A Safety Audit Approach in Ranking Urban Road Crash Hotspots Using Analytical Hierarchy Process (AHP)
(Case Study: Region 20 of Tehran)

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Abstract:
Today existence of reliable crash data plays an important role in ranking hotspots and planning for road crash prevention programs. Yet, so many ***Road Crash data-based models*** have been developed for ranking hotspots. But crash data are rarely available in sufficient quantity or accuracy to justify the approaches in many countries and this problem prohibits even using ordinary crash data-based ranking models. To compensate this, the methodology presented in this study, aims to introduce a method for ranking high potential crash risk locations instead of ***actual high crash*** risk locations (locations with actual high crash history). The methodology used, involves defining a Safety Deficiency Value (SD-Value) to rank urban hotspots. SD-Value is defined as a number denoting the lack of safety in a distinct location and is measured by direct field inspection and measurement of crash contributing factors. The more the SD-Value is, the greater is the priority of location in the ranking. Road Crash contributing factors considered in this study have been Lighting, Marking and Signing Inadequacy, Not provided enough sight distances, Inadequate Drainage, Not Enough Pedestrian Facilities (if needed), Not Providing Safety Equipment (if needed), Existence of Effective Pavement Failures and Excessive Speeds of Vehicles. On the other hand, Road Crash contributing factors have different effects on lowering the safety level in crash hotspots. The importance weight of each factor has been calculated based on an analytical hierarchy approach (AHP). Moreover as the risk levels and the weights of contributing factors may be different in roadways and intersections, the hotspot type (the type of location) must also enter into the methodology. The total SD-Value of a location is calculated as the summation of the amount of each contributing factor times its respective weight of importance, regarding the location type. Finally to illustrate the methodology, an actual ranking problem has been followed as a case study for 7 hotspots of region 20 of Tehran, Iran. In this case study, the reported hotspots by the local officials, have been carefully inspected by a RSA team and contributed factors have been measured and based on the results, the ranking methodology has been applied.

1 INTRODUCTION

Worldwide, over 1.2 million people die each year on the world's roads, and between 20 and 50 million suffer non-fatal injuries. In most regions of the world this epidemic of road traffic injuries is still increasing (World Health Organization, 2009). Without increased efforts and new initiatives, the total number of road traffic deaths worldwide and injuries has been forecasted to rise by some 65% between 2000 and 2020 (World Health Organization, 2004). Economically, the cost of road crash injuries is estimated at roughly 1% of gross national product (GNP) in low-income countries, 1.5% in middle-income countries and 2% in high-income countries. As well, on current trends, by 2020, road crash injury is likely to be the third leading cause of disability-adjusted life years lost (World Health Organization, 2004).

Recognizing the need for reducing the social and economic costs of road crashes, road agencies establish highway safety improvement programs. The approach commonly followed is referred to as accident hotspots remediation (Sayed, 1997). In such an approach, the phenomenon of accident clusters should be carefully recognized. There is considerable evidence showing that the identification and treatment of such sites with low-cost engineering remedial measures can be extremely cost-effective (Sayer, 1994).

Although, no universally accepted definition of road crash hotspots is given (Geurts and Wets 2003), the locations will in general be described as road crash hotspots. In broad terms, road crash hotspots programs involve the following functions (Sayed, 1997).

- Continuous monitoring of the road network to identify road crash hotspots;
- Analysis of the identified locations to find out what causes them to be crash hotspots;
- Given these locations and their problems, what countermeasures are effective to alleviate the problem?

The first function is usually referred to as the detection phase which defines the scope and size of the "safety problem". For a location to be identified as crash hotspots, it must exhibit a higher crash occurrence than an established "norm". Due to the random nature of crash occurrence, statistical techniques have been widely devised to ensure that only locations that have a "true" higher potential for crashes are identified as crash hotspot. These techniques are usually based on the hypothesis that crashes occur as random events with a known statistical distribution.

Virtisen (2002) describes that high-risk sites are targeted with the aim of improving safety on the road network through remedial treatment of these sites (Geurts and Wets 2003). Any achieved positive effect of safety measures at crash hotspots are denoted as the benefits of the implemented measures. Implementing safety measures is costly, but in theory, all measures generating a positive net-benefit should be applied. However, the restricted funding for hot spot safety work does put a limit to the number of sites that may be treated. Therefore, it is necessary to prioritize sites in order to utilize the limited funds as effectively as possible (Geurts and Wets, 2003).

There are many models used for identification and ranking crash hotspots, some of them are considered in literature review of this research in the next part. As it would be noted, almost all patterns of ranking crash hotspots are set based on crash data. Therefore existence of a reliable crash data plays an important role in road crash prevention programs. However, the problem may arise when dealing with insufficient or unreliable crash data, which may usually be occurred in developing countries.

Generally, despite the presence of traffic police at crash scenes in Iran, achieving the exact crash locations are often impossible due to some problems in data gathering. Of course efforts are underway to correct the police crash forms and to provide them with equipment for more exact registration of crash data. On the other hand, there is no regular program for gathering environmental and traffic data in municipality of Tehran in order to apply them in ranking crash hotspots.

Because of large mentioned deficiencies of ranking crash hotspots based on crash data in Iran, the main purpose of this study is to develop a prioritization model based on field observation and investigation to rank them. In other words, an attempt is made in this research to identify and utilize the road related factors that pose high crash potentiality to the observed locations for ranking them. The method used to identify the importance of each crash contributing factor is AHP. This method will be described in methodology of this research.

2 RANKING CRASH HOTSPOTS

Some methods rank locations by crash rate (crashes per vehicle-kilometers or per entering vehicles), some use crash frequency (crashes per km-year or crashes per year) and some use a combination of the two (Hauer, 1996). More recently, the proportion of crash types considered susceptible to treatment is also used for ranking (Geurts and Wets 2003). Another dimension of diversity in practice is that rank may be determined by the magnitude (either of rate or frequency) or, as is more common, by the amount by which the rate or frequency exceed what is normal for such sites. According to The Bureau of Transport and Regional Economics of Australia (2001) locations are in general classified as crash hotspots after an assessment of the level of risk and the likelihood of a crash occurring at each location (Geurts and Wets 2003). At certain sites, the level of risk will be higher than the average level of same road elements.

As noted before, ranking crash hotspots are mostly based on crash datasets; but reliable crash data is hardly available to apply these approaches in the case of Tehran. Therefore this study's aim is to present a methodology for ranking crash hotspots regardless of crash data. Up to now, limited similar investigations have been carried out. For example Mandloi and Gupta ranked crash hotspots using Geographical Information Systems (GIS) (Mandloi and Gupta 2003). Their model consists of prioritization of crash hotspots determined on a digitized map. They scored different locations based on the assessment of some parameters leading to crashes on each site. These parameters include road width, number of lanes, approximate traffic volume, type of road, drainage facilities, pavement surface condition, frequent vehicle types, presence of shoulders, edge obstructions, median barriers and radius of horizontal curves. Based on the site condition, a score is given to each parameter of the site and the final score of each site was calculated as the sum of the sub-scores of all parameters. This final score was used directly in ranking. In another research (Pirdavani, 2007), a method was proposed to identify and define relevant criteria implying crash hotspots' characteristics, then a value was given to each criterion in order to develop a model to prioritize crash hotspots. To do this, the "Delphi" method was adopted and a prioritization model was developed, using "Multiple Criteria Decision Making" method (Pirdavani, 2007).

3 RESEARCH METHODOLOGY

The researchers generally define crashes as being a consequence of driver behavior that is not correctly matched with the demands of the road environment or to vehicle characteristics, or to both (Geurts and Wets 2003). The demands of the road environment vary due to factors such as traffic flow rates, geometric features of the road and type of road. Drivers normally adapt their performance level to the demands of the road system. A crash occurs when the driver's performance level is insufficient to meet the performance demands of the road environment.

Most of the time, driver capabilities exceed performance demands. Crash hotspots are points of peak performance demand. Engineering improvements in the road network lower performance demands on the driver while it increases the safety margin between the driver's performance level and the performance demands of the road environment, and reduces the probability of a crash (Geurts and Wets 2003).

Based on the above discussion, this research comprises of the following steps:

- Identification of crash contributing factors (Road Environment Demand Factors)
- Finding the importance of each crash contributing factor in a quantitative basis and developing an index shows the safety deficiency in each site
- In-situ observation of distinct crash hotspots, measuring the crash contributing factors and finding the score (in term of safety deficiency value) in each location for final ranking.

Regarding the lack of the statistical resources, Roadway (or Intersection) safety deficiency (SD) denotes the lack of safety in a distinct location. In fact SD value is substituted with the crash related independent variables in ordinary crash predicting models. Though there are so many researches and experiences denoting the environmental contributing factors, resulting to the crashes (Pirdavani 2007 and Campbell 2003), to discover the exact factors affecting SD values, a survey also was conducted. Accordingly, important contributing factors distinguished as following[1]:

- Poor lighting
- Poor marking
- Poor signing
- Poor sight distances
- Poor drainage
- Poor pedestrian facilities
- Inadequate other needed equipment (sand barrels, guardrails, road studs, signals, etc if needed)
- Poor pavement condition
- Speed violence

The above factors show the homogeneity (the more the factor value, the worse the safety condition), as well as the independency. Each factor's value should be computed based on field observation via a Road Safety Audit (RSA) procedure. Therefore to better setting the data, each factor must be quantified. Table 1 shows the contributing factors as well as how to measure them in a quantitative basis. As Table 1 shows, the amount of each factor varies between 0 and 100; while using medial amounts are also allowed. The upper limit denotes the worst condition, whilst the lowest amount represents the best.

[1] Assuming "drivers select their speed based on the roadway conditions", all contributing factors are in correlation with roadway and therefore using the auditing approach would be useful.

Table 1 – Quantifying Crash Contributing Factors

Contributing Factor	Symbol	Measurement*	
		Intersections	Roadway links
Lighting	X_1	0 if with proper lighting and 100 if without lighting	
Marking	X_2	0 with good condition of marking and 100 with no marking	
Signing	X_3	Percentage of improper signings, Damaged or without signs	
Sight Distances	X_4	0 if provided and 100 if not provided	Percentage of the length without sight distance
Drainage	X_5	0 if good condition and 100 if without	
Pedestrian Facilities	X_6	$100\times(\frac{Length\ \ without\ \ Longitudinal\ \ Pedestrian\ \ Facilities}{Longitudinal\ \ walking\ \ length}+\frac{Required\ \ Crossing\ \ Facilities}{Total\ \ crossing\ \ facilities})$	
Safety Equipment	X_7	Judgment on percentage of equipment loss	
Pavement Failure	X_8	$\frac{Affecting\ \ Area\ \ of\ \ Damaged\ \ pavements}{Total\ \ Pavement\ \ Area}$	
Speed	X_9	100 if hazardous and 0 if not hazardous[2]	
* The amount between 0 and 100 is allowed according to the opinions of RSA team.			

It should be stated that the importance of each contributing factor is not necessarily the same as the others and the proper weights must be considered. The total score of a site denoting the deficiency of safety in a distinct site (SD-value) is calculated as is shown in Equation 1.

$$SD = \sum_{i=1}^{9} \alpha_i X_i \qquad \text{Equation 1}$$

SD = Safety Deficiency value

X_i = The amount of i^{th} crash contributing factor derived from Table 1 and field measurements

α_i = the weight of each X_i derived from an AHP approach

The weights of the contributing factors (α_i) are derived based on AHP in this study. This process is considered as one of the most popular analytical techniques for complex decision-making problems. Saaty developed AHP. This method which is found by Saaty decomposes a decision-making problem into a system of hierarchies of objectives, criteria, and alternatives. An AHP hierarchy can have as many levels as needed to fully characterize a particular decision situation.

[2] Hazard speed condition here, is defined as when most drivers exceeding the speed limit. Speed limit is the posted speed limit (if there is a speed limit sign) or the statutory speed limit (if there is no speed limit sign)

The main procedure of AHP technique is as follows:

Step 1: Determine the objective and the evaluation criteria and develop a hierarchical structure with a goal or objective at the top level, the criteria at the second level and the alternatives at the third level. (Number of levels may be different based on the extent of the problem)

Step 2: Determine the relative importance of different criteria with respect to the goal or objective.

- Construct a pair-wise comparison matrix using a scale of relative importance. The judgments are entered using the fundamental scale of AHP (Saaty 1980, 2000). To do this, suppose:

w_i = weight for criterion i, i=1,.., n where n = number of criteria

$a_{ij} = w_i / w_j$ = the result of a pair-wise comparison between criterion i as compared to criterion j

W = matrix of pair-wise comparison values, a_{ij}

Thus a set of pair-wise comparisons can be represented as the matrix below.

$$W= \begin{array}{c|ccccc} & x_n & \cdots & x_3 & x_2 & x_1 \\ \hline x_1 & a_{1j} & \cdots & a_{13} & a_{12} & 1 \\ x_2 & a_{2j} & \cdots & a_{23} & 1 & a_{21} \\ x_3 & a_{3j} & \cdots & 1 & a_{32} & a_{31} \\ \vdots & \vdots & & \vdots & \vdots & \vdots \\ x_n & 1 & \cdots & a_{i3} & a_{i2} & a_{i1} \end{array} = \begin{vmatrix} \frac{w_1}{w_j} & \cdots & \frac{w_1}{w_3} & \frac{w_1}{w_2} & \frac{w_1}{w_1} \\ \frac{w_2}{w_j} & \cdots & \frac{w_2}{w_3} & \frac{w_2}{w_2} & \frac{w_2}{w_1} \\ \frac{w_3}{w_j} & \cdots & \frac{w_3}{w_3} & \frac{w_3}{w_2} & \frac{w_3}{w_1} \\ \vdots & & \vdots & \vdots & \vdots \\ \frac{w_i}{w_j} & \cdots & \frac{w_i}{w_3} & \frac{w_i}{w_2} & \frac{w_i}{w_1} \end{vmatrix}$$

- Find the relative normalized weight (w_j) of each criterion by (i) calculating the geometric mean of the i-th row, and (ii) normalizing the geometric means of rows in the comparison matrix.
- Determine the maximum Eigen value (λ_{max}) that is the average of matrix. Calculate the consistency index CI = ((λ_{max}) - n) / (n - 1). The smaller the value of CI, the smaller is the deviation from the consistency.
- Obtain the random index (RI) for the number of criteria used in decision making.
- Calculate the consistency ratio CR = CI/RI. Usually, a CR of 0.1 or less is considered as acceptable, and it reflects an informed judgment attributable to the knowledge of the analyst regarding the problem under study.

Step 3: The next step is to compare the alternatives pair-wise with respect to how much better (i.e., more dominant) they are in satisfying each of the criteria, i.e., to ascertain how well each alternative serves each criterion. If there is N number of alternatives, then there will be M number of N x N matrices of judgments, since there are M criteria. Construct pair-wise comparison matrices using a scale of relative importance. The judgments are entered using the fundamental scale of the AHP method (Saaty, 1980, 2000). The steps are the same as those suggested under main step 2.

Step 4: The next step is to obtain the overall or composite performance scores for the alternatives by multiplying the relative normalized weight (w_j) of each criterion (obtained in step 2) with its corresponding normalized weight value for each alternative (obtained in step 3), and summing over the criteria for each alternative.

Note that there are some software packages, such as Expert Choice which can do the AHP calculations and give the exact values. This Package has been used for determining the weights of contributing factors in this research.

4 APPLICATION

In literature, several approaches have been proposed to determine weights (Saaty, 1980, Hwang and Lin 1987, and Hwang and Yoon1981). The majority of them can be classified into either subjective approaches or objective approaches depending on the information provided. The objective approaches determine weights based on objective information (i.e. a decision matrix) and these weights may be different from one decision matrix to another. In other words, weights which are calculated from two decision matrices with the same criteria but different alternatives will be different (not unique). The subjective approaches select weights based on preference information of criteria given by the Decision Makers (DM). Amongst others, they include the eigenvector method (Saaty, 1977), the weighted least square method (Chu, Kalaba and Spingarn 1979) and the Delphi method (Hwang and Lin 1987). This research follows a subjective approach because the purpose of this study is to make one unique weight vector to be used in a comprehensive model.

The simple used hierarchy is illustrated in figure 1. The analysis is carried out for roadway links and intersections, individually.

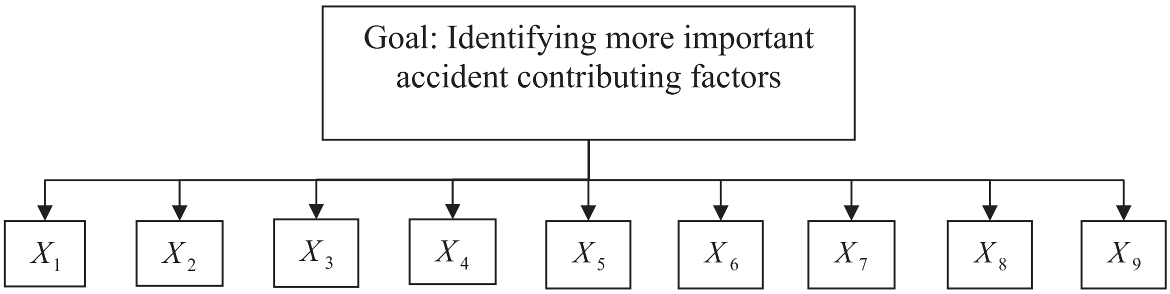

Fig1- Hierarchy for finding crash contributing factor weights

To form the judgmental matrix, a survey was conducted and some experts were asked for pair-wise comparing the contributing factors. They also were asked to declare the relative importance weights (denoting the weights of dominant factor in pair-wise comparison in a 1 to 9 basis). The survey was carried out separately for roadway links and intersections. Tables 2 and 3 denote the judgmental matrices resulted from the survey, for roadway links and intersections respectively.

Table 2- Experts' Comparison of Crash Contributing Factors on Roadway Links

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
X_1	1	2	2	1	4	½	2	2	1/4
X_2	1/2	1	1	1	2	½	1	1/2	1/4
X_3	1/2	1	1	1/2	1	1/3	1	1/2	1/4
X_4	1	1	2	1	2	1	2	3	1/4
X_5	1/4	1/2	1	1/2	1	1/2	1	1/2	1/5
X_6	2	2	3	1	2	1	2	1	1/3
X_7	1/2	1	1	1/2	1	1/2	1	1/2	1/5
X_8	1/2	2	2	1/3	2	1	2	1	1/3
X_9	4	4	4	4	5	3	5	3	1

Table 3- Experts' Comparison of Crash Contributing Factors at Intersections

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
X_1	1	2	2	1/3	3	1	3	4	1/2
X_2	1/2	1	1	1/5	2	1	2	2	1/4
X_3	1/2	1	1	1/6	2	1	2	2	1/4
X_4	3	5	6	1	8	4	8	8	3
X_5	1/3	1/2	1/2	1/8	1	2	1	1	1/3
X_6	1	1	1	1/4	½	1	5	4	1/2
X_7	1/3	1/2	1/2	1/8	1	1/5	1	1	1/6
X_8	1/4	1/2	1/2	1/8	1	1/4	1	1	1/7
X_9	2	4	4	1/3	3	2	6	7	1

To find the absolute weights of contributing factors with AHP approach, the Expert Choice Software was used. Using this software, weight values as well as the inconsistency ratio in the comparisons are shown in Table 4. As the Consistency Ratio (CR) values show, the comparisons have been consistent.

Table 4- Weights of Crash Contributing Factors

Contributing factors	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	CR
Roadway Links	0.119	0.069	0.055	0.118	0.049	0.127	0.055	0.094	0.314	0.03
Intersections	0.113	0.067	0.066	0.350	0.054	0.089	0.034	0.033	0.194	0.04

Regarding weight vector and observed values of X_is measured by the RSA team at road crash hotspots, using equation 1, the safety deficiency values can be calculated. The values are directly used in ranking the locations.

5 CASE STUDY - DISTRICT 20 OF TEHRAN

Tehran metropolis, the capital of Iran, is divided by 22 districts. Each district is under the supervision of the local municipality. Traffic deputy in each district is responsible for managing traffic related issues (network analysis of traffic, road safety investigations, transit development, maintenance and rehabilitation, etc). On the other hand, Tehran Traffic and Transportation Organization (TTTO) is the superior part, supervising the 22 traffic deputies and control their activities. TTTO also cooperate with other departments of the municipality to provide the most efficient and safest traffic situation.

To well manage the crash hotspots in road networks, the deputies of districts were asked in this study to provide the TTTO with the list of crash hotspots. To provide the consistency in filling forms, high crash locations were defined as the sections or intersections, with annually 5 crashes or more. Table 5 shows the form used for gathering crash hotspots in each district. As Table 5 shows, the deputies were also asked to prioritize the high crash locations. This would help us to compare the research results with what was declared by the deputies. Consulting the traffic police, the deputies finally send the filled forms to TTTO.

Thereafter, an expert investigation was done for each spot reported by district's traffic deputy. The aim of the investigation was to determine the causes the reported locations were set as crash hotspots. The investigation was carried out according to the principles of RSA. Investigations were done in a quantitative basis (i.e. practitioners were asked to calculate the amount of each X_i according to Table 1). Knowing the values of crashes contributing factors and the weights of them, the SD values can be calculated for each reported location by Equation 1. In this section, the findings of the investigation on different reported locations of District 20 are addressed. SD values can be directly used to rank the crash hotspots.

Table 5- Survey form Used for Gathering Crash Hotspots' Data in Each District

Priority	Exact Address of Accident Prone Location	The Kind of Accident Prone Location (Determine with Asterisk)					Type of the Most Accidents (Determine with Asterisk)						Approximate Number of Accidents Through the Past Year			Expert judgments of the main reasons for Accidents	Proposed Countermeasures
		Road Section (Section Lenth)	Signalized Intersection	Unsignalized Intersection	Roundabout	Others	With Stationary Objects	With Pedestrian	With Other Vehicles	With Cycles or Motorcycles	Deviation, Rolling Over or Falling	Others	Fatal	Casual	Damage		

The traffic deputy of district 20 reported 7 locations as road crash hotspots. These locations are listed in Table 6.

Table 6- Reported Crash Hotspots in District 20, Tehran

Location	ID	Type
Qom–Qeibi Intersection	P1	Intersection
Rajaee–13Aban Intersection	P2	Intersection
Namaz Square	P3	Intersection
Varamin T-junction	P4	Intersection
Qom–Iran Transfo Intersection	P5	Intersection
Alinavaz–Basij Intersection	P6	Intersection
Fadaee–Salman Farsi Intersection	P7	Intersection

After receiving reports, the RSA team investigated safety conditions of each location. In fact the team was to reply this question: What has made this location to be categorized as a crash hotspot? To reply explicitly, the RSA team measured the X_i values according to Table 1 in each site. The results of the investigation are gathered in Table 7.

Table 7- Findings of the RSA Team about Reported Locations

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	SD Value	Rank
P1	25	20	100	25	0	60	30	10	100	136.8	4
P2	0	20	30	0	0	40	0	0	0	20.6	7
P3	0	0	30	0	0	25	0	0	100	70.8	6
P4	25	100	30	20	50	75	30	0	0	86.7	5
P5	30	40	100	50	30	60	60	10	100	176.7	1
P6	50	25	25	25	100	80	30	10	100	152	3
P7	60	30	100	40	40	70	30	0	100	174.6	2

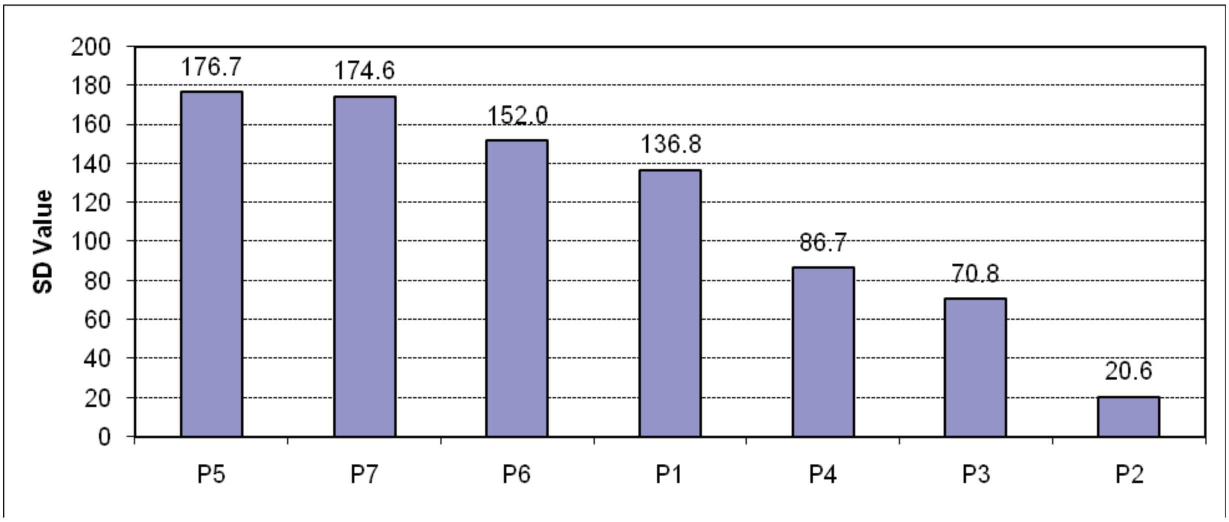

Fig 2- Ranking crash hotspots according to SD index

6 CONCLUSIONS AND RECOMMENDATIONS

As noted in this research, knowing the priority of crash hotspots is vital for scheduling the proper strategy to improve safety situation in such locations. Though there is no unique definition of crash hotspots and constant method for identification, almost all methodologies rely on road crash data for identification and prioritization of road crash locations. On the other hand, a proper road crash dataset has not ever established in some developing countries, though so many efforts are underway. Regardless of existence of a proper database, improving the condition of high crash locations is inevitable. To do this, a simple methodology was developed for ranking road crash hotspots without using road crash statistics. Key factors in dealing with this methodology are:

- The locations are to be ranked must be apparent exactly. Such locations may be listed according to police general reports, complements of living people, etc. The exact details of crashes would definitely help, though they don't exist, sufficiently. Thus this method may be useful in locations with no exact crash data.

- Poor physical condition of the location may cause crashes. To find such condition, an RSA approach was used.
- This paper served 9 crash contributing factors. These factors were mainly selected based on the experts' experiences as well as literature review. More factors (including the traffic volume, percentage of trucks, etc) may be investigated independently or in combination with other factors in more researches.
- To achieve more consistency in ranking conclusions, it is better to do an RSA by constant team at least in each district.
- Each relevant factor has not the same effect on crash occurrences. To find a proper weight of each factor, decision makers were asked about it.
- Estimate of funds needed to be spent in each location and the results in terms of decreasing road crash costs may be considered as a complementary approach in crashes' investigation. Such an approach may be carried out in future investigations.

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