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# Ranking of Hazardous Road Locations in Two-Lane Two-Way Rural Roads with No Crash Record

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## Abstract

Crash data availability is a significant requirement for identifying hazardous roads. However, for roads with poor data sets or no crash record, a method is needed to find and rank road segments independent of the crash records. In this paper, an auditing based methodology is proposed to determine the hazardous locations. A Rural road is investigated by decomposing it first into six elements, and then into safety factors corresponding to each element. The elements are: straight segments, horizontal and vertical curves, bridges, tunnels, merges and intersections, and side road land use. The relative contribution of the elements to the safety of a road segment is determined using the Analytical Hierarchy Process (AHP) via a system of weights which are suggested by an expert panel. Subject to a consistency test of the expert responses, AHP determines the weight of elements. In an independent survey, roads are audited and ranked with respect to their elements. The weighted sum of these ranks is used to calculate a Safety Index (SI) for a road segment. Road segments with the lowest values of SI are identified as the most hazardous locations.

## 1. Introduction

Evaluation of transport safety has been a concern of road authorities for many years. Human, road, environment and vehicle characteristics are the main factors influencing the safety level of road networks (Ogden 1996; Evans 2004). Improvement of road infrastructure, road design, vehicle design and human training contribute to a decline of the number of casualties on rural and urban roads. However, accidents occur as the mobility of people on the road networks increases. There has been considerable research carried out to study transportation safety and enhance the safety performance of roads. Transport researchers have utilized different analysis methods to conduct road safety evaluation.

The first group of researchers considered crash outcomes as the main parameter to evaluate road safety. Statistical modelling has been used to establish a relationship between road, environmental, and traffic characteristics and the number of crashes (Lord, Washngton et al. 2005; Haung, Chin et al. 2009; Lovegrove, Lim et al. 2010). Crash severity investigation has also been carried out using statistical analysis (Quddus, Wang et al. 2010; Zhu, K.Dixon et al. 2010). In some other studies, road, environmental, traffic, human, and vehicle characteristics have been considered as explanatory variables to predict the severity of crashes and explore main factors influencing crash severity (Das, Abdel-Aty et al. 2009; Christoforou, Cohen et al. 2010; Liu, Chen et al. 2010; Schultz, Braley et al. 2010; Sobhani, Young et al. 2010). Naderan and Shahi (2010) and Ma et al. (2008) have used statistical analysis to find out the number of crashes for severity levels.

The second group of researchers approached the problem from a micro-level analysis viewpoint. They have examined *conflicts* instead of crashes since conflicts occur more often than crashes (Federal Highway Administration 2003; Archer 2005). Traffic micro-simulation models have been utilized to replicate a conflict using surrogate safety measures (Rao and

Rengaraju 1997; Davis 2007; Cunto 2008; Federal Highway Administration 2008; Davis and Morris 2009; Guido, Saccomanno et al. 2010; Laureshyn, Svensson et al. 2010).

All the studies using the above two methods of assessment (i.e. statistical modelling and micro-simulation) used either crash or conflict data as the main element of the research. There are two general steps in the application of these methods to an entire, or a part, of a road network. The first step is data collection and data preparation for analysis. The second step is data analysis using statistical or simulation analysis methods.

Although those methods improve the understanding of the safety performance of roads, they all require crash and conflict data. The preparation of such databases is, however, expensive and time-consuming; especially, when the data is prepared for a road network. As a result, there is often a general lack of this type of data. This is particularly the case in developing countries. An alternative approaches is to use road safety audit. Although this method can be conducted to diagnose the existing safety deficiencies (Ogden 1996; Elvik and Vaa 2004), it cannot provide a quantified measure of safety performance. Moreover, a general star rating system is developed by the Australian Automobile Association to rank the safety of the roads based on overall physical conditions (AusRAP 2011).

Overall, therefore, there is a need of developing a framework to rank potential unsafe locations of the road network that has less reliance on crash and conflict data.

In this paper a framework is proposed to carry out a preliminary assessment of the safety level of a road. A road is decomposed into six generic elements and the crash risk of each element is investigated. The six elements are: straight segments, horizontal and vertical curves, bridges, tunnels, merges and intersections, and side road land use. For each road element, a series of factors are identified which contribute to the crash risk of the road element and subsequently the crash risk of the road.

Based on this assessment, the high risk roads can be determined using a quantitative method. Depending on the available budget, the hazardous locations can be treated. The developed framework is based on an expert panel investigation and Analytical Hierarchy Process (AHP) method. Mesbah and Habibian (2006) suggested that AHP method can be used to investigate the importance of factors influencing road safety. The framework proposed in this paper extends the approach developed by those authors. In the second section of the paper, a brief description of the developed framework is provided. Then, the factors involved in the crash risk of each road element are listed. After that, the concept of AHP is explained and finally an application of AHP method is outlined. The paper closes with conclusion and suggestions for future research.

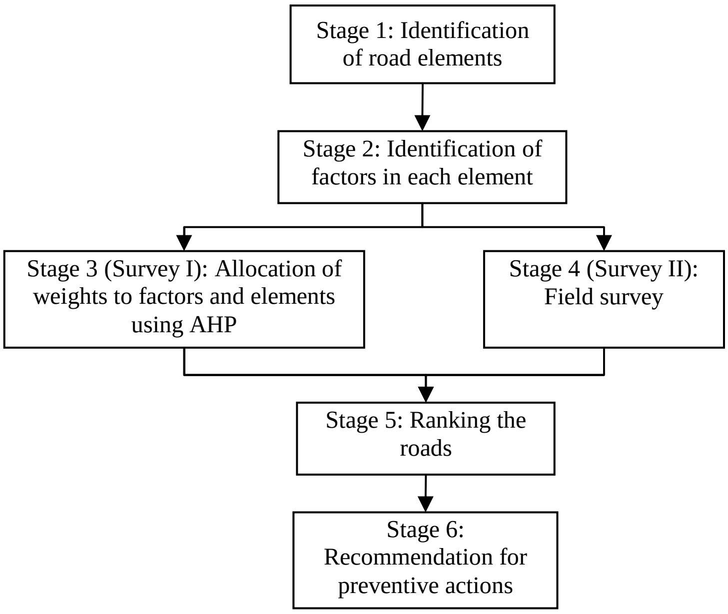
## 2. The Ranking Framework

A rural road consists of a number of elements. The objective of the proposed method is to categorize the safety risks in the elements and quantify this risk. This enables the method to rank and prioritize the roads for preventive actions. The proposed assessment framework is outlined in Figure 1. At stage 1, a road is decomposed to its consisting elements. Then at stage 2 the factors affecting the safety risk of each element are identified. After stage 2, two surveys should be carried out:

- Survey I to determine the relative weight of elements and factors, and
- Survey II to associate a score to roads under each factor.

In Survey I, an algorithm is required to determine the relative weight of the road elements and the respective factors which is the aim of this paper. To this end, an Analytical Hierarchy Process (AHP) is applied. Survey II estimates the condition of road segments for each of the factors. The combined result of Survey I and II provides quantitative values to compare the risk, which provides a measure for ranking of the road segments. This measure is calculated in Stage 5. Finally, more elaborate analysis or suitable remedial measures are recommended to reduce the risk in the roads with priority at stage 6. This paper focuses on Stages 1 to 3 of the proposed framework.

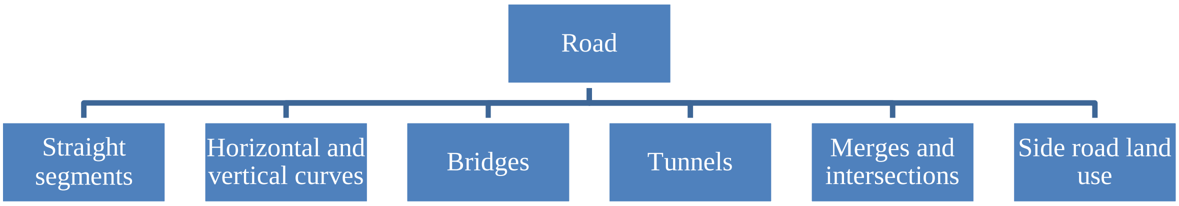
**Figure 1: The structure of the proposed framework**




## 3. Elements and Factors

Stage 1 and stage 2 of the proposed framework are covered in this section which investigates the road elements and factors affecting the safety of a road segment. A road is assumed to consist of six main elements (Figure 2): straight segments, horizontal and vertical curves, bridges, tunnels, merges and intersections, and side road land use.

**Figure 2: Road Elements**




Many factors contribute to the safety of a road element including human, vehicle, and road factors. However, the goal of this study is to determine locations needed to be studied in detail where more data collection is also required. Moreover, it provides a basis for prescribing some treatment on the road.

The factors for each element are listed in Table 1.

**Table 1: Factors in each element**

| |
|---|
| 1. Straight Segments:<br>A. Proper posting of speed limit signs and no overtaking signs<br>B. Lighting poles and reflective signs<br>C. Road marking<br>D. Shoulder width<br>E. Pavement maintenance condition<br>F. Drainage |
| 2. Horizontal and Vertical Curves:<br>A. Speed advisory signs and bend or crest/sag warning signs<br>B. Lighting poles and reflective signs<br>C. Road marking before and in the curve<br>D. Shoulder width<br>E. Combination of horizontal and vertical curves<br>F. Pavement maintenance condition<br>G. Drainage<br>H. Sight distance provision<br>I. Superelevation in horizontal curves |
| 3. Bridges:<br>A. Proper posting of speed limit signs, no overtaking signs, and weight limitation<br>B. Lighting poles and reflective signs<br>C. Road marking<br>D. Reduction in the pavement width and shoulder width<br>E. Pavement maintenance condition<br>F. Drainage<br>G. Guardrails |
| 4. Tunnels:<br>A. Proper posting of speed limit signs, no overtaking signs, and tunnel warning signs<br>B. Lighting and reflective signs<br>C. Combination of a horizontal curve and a tunnel<br>D. Road marking<br>E. Shoulder width<br>F. Pavement maintenance condition<br>G. Drainage<br>H. Entrance protective barriers and illumination |
| 5. Merges and Intersections:<br>A. Proper posting of speed limit signs and warnings<br>B. Lighting poles and reflective signs<br>C. Road marking<br>D. Shoulder width<br>E. Pavement maintenance condition<br>F. Drainage<br>G. Sight distance provision<br>H. Distance to the previous intersection and intersection spacing<br>I. Reducing the speed by appropriate geometry design |
| 6. Side Road Land Use<br>A. Information signs on hotels and restaurants<br>B. Lighting poles and reflective signs<br>C. Road marking<br>D. Shoulder width and direct access to the land use<br>E. Pavement maintenance condition<br>F. Drainage<br>G. Spacing of the rest areas<br>H. Reducing the speed before entering residential areas |

# 4. Analytical Hierarchy Process

The elements and factors discussed in the previous section, may not equally affect the safety of a road. A system of weights therefore needs to be introduced to reflect the contribution to safety of each element and factor. The relative weights of the above elements and subsequent factors are determined using Analytical Hierarchy Process (AHP). As a mathematical procedure, AHP can find the contribution of each item ( e.g., element) in a problem. Moreover, if there is a hierarchy of items, as is the case in this study, where there are elements and then factors, AHP can also attribute a weight to the sub items (e.g., factors).

Mathematically, AHP uses pair-wise comparisons to systematically scale the items. It calculates the eigenvalues of the Relative Weight Matrix *(RWM)*, and determines the relative weights by determining the eigenvector (Saaty 1990; Vaidya and Kumar 2006). The process is as follows:

1. Set up a RWM for each level in the hierarchy
2. Calculate the eigenvector of the RWM(s)
3. Measure the consistency of the comparisons.

## 4.1. Construction of Relative Weight Matrices

In AHP, the weight of items, is found by using a RWM (Saaty, 1990). This Process is based on pair-wise comparisons. An expert is asked to compare each two items and associate a relative importance to the pair. The relative importance is assessed using the scale in Table 2. If item ‘x’ is more important than item ‘y’ then this importance is mapped into a scale of 1 to 9 where 9 is the absolute importance. In Saaty’s scale, the relative importance of item ‘y’ to item ‘x’ is the reciprocal of the importance of item ‘x’ to item ‘y’ (Saaty and Wong 1983).

**Table 2: Relative Importance of Categories (Saaty and Wong 1983)**

| Relative Importance | Qualitative Scale | Comments |
|---|---|---|
| 1 | Equal | |
| 3 | Moderate importance | |
| 5 | Strong importance | |
| 7 | Demonstrated importance | |
| 9 | Absolute importance | |
| 2,4,6,8 | Values between the levels above | Used only when a compromise in comparisons is necessary |
| Reciprocal | If importance of item x to item y is $a_{i,j}$ then the importance of item y to item x is $a_{j,i} = 1/a_{i,j}$. | |

AHP uses all possible pair-wise comparisons to calculate the weights. For example, when there are three items ( e.g., elements or factors); *x*, *y* and *z*, ideally two comparisons would be enough, but AHP compares all possible comparisons, that is three in this case; "*x* and *y*", "*y* and *z*", and "*x* and *z*". The extra comparison(s) are used to:

- solve the unknown situations or transitivity gaps (e.g., if x>y and x>z then an extra comparison between ‘y and z’ is required),
- verify consistency in the experts judgments (e.g., if x>y and y>z then obviously x>z).

Adding all possible comparisons gives the RWM:

**Table 3: The Relative Weight Matrix, (A)**

| Matrix A | a | b | c |
|---|---|---|---|
| a | 1 | $a_{1,2}$ | $a_{1,3}$ |
| b | $a_{2,1}$ | 1 | $a_{2,3}$ |
| c | $a_{3,1}$ | $a_{3,2}$ | 1 |

An expert is asked for the values of the elements of the upper triangle, $a_{1,2}$, $a_{1,3}$, $a_{2,3}$; where $a_{i,j}$ is the relative preference of i to j, and therefore, the relative preference of j to i is given by: $a_{j,i} = 1/a_{i,j}$ . By an increase in the number of categories, the number of comparisons will increase. If *n* categories are investigated, $\frac{n(n-1)}{2}$ comparisons would be needed. Consequently, for 15 subjects, more than 100 comparisons are required. Since it is impractical to ask the experts to do such a number of comparisons consistently, the number of items is the main limitation of the process. In this study the number of items is kept less than or equal to 9 which is equivalent to a maximum of 36 comparisons.

## 4.2. Calculation of Weights

The next step is to determine the weights of the items by calculating the eigenvector of the RWM. Assuming that the weights for item i is $w_i$, by definition, the RWM consists of pair-wise comparisons ($a_{i,j}$) which are the ratio of the weight of item i to that of category j:

$$a_{i,j} = w_i/w_j \quad (1)$$

Therefore, the vector of weights itself $w = (w_1, w_2, \ldots, w_n)$ is an eigenvector for the RWM. As a result, the problem becomes that of finding an eigenvector w in order to satisfy equation (2):

$$Aw = \lambda_{max} w \quad (2)$$

where $\lambda_{max}$ is the largest eigenvalue of the matrix A.

For each expert the RWM (matrix A as in Table 3) is specified; then, eigenvector of RWM is calculated using equation (2). The eigenvector gives the weights of each item based on the expert's viewpoint. This calculation is repeated for all experts.

## 4.3. Consistency Index

Although, the extra comparisons in AHP may be time consuming, they can be used to check the consistency of each expert's judgments. The consistency test involves calculation of consistency index (CI) as demonstrated in equation (3):

$$CI = (\lambda_{max} - m) / (m-1) \quad (3)$$

where m is the dimension of RWM (matrix A). This consistency index is compared against a reference average Random Index (RI) which is given in Table 4 (Saaty and Wong 1983).

**Table 4: Random Index (RI) for different dimensions of RWM (Saaty and Wong 1983)**

| Dimension | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | N.A. | N.A. | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

The ratio of consistency index, CI, to the average random consistency index, RI, is called Consistency Ratio which is calculated by equation (4).

CR=CI / RI (4)

The RWM (matrix A) is considered reasonable if CR<0.1 (Saaty and Wong 1983). In other words, if CR<0.1 for the pair-wise comparisons of an expert, his/her judgment is approved by the consistency test.

## 5. Application of AHP

The result for Stage 3 (Survey I) of the proposed framework is presented in this section. A survey was conducted on five experienced safety experts in Iran. Using a questionnaire, these experts were asked to state the importance of each element and factor. The questionnaire had a description of the intervening factors for each element. Then the experts were asked to state their pair-wise comparisons in order to construct the RWM similar to Table 3. A RWM was constructed for the elements and separate ones for factors in each element. For the elements level (which is the top level), a 6×6 RWM was constructed for each expert and the consistency of the experts ideas were checked using equation (3). The CI verified the comparisons of four experts. For these four experts, the category weights were calculated. Based on equation (2), the eigenvector of the respective $\lambda_{max}$ is obtained; after that, the normalized eigenvector is introduced as the elements' weights. The mean values of these weights are demonstrated in Table 5. The mean values of this table are mapped to a scale of 0 to 1. On average, the experts weighted the 'side road land use' as the most important element.

**Table 5: Average expert's weights for each element**

| Element | Straight segments | Horizontal and vertical curves | Bridges | Tunnels | Merges and intersections | Side road land use |
|---|---|---|---|---|---|---|
| Weight | 0.05 | 0.17 | 0.20 | 0.17 | 0.18 | 0.23 |

A similar procedure was then applied at the factors level. At this level, a RWM was constructed for each expert for each element (i.e. a total of 4x6=24 RWMs). Calculating the CI, all remaining four experts were consistent in comprising the factors. Table 6 shows the normalized average weight of the experts.

**Table 6: Average experts' weights for each factor**

| Factor* | Straight segments | Horizontal and vertical curves | Bridges | Tunnels | Merges and intersections | Side road land use |
|---|---|---|---|---|---|---|
| A | 0.17 | 0.10 | 0.10 | 0.07 | 0.07 | 0.10 |
| B | 0.24 | 0.16 | 0.20 | 0.27 | 0.21 | 0.21 |
| C | 0.19 | 0.08 | 0.11 | 0.22 | 0.03 | 0.08 |
| D | 0.12 | 0.05 | 0.25 | 0.10 | 0.03 | 0.20 |
| E | 0.19 | 0.20 | 0.06 | 0.11 | 0.13 | 0.06 |
| F | 0.18 | 0.05 | 0.05 | 0.06 | 0.07 | 0.04 |
| G | N/A | 0.04 | 0.22 | 0.06 | 0.16 | 0.10 |
| H | N/A | 0.19 | N/A | 0.10 | 0.15 | 0.20 |
| I | N/A | 0.13 | N/A | N/A | 0.15 | N/A |
| Sum | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

*Factors are defined in Table 3.

The calculated weights for elements and factors can then be used to have an overall assessment of a road based on the relative importance of each element. This is of value as road safety is a multi causal phenomena and the interaction of the items indicates the overall safety level of the road segment.

## 6. Safety Index

The weights of the elements (and factors) are determined as the result of the AHP approach. According to stage 4 of the proposed framework, the safety condition of a road is estimated by some experienced safety auditors which could be different from the experts. These auditors would inspect the road and score it in each factor of each element. Scoring is one of the Effectiveness Analysis methods to quantify subjective judgments (Papacostas and Prevedouros 2001) . The auditors would consider the factors in each element as outlined in Table 1 and assign a score to a road from 1 to 5. The higher the score, the safer is the road condition.

At Stage 5 of the proposed framework, the Safety Index of a road is introduced as the weighted sum of the factor scores as given by equation (5) :

$$SI = \sum_{i=1}^{6} w_i \sum_{j=1}^{n_i} u_j p_j \qquad (5)$$

where $w_i$ is the weight of element i from the six elements, $u_j$ is the weight of factor j, $p_j$ is the respective score ,and $n_j$ represents the number of factors in an element. A high Safety Index (SI) indicates a low risk of accident, where roads with low SI should be nominated for further data collection and precautionary treatments. Using this index, one can rank the road segments in a network in a priority list for further actions. Should there be a limited budget for safety improvements, road segments from the top of the list are picked up as long as the budget allows.

In addition to the SI, when the score of a road segment is very low in a specific element ( $\sum_{j=1}^{n_j} u_j p_j$ ), that segment should also be considered for further investigation. Choosing the high risk locations is the role of any road safety audit. In the quantitative framework of this paper, the average value ( $\mu$ ) and the standard deviation ( $\sigma$ ) of the element score ( $\sum_{j=1}^{n_j} u_j p_j$ ) are used to determine the roads to be treated. If a Lower Bound (LB) is defined as presented in equation (6), one can select the approaches with lowest scores.

$$LB = \mu - (\beta \times \sigma) \qquad (6)$$

where, $\beta$ is a constant depending on the level of confidence. Statistically, it can be shown that if the distribution of scores follows a normal distribution, the value of $\beta$ can be derived from the t-student distribution. In addition to the SI ranking, the roads with an element score less than the related LB are also nominated as a hazardous location.

## 7. Conclusions

In this paper a framework is proposed to identify and rank hazardous road locations in two-lane two-way rural roads. Different approaches which were proposed by researchers to investigate the safety level of roads were reviewed. The literature suggested that there are two main approaches to evaluate the safety performance of a road. These approaches are statistical analysis and micro-simulation models. For either of these approaches, data collection is the first step of road safety evaluation. However, data collection for a road network is very expensive and time consuming. Thus, it would be helpful to have an assessment method that enables road safety authorities to prioritize hazardous road locations in the absence of data. Based on the identified rankings of roads, a more efficient data collection process can be carried out. Furthermore, safety problems, which can be improved through simple countermeasures, can be treated.

An audit based framework is proposed to carry out a preliminary assessment of the safety level of a road network. Based on this assessment, the potential hazardous road locations are identified. Thus, the priority of data collection for an elaborated study is determined using the results of the preliminary assessment. The developed framework uses an expert panel investigation and Analytical Hierarchy Process (AHP) method.

A road is decomposed to six elements, namely, straight segments, horizontal and vertical curves, bridges, tunnels, merges and intersections, and side road land use. For each element, a list of intervening safety factors is also described. The AHP method is used to find out the weight of the elements and factors. In order to calculate the weight of the categories, a questionnaire is designed. In the designed questionnaire the relative importance of the elements and factors affecting road safety were stated by road safety experts. The resulting weights specified by the experts of a developing country for rural road network were presented. Conducting a road safety audit, a score is assigned to each factor. The experts used in the early stage of the method could be deployed as auditors; nevertheless, the auditors could be different. The weighted sum of the scores called Safety Index (SI) is introduced as a measure for ranking hazardous locations.

The proposed framework enables the road safety authorities to carry out a preliminary assessment of the safety performance of the road network and identify the ranking of high risk roads. Moreover, the priority of future data collection can be indicated based on the ranked hazardous road locations. However, there are some areas of this research which need to be improved in future studies. For example, this study should be applied to a road system where enough crash data is available in order to validate the results of the framework. Such a study can investigate whether the roads identified using the proposed framework, actually fit with the road segments where the highest number of accidents has occurred.

In terms of the transferability of the results, the proposed theory is considered to be transferable. However, the weights should be recalculated deploying local experts. As such, it will have certain characteristics which are peculiar to design standards, behaviour and road conditions in that area.

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