes. Integration of GIS and transportation has led to a trend of analysis, decision making and the implementations of projects which can be done faster and with more confidence. Application of GIS in better and more optimized designation of path, place-finding for parking, determination of black spots in road accidents which is an aspect that most engineers use today. GIS which provides visual and text equipment allows users and experts to view the results of before and after the analysis, and to see possible results with changes in the input data or analysis parameters. The purpose of this paper is to describe the use of GIS in emergency management to determine the best emergency services location along the roads according to black spot information in Khuzestan province as a case study.

2. Determination of Black Spot in Road Accidents

It is very important that road accident black spots recognized according to accidents and traffic data and road information. There are many methods for this reason, but today five significant methods determine to identify accident black spots.

2.1 Frequency method

The frequency method ranks locations by the number of accidents. The location with the highest number of accidents is ranked first, followed by the location with the second highest number of accidents, and so on. This method does not take into account the differing amounts of traffic at each location. Therefore, the frequency method tends to rank high volume locations as high accident locations, even if those locations have a relatively low number of accidents for the traffic volume. In addition accident severity has been neglected in this method. Many agencies use the frequency method to select a group of high-accident locations, and then use some other method to rank the locations in order of priority.

Although this method is very simple but, the crash frequency method does not take into account crash severities, such as fatalities and /or serious crashes. This method ranks high-volume locations as high-crash locations which cause some locations that are not high-crash locations to be looked at and further evaluated.

2.2 Rate method

The accident rate method compares the number of accidents at a location with the number of vehicles or vehicle miles of travel at a location. This comparison results in an accident rate. The rate is stated in terms of “accidents per million vehicles” for intersections (and other spots), and “accidents per million vehicle-miles of travel” for segments. The locations are then ranked in descending order by accident rate.

2.3 Frequency-rate method (Matrix method)

This method takes accident number and accident rate as the criterion, the level axis denotes accident number, upright axis presents accident rate. One matrix cell expresses one section of road. The matrix cell value shows the degree of risk of section. The riskiest section has the highest accident number and accident rate in down right corner of the matrix. It is merit for method to think over the accident number and accident rate, but there are some shortcomings. It can show the degree of risk of section, but cannot distinguish these sections in which accident number is low and accident rate is high or accident number is high and accident rate is low, only to regard them as nothing of Black spots and can’t consider the criterion and severity of accident.

The frequency-rate method provides a list of high- crash locations that are then evaluated using other methods. Sites that should be investigated further might not be and sites that should not be investigated might be, causing time to be wasted. This method does not take into account crash severity, such as fatalities and/or serious crashes (Ghulam H. Bham, Ph.D. and Uday R. R. Manepalli, February 2009).

2.4 Quality Control Method

The quality control methods consider various highway categories to rank high crash locations. The method compares site crash frequencies, densities, or rates against predetermined average values for sites with similar characteristics.

2.4.1 Number Quality Control Method

The number quality control method applies statistical analysis to find a particular crash site's frequency/density and then com pares it with the mean frequency/density for similar sites. The number quality control method is used on sites where crash frequency and crash density are much greater than other sites across the region. The formula to find the critical crash rate at a roadway location is as follows (Ghulam H. Bham, Ph.D. and Uday R. R. Manepalli, February 2009):

$$\mathrm{F_c} = \mathrm{F_a} + \mathrm{k}\sqrt{\frac{\mathrm{F_a}}{\mathrm{M}}} + \frac{1}{2\mathrm{M}} \qquad (1)$$

Where:

Fc = critical rate for a particular location,

Fa = average crash frequency/density for all road locations of like characteristics,

k = probability factor determined by the level of statistical significance desired for Fc, and

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

2.4.2 Rate Quality Control Method

The rate quality control method is used in the identification of hazardous road location s by means of a statistical test which compares the traffic crashes rates for roadway segments and intersections with similar characteristics to determine if a site may have a higher rate of traffic crashes. The formula to find the critical crash rate at a roadway location is as follows (Ghulam H. Bham, Ph.D. and Uday R. R. Manepalli, February 2009):

$$\mathrm{R_c} = \mathrm{R_a} + \mathrm{k}\sqrt{\frac{\mathrm{R_a}}{\mathrm{M}}} + \frac{1}{2\mathrm{M}} \qquad (2)$$

Where:

Rc = critical rate f or particular location (crashes per million vehicles or c rash per million vehicle-km),

Ra = average crashes rate for all road locations o f like characteristics (crashes per million vehicles or million vehicle-km),

k = probability factor determined to be the level of statistical significance desired for Rc, 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.

2.6 Crash severity method

The severity method is based on converting each crash to a "property damage only" (PDO) equivalency. The severity of a crash is determined by the most severe injury involved in the incident regardless of the number of injuries (for example, if a crash has one A type injury and six C type injuries, then it is classified as an A type crash). The equivalent property damage only (EPDO) index is calculated using calibrated coefficients based on crash cost data and was last calibrated in 1995 (Highway Safety Manual, spring 2008). The severity index (SI) is essentially the EPDO for the average crash and is calculated by dividing the EPDO by the number of crashes. This method is generally biased towards locations that have more severe crashes (such as rural locations) and is sensitive to the severity of the injuries involved in crashes.

$$\mathrm{EPDO} = \mathrm{C}_1(\mathrm{K}+\mathrm{A}) + \mathrm{C}_2(\mathrm{B}+\mathrm{C}) + \mathrm{PDO} \qquad (3)$$

$$\mathrm{SI} = \frac{\mathrm{EPDO}}{\mathrm{N}} \qquad (4)$$

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 (currently, 12.0)

C2 = EPDO constant for B and C type crashes (currently, 3.0)

SI = severity index

N = Number of total crashes

3. Shortest Path Algorithm

With the popularity of the computer and the development of the geographic information science, GIS has been increasingly extensive and in-depth applications for its powerful functions. As one of the most important functions, network analysis has played an important role in lots of fields, such as electric navigation, traffic tourism, urban planning and electricity, communications, and other various pipe network designs and so on. The key problem about network analysis is his shortest path analysis. The shortest path analysis not only refers to the shortest distance in general geographic sense, but also extends to other measurements, such as time, cost, and the capacity of the line. Correspondingly, the shortest path analysis is turned into the problem of the fastest path, the lowest cost and so on. With the map scale of the nationwide increased, such as the national map with the scale of 1:5 million(the total 20,000 pieces all round the nation, each ones including about three thousands nodes), the huge network analysis is necessary. The classical algorithm Dijkstra is the theoretical foundation for solving the problem about the shortest path (Fuhao ZHANG, Ageng QIU, Qingyuan LI, 2007).

3.1 Dijkstra Algorithm Principal

Hypotheses that D = (V,A,w) is non-negative weights network, V = (v1,v2,…,vn). Then the min D (vi,vj) ∈A satisfies the function:

$$u_1 = 0$$

$$u_j = \min\left(u_k + w_{kj}\right) \qquad (5)$$

$$(j = 1,2,3, \ldots, n)$$

The shortest path from vertex v1 to other vertex in D arranges from large to small as follows:

$$u_{i1} \leq u_{i2} \leq \cdots \leq u_{in}$$

Here $i_1 = 1$, $u_{i1} = 0$, then from equation (5) we can obtain:

$$u_{ij} = \min\{u_{ik} + w_{ikij}\}$$
$$k \neq j$$
$$= \min\{min\{u_{ik} + w_{ikij}\}, min\{u_{ik} + w_{ikij}\}\} \qquad (j = 2,3,\ldots,n)$$
$$k < j \qquad\qquad k > j$$

If $If\ k > j\ , u_{ij} \geq u_{ij}\ , and\ w_{ikij} \geq 0\ , then\ we\ can\ obtain$:

$$u_{ij} \leq u_{ik} + w_{ikij}$$

So

$$u_{ij} \leq \min\{u_{ik} + w_{ikij}\}$$
$$k > j$$

So

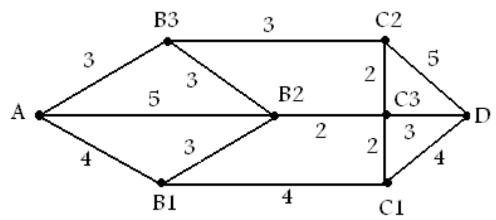
$$u_{ij} = \min\{u_{ik} + w_{ikij}\}$$
$$k < j$$

We can get the following equation easily:

$$u_{i1} = 0$$
$$u_{ij} = \min\{u_{ik} + w_{ikij}\}$$
$$k < j$$

In $(u_{i1}, u_{i2}, \ldots, u_{in}), u_{ij}$ is the shortest length of (u_i, u_i) , $j = 1,2,\ldots,n$

Figure1. A network, its Adjacency matrix and its distance matrix



$$\begin{array}{c} \left\{\begin{pmatrix} 0&1&1&1&0&0&0&0\\ 1&0&1&0&1&0&0&0\\ 1&1&0&1&0&0&1&0\\ 1&0&1&0&0&1&0&0\\ 0&1&0&0&0&0&1&1\\ 0&0&0&1&0&0&1&1\\ 0&0&1&0&1&1&0&1\\ 0&0&0&0&1&1&1&0 \end{pmatrix}\right\} \begin{matrix} A\\ B1\\ B2\\ B3\\ C1\\ C2\\ C3\\ D \end{matrix} \\ \text{adjacent matrix} \end{array}$$

$$\begin{array}{c} \begin{matrix} A & B1 & B2 & B3 & C1 & C2 & C3 & D \end{matrix} \\ \left\{\begin{pmatrix} 0&1&1&1&\infty&\infty&\infty&\infty\\ 1&0&1&\infty&1&\infty&\infty&\infty\\ 1&1&0&1&\infty&\infty&1&\infty\\ 1&\infty&1&0&\infty&1&\infty&\infty\\ \infty&1&\infty&\infty&0&\infty&1&1\\ \infty&\infty&\infty&1&\infty&0&1&1\\ \infty&\infty&1&\infty&1&1&0&1\\ \infty&\infty&\infty&\infty&1&1&1&0 \end{pmatrix}\right\} \begin{matrix} A\\ B1\\ B2\\ B3\\ C1\\ C2\\ C3\\ D \end{matrix} \\ \text{distancematrix} \end{array}$$

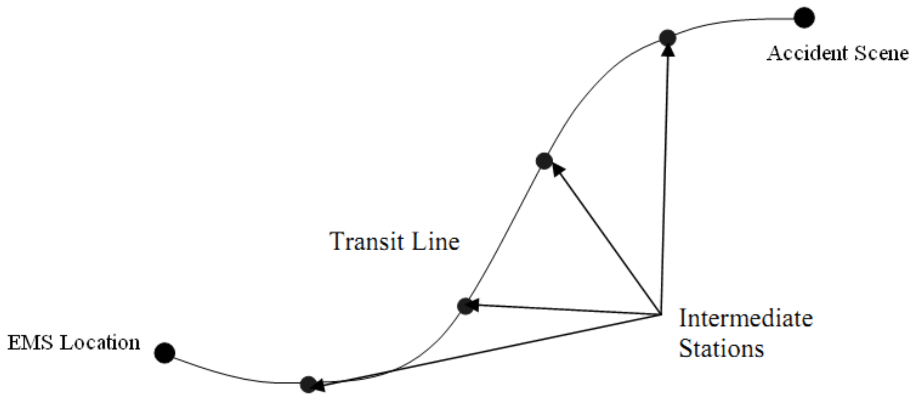
A simple network is shown in figure 1. The adjacency matrix and the distance matrix are obtained based on the relationship of distance and the vertex. It is easy to get the shortest distance from vertex A to vertex D based on the Dijkstra algorithm (Fuhao ZHANG, Ageng QIU, Qingyuan LI, 2007).

3.2 Shortest path criteria

The station location problem along a transit line (Figure 2) is a challenging problem. The positions of stations can be determined based on a lot of parameters such as, the user cost, right-of-way cost, construction cost etc. But when arrive time is important the user's perspective the travel time to the station from home is the most important deciding factor as the freeways and arterial streets are heavily congested during rush hours (Samanta .S, , Manoj K. Jha, Charles O. Oluokun,Travel, July 25-29, 2005). This factor is a principal factor to EMS location because sometimes seconds have very important for survive accident victims. The in-vehicle travel time is less significant 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. So, a good candidate location will be the one with higher degree of accessibility.

The problem can be described as an optimization problem where the alignment of the transit line between two points, e.g., EMS location and accident scene are given (Figure2). The positions of the intermediate stations are to be determined optimally. Though the problem is associated with various factors governing the final locations of the stations, the travel time cost can be identified as the predominant component to decide the optimal solution. The aim is to model the problem based on the travel time cost.

Figure 2: Station Location Problem



The Geographic Information System (GIS) is an emergent tool used to analyze the spatial data functionally for various transportation problems. Network Analyst, an extension of ArcView GIS, which is used to calculate the travel time cost, is integrated with the optimization algorithm to obtain the optimal location of a station. For this means we use travel time from travel time –volume equation for using in path in Dijkstra algorithm.

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

Where:

t: Travel time (min)

V: traffic volume that in this equation equal to Daily Hour Volume (DHV) and: $DHV = t$ ×ADT[1] (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 parameter from road type. In most study β= 0.15 and n =4.

[1] Average Daily traffic

4. Methodology

The overview of the methodology for system development can be seen the Figure 3 below, and a brief description of each phase will follow. In this paper police accidents data from 2006 to 2009 were collected from Khuzestan Police Officers. Also for identify accident black spot crash severity method has been used so after data collection, EPDO is calculated and input in GIS database. In addition for calculating travel time- volume, speed in all of roads is inserted in a special field in GIS road map. In figure 4 shows a part of GIS map data field that is used in this project.

Figure 3: The overview of the methodology for system development

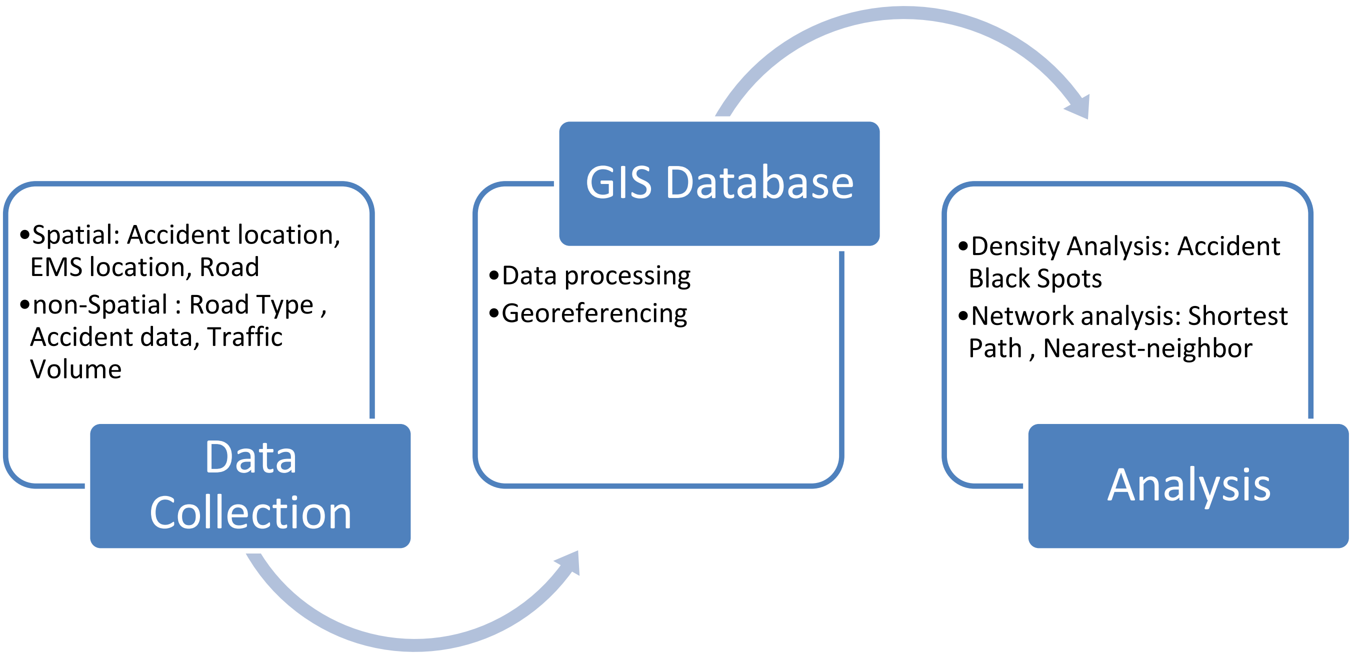


Figure 4: A part of GIS map data filed

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

5. Results

Figure (5) shows 5-kilometer sections of Ramhormoz - Behbahan highway as an example of Khuzestan road network which is categorized based on EPDO. According to this figure, the sections 11, 17, 18, 19 and 20 had the most crash severity and are accident black spots in this route. In addition, figure (6) shows service area of EMS location along the route for three different response times, 10, 15 and 20 minute respectively. According to figure (6) EMS location did not cover most of black spots even by 20 minute service area. It means that most of crash victims in these points do not have chance to survival in tense accidents. In accidents point with less severity (EPDO 11-17) response time are at least 15 minute that is very long for rescue aid.

In most Khuzestan roads, inappropriate EMS location cause to response time were more than 15 minute. In addition, EMS technical weakness such as ambulance and equipment are other factors in significant and dramatically statistic of road accidents victims in Khuzestan province.

Figure (7) indicates recommended EMS location according to 15 minute response time that analyzed by GIS network analyze. In recommended EMS pay special attention to accident black spots as with displacement of EMS in recommended location rescue time in worst condition is 15 minute.

Figure (5) : Accident Black Spots in Ramhormoz – Behbahan Road

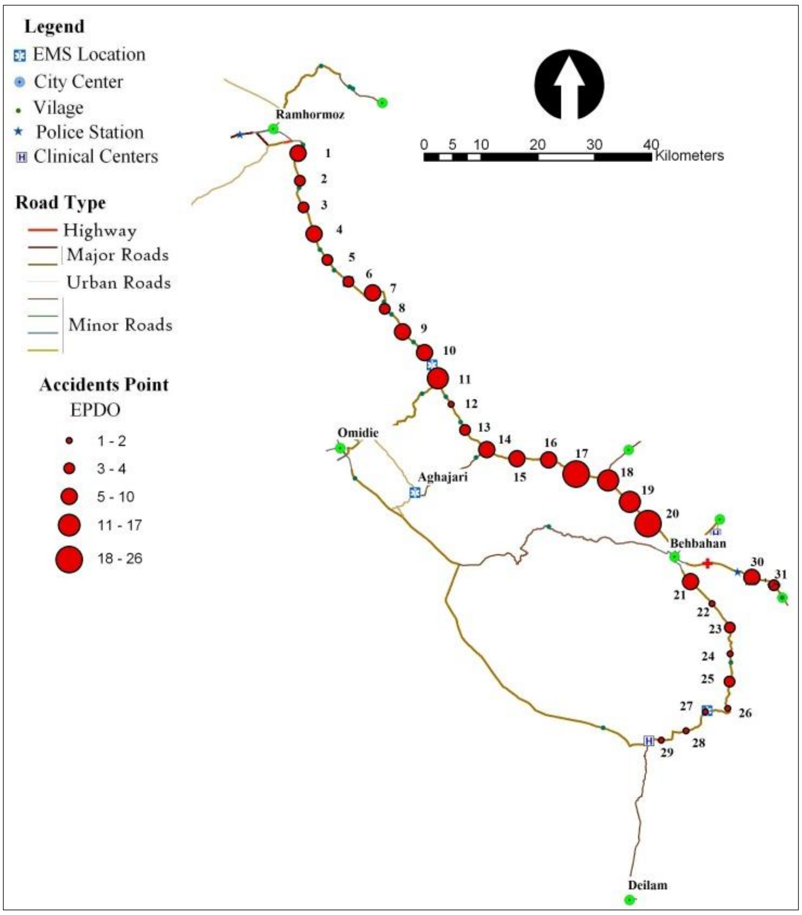


Figure (6) : EMS service area with different response time in Ramhormoz – Behbahan Road

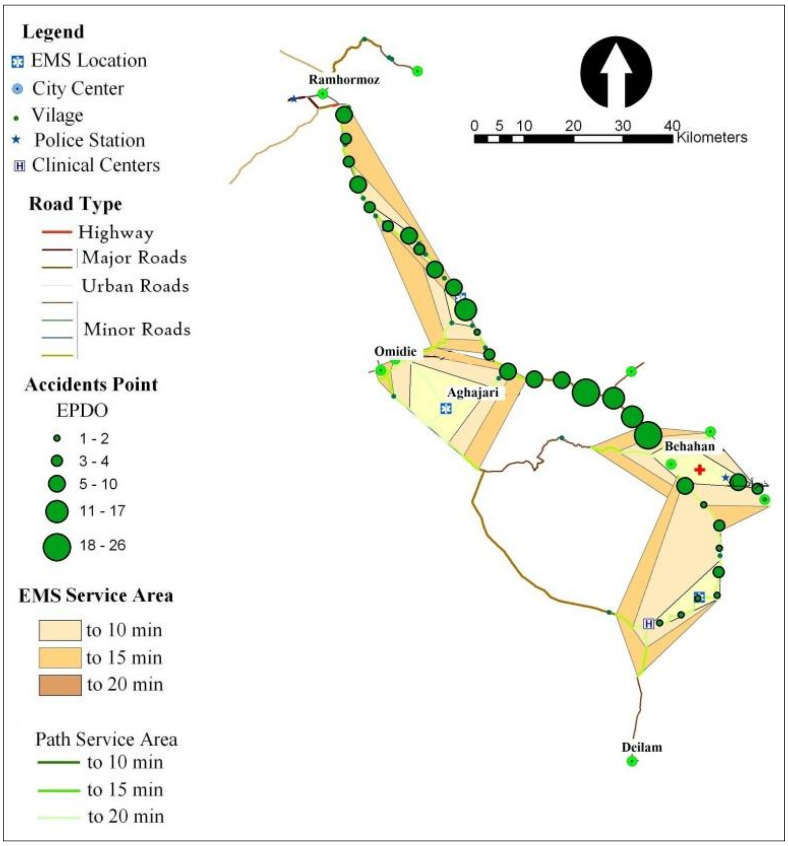
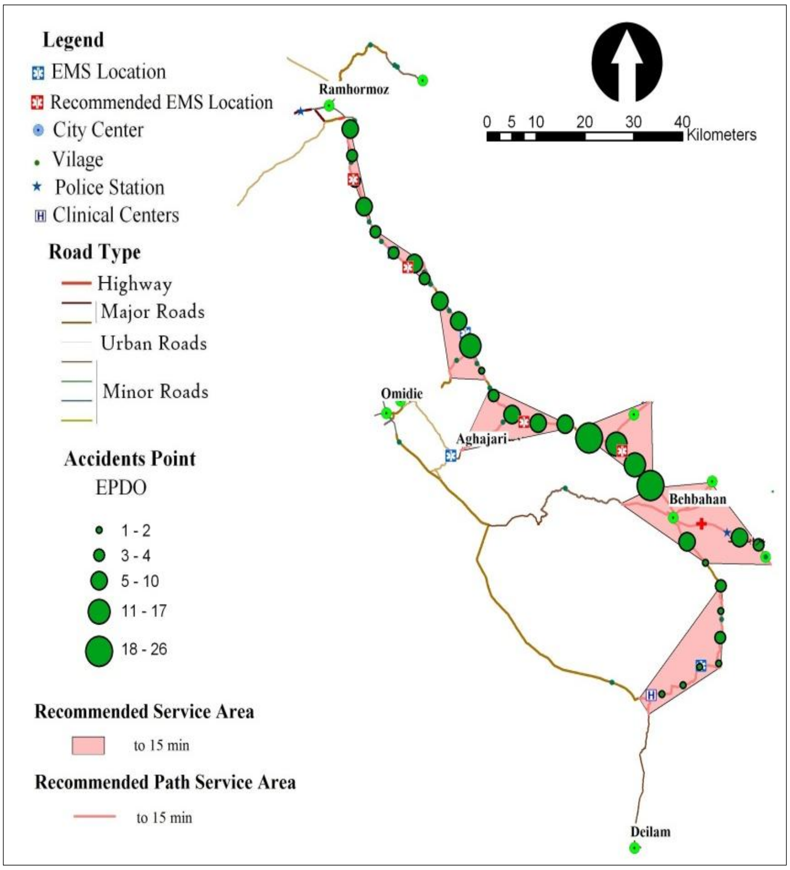


Figure (7) : Recommended EMS location and service area with 15 minute response time in Ramhormoz – Behbahan Road



5. Conclusion

It is recognized that time is a crucial factor in dealing with medical emergencies resulting from road traffic accidents. In addition identify crash black spot is necessary in EMS planning. Today there are many methods to identify crash black spots but EPDO method is biased towards locations that have more severe crashes and is sensitive to the severity of the injuries involved in crashes and many used in rural accidents analysis. EMS locations are very important factor in response time especially in road accidents. GIS provide powerful tools for map analysis such as density analysis, shortest path and nearest-neighbor analyzing. By using GIS and build suitable data base according to EPDO method and travel time it is possible to identify black spots and EMS service area. Inappropriate EMS location along the road network is caused that more than 60 per cent of road accidents victims were pre-hospital in Khuzestan province. This study shows that current EMS locations are not according to accidents black spots. In many accidents black spots response time is more than 20 minute that is the main factor of pre-hospital death. For decreasing crash victims relocation of EMS is necessary. New EMS locations recommended in this study according to 15 minute response time by GIS network analysis and with attention to crash black spots. For decreasing response time less than 15 minute it is essential to decrease distance of EMS locations or re-analyzing GIS data.

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