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Assessment of Road Elements in Relation to Road Safety by Multi-Criteria Decision Making Approach

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Abstract
In Nepal, due to rapid urbanization an issue of road safety hazard is on the rise. In case of the Kathmandu ring road various elements affect the treatment of road safety. This study presents six stage methodological framework for assessment of various factors prominent for causing road safety risks based on Analytical Hierarchy Process (AHP) and field survey(condition rating) to identify the hazardous elements of Kalanki-Koteshwor Road Section by weighing the safety parameters of the road section and calculating the Safety Hazardous Index (SHI). Further by making a comparative analysis, between the field data and the weights for the factors, the risk factors can be assessed in terms of their importance based on their score and correlation. Thus allowing the focusing of efforts towards specific factors to improve the road safety.

Keywords
Road Safety, condition rating, weightage of safety factors, Analytical Hierarchy Process

1. Introduction

The number of road traffic deaths remains unacceptably high. Globally about 1.35 million deaths occur due to road traffic crashes [1]. It is observed that road traffic death rate is 3 times higher in lower income countries and Nepal is one of them[1]. Despite of the public-private awareness to road crashes, number of road crashes in Nepal remained unacceptably high.

It is known that the ring road around Kathmandu is subjected to higher traffic flows causing safety issues to be more and more likely and thus road safety is of a major concern. Due to the growing number of vehicles and ease of access of the various roads into the city areas through the ring road a large portion of vehicles favor the use of the ring road for their travel routes. In order to address the safety concerns, road sections need to be analyzed for their risk elements and then apply measures to suppress these risk elements, thus making roads safer.

In the past primary concern for roads has been to promote connectivity in the country and the safety has been a lesser discussed issue. With urbanization, the mobility need is increasing and most roads even the newly constructed ones have been further upgraded to sustain heavier traffic flows. However, the number of conflicts points and road crashes are also increasing. The Kathmandu Ring Road (KRR) is one of such cases. Originally the road was constructed with a vision of urban arterial road but has been added as a national highway NH42 (27 km length) and with this the highway is experiencing increased vehicular flow and serious road safety issues.

Previous studies suggest that in order to identify risk factors detailed crash statistics are required which might not be easily available. This thesis study relax the need of such databases by analyzing risk elements that are evident in the various road elements and determining their weightage in the overall risk value.

2. Literature Review

While considering crashes and road safety issues we mostly deal with four primary factors: Road users, road infrastructure, vehicles and environment. As engineers we are mostly concerned with improving road infrastructure standards so road safety is optimally improved. This is because it is hard to change road users behaviour while environmental aspects cannot be controlled. Thus it is necessary to investigate the safety risk factors and how severely they affect road safety. Various methodologies have been used in order to describe the risk of factors causing accidents on the road. Some studies have based their approach on road crash data using them to establish statistical models of crashes. [2], [3]. Some other studies have based their approaches on a more explanatory manner because of lack of accessibility to road crash data or a lack of reliability on said data [4].

There are three common methods to evaluate road safety when there is a lack of reliable data available: ”Traffic Conflict Technique”, ”Subjective Rating System” and ”Multi-criteria Decision Making Approach”. The concept of traffic conflicts was proposed by Perkins and Harris as an alternative to crash data, particularly to be used when there is no reliable crash data available. Their objectives were to define traffic incidents that occur frequently, can be clearly observed, and are related to road crashes. ”Subjective Rating System” was initially used by Transport Road Research Laboratory in 1990 to identify and investigate the characteristic road parameters leading to crashes. This approach of subjective road safety evaluation involves a drive-through technique.”Multi-Criteria Decision Making Approach” is mostly applied to rank the parameters of road crashes[4].

The literatures which follow the Multi-criteria Decision Making Approach to assess factors usually implement Analytical Hierarchy Process(AHP). AHP is a method which has been extensively used in a large number of road safety researches and its primary usage for assessing and identifying accident prone zones has been shown by many researchers.[4],[5] suggested methodologies for ranking black spots in terms of a Safety Index and Safety Hazardous Index respectively using AHP.

Najib et al.[6] implied six steps of AHP to identify that ’driving faster than limited speed’ has the highest weights among all causes leading to accidents in Malaysia.

Mazdak et al.[7] evaluated traffic risk indexes in Iran’s rural roads with regards to the two main criteria: Effect on Accidents number and Effects on Accident Severity using a Multi-criteria Decision Making Approach of AHP to find the score of Risk Index of each chosen parameters followed by ranking them in respect to the two main criteria.

Mahmoudreza et al.[8] attempted to identify and prioritize black spots in Baluchistan, Iran without using accident data but rather making use of an Expert Choice Software for implementing AHP.

Mohammed et al.[9] utilized AHP to analyze the traffic accidents in Kuwait with the main objective to identify the most strategic policies to be used by the authorities in Kuwait in order to minimize the severe effect of traffic accidents on property and people.

Salin et al.[10] utilized AHP to analyze road sections of the Kathmandu Ring Road(KRR) and rank the road in terms of their safety performance in respect of the Safety Hazardous Index at 2 km intervals.

3. The Need and Objective of the Study

3.1 The Need of the study

Many highways in the country like Kathmandu Ring Road have large traffic volumes but at the same time are functional under urban environment and therefore affected by congestion in the central cities. Such sections are required to take on heavier traffic speeds and flow volumes which in turn increases the risk of crashes and raises safety concerns. According to previous study, during the year 2018/2019, the Kalanki-Koteshwor section of the ring road alone faced 1060 cases of crashes and recent data from Metropolitan Traffic office Kathmandu states in 2020/2021, 3995 cases of traffic crashes were reported in ring road Therefore, identification of the major road safety factors, rating the current transport infrastructure based on these factors and provision of suitable remedial solutions is of vital importance.

3.2 The Objective of the study

The main objective of this study is to identify and investigate the safety factors of road elements and ranking them based on their importance in road safety. For this, “Safety Hazardous Index” is used to define the risk of a safety factor or a feature in causing road crashes.

The specific objectives of the study are:

1. To identify road elements that largely affects the road safety status of the road sections.
2. To determine ranking of the factors based on their Safety Hazardous Index using multi-criteria decision making approach.

4. Limitations

The limitations of this study are:

1. Not more than 10 safety factors for each road section so as to avoid complexity during pairwise comparison
2. Only limited number of experts may be familiar with the road considered for the study and thus some judgment has to be discarded in case of inconsistency during computations

5. Methodology

5.1 Study Area

Kathmandu Ring Road is an eight lane ring road circling around cities of Kathmandu and Lalitpur. KRR has been classified as National Highway code NH42. It serves as the main arterial road in Kathmandu valley. It has been upgraded for the purpose of reducing the traffic congestion along radial road from Central Business District (CBD). It serves as one of the major transport link in Kathmandu Valley to ease connectivity between various parts of the city. In present scenario, this road is facing heavy traffic flow and causing congestions at major intersections.

The Southern portion of KRR from Koteshwor to Kalanki shown in figure 1 was selected as study area.

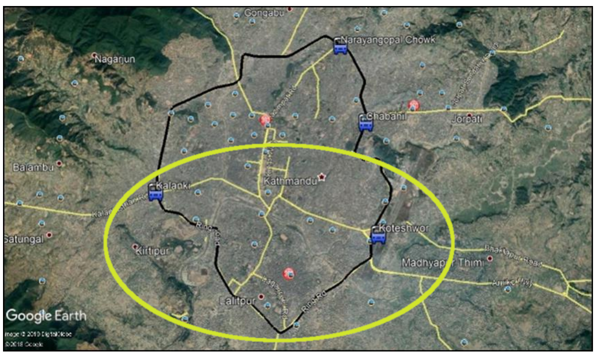

Figure 1: Selected Study Area

5.2 Overview of Methodology

The proposed framework for the research work is divided into six stages as shown in the figure 2 below.

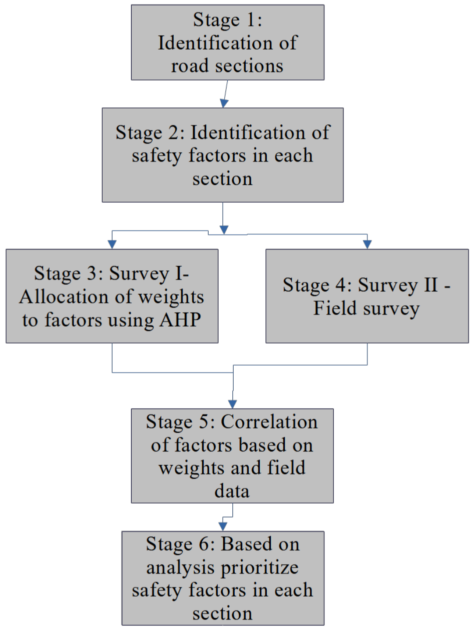

Figure 2: Methodological framework

5.2.1 Stages 1 and 2: Identification of road sections and safety factors in each section

Based on literature review of prior research on AHP and road safety, field visit and experiences, four types of road sections (elements): straight, curve, merge and intersections & bridges were considered and factors affecting safety for each types were identified and assigned. The factors and elements/sections considered are shown in Table 1.

5.2.2 Stage 3: Allocation of weights to factors using AHP

Once the criteria have been identified, and the concepts of establishing priorities and consistency were clearly understood, the relative weights were allocated to the selected criteria at each hierarchy level. For this, a scale needs to be established. Many studies have been conducted for finding the most appropriate scale of measurement. Dr.Saaty's Intensity of Importance has been preferred which is shown in Table 2. For this research 9 experts have performed the pairwise comparison.

After scaling the relative of data and constructing the pairwise comparison matrices to get following matrices which are known as Relative Weight Matrices(RWM).

Table 1: Elements and factors considered

Element	Factors
1.Straight Segments	A.Speed limit and no overtaking signs B.Road marking C.Pavement maintenance condition D.Road Skid resistance E.Vehicle flow F.Operation Speed
2.Horizontal and vertical curves	A.Speed advisory signs, sharp bend, steep up/down grade warning signs B.Combination of horizontal and vertical curves C.Pavement maintenance condition D.Sight distance provision E.Superelevation in horizontal curves F.Road Safety Intervention G.Vehicle Flow H.Operation Speed
3.Bridges	A.Speed limit, no overtaking and load limit signs B.Guardrails and bridge approach protection C.Pavement maintenance condition D.Reduction in the pavement and shoulder width E.Vehicle flow F.Operation speed
4.Merge and Intersections	A.Speed limit and warning signs B.Road marking C.Visibility(Sight distance)/turning radius D.Pavement condition E.Lighting poles and reflective signs F.Vehicle flow

$$\begin{bmatrix} 1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & 1 & \dots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & 1 \end{bmatrix} \tag{1}$$

Following this the calculation of matrix eigen vector was carried out and consistency index test(CI) of the matrix was done.
Eigen vector,

$$A_{ij} = \frac{\sum_{i=1}^{n}(w_1/w_1 \times w_1/w_2 \times \dots \times w_1/w_n)^{1/n}}{\sum(\sum_{i=1}^{n}(w_1/w_1 \times w_1/w_2 \times \dots \times w_1/w_n)^{1/n}} \tag{2}$$

Eigen value,

$$\lambda = \frac{\sum_{j=1}^{n}(\sum_{i=1}^{n} A_{ij})w_j}{A_i j} \tag{3}$$

Consistency test,

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \tag{4}$$

Consistency ratio,

$$CR = \frac{CI}{RI} \tag{5}$$

Table 2: Saaty's rating scale

Relative Importance	Qualitative Scale	Comments
1	Equal	Two factors are equally important
3	Moderate importance	Slightly favor one over another
5	Strong importance	Strongly favor one over another
7	Demonstrated importance	Very strongly favor one over another. its dominance demonstrated in practice
9	Absolute importance	Very strongly to Extremely strongly preferred
2,4,6,8	Values between the levels above	Used only when a compromise in comparison is necessary
Reciprocal		If importance of an item x to item y is aij then the importance of item y is aji =1/aij

The consistency index was compared against a reference random index(RI) which is given in Table . This ratio of consistency index(CI) to the random index(RI) is called the consistency ratio(CR). CR is acceptable if it does not exceed 0.10(Saaty and Wong 1983).If CR is greater than 0.10, the judgment matrix should be considered as inconsistent and the judgment should either be revised or should be discarded. Klaus D. Goepel version 11.10.2017 AHP spreadsheet Template is used for verifying pairwise comparisons.[4]

5.2.3 Stage 4: Field survey

The field survey was conducted by dividing the route into parts of 500 m section for condition rating. All road safety factors of the respective section were separately analyzed using rating scale as shown in Table 4. This was carried out in following steps:

1. Reconnaissance survey

Table 3: Random Index for different dimension of Relative Weight Matrices(Saaty and Wong 1983)

Dimension	RI
1	NA
2	NA
3	0.58
4	90
5	1.12
6	1.24
7	1.32
8	1.41

Table 4: Condition rating of road safety factors

SN	State of condition	Value
1	Excellent condition	0
2	Good condition	0.10-0.24
3	Average condition	0.25-0.49
4	Poor condition	0.50-0.74
5	Very poor condition	0.75-1.0

2. Facilities Checking
3. Comparison with guidelines

5.2.4 Stage 5: Correlation of factors based on weights and field data

Combining the weight of safety factors and condition rating of each factors obtained after stage 3 and 4, Safety Hazardous Index(SHI) was developed using formulas as below.
Safety Hazardous Index at Straight sections:

$$SHI_s = \sum W_{sfs} \times R_{sfs} \tag{6}$$

Safety Hazardous Index at Curve sections:

$$SHI_c = \sum W_{sfc} \times R_{sfc} \tag{7}$$

Safety Hazardous Index at Bridge sections:

$$SHI_b = \sum W_{sfb} \times R_{sfb} \tag{8}$$

Safety Hazardous Index at Merge and Intersection sections:

$$SHI_i = \sum W_{sfi} \times R_{sfi} \tag{9}$$

Where, SHI_s, SHI_c, SHI_b, SHI_i = Safety Hazardous Index for straight, curve, bridge and intersections respectively.
W_{sfs}, W_{sfc}, W_{sfb}, W_{sfi} = Weight of safety factors at straight, curve, bridge and intersections respectively.
R_{sfs}, R_{sfc}, R_{sfb}, R_{sfi} = Condition rating of safety factors at straight, curve, bridge and intersections respectively.
Further SHI for each road section considered is calculated by computing the sum of SHI for all the factors within the respective section as

$$SHI_{SA} = SHI_{sa1} + SHI_{sa2} + SHI_{sa3} + SHI_{sa4} + \dots \tag{10}$$

$$SHI_{CA} = SHI_{ca1} + SHI_{ca2} + SHI_{ca3} + SHI_{ca4} + \dots \tag{11}$$

$$SHI_{BA} = SHI_{ba1} + SHI_{ba2} + SHI_{ba3} + SHI_{ba4} + \dots \tag{12}$$

$$SHI_{IA} = SHI_{ia1} + SHI_{ia2} + SHI_{ia3} + SHI_{ia4} + \dots \tag{13}$$

Where, SHI_{SA}, SHI_{CA}, SHI_{BA}, SHI_{IA} = Total Safety Hazardous Index for straight, curve, bridge and intersections for the factor A respectively.
SHI_{sj}, SHI_{cj}, SHI_{bj}, SHI_{ij} = Safety Hazardous Index for straight, curve, bridge and intersections $at\, j^{th}$ observation point of the factor A (j=1,2,...) respectively.
Similarly total SHI for other factors are also determined. Higher value of SHI for a specific factor in comparison to the SHI for other factors is analogous to higher safety risk for that specific factor.

5.2.5 Stage 6: Based on analysis prioritize safety factors in each section

Based on the analysis performed in stage 5, comparative study of the factors is conducted which will allow the assessment of various factors in terms of their correlation with field rating and field data as well as their importance in terms of weightage which allows for a priority order for safety risk factors to be determined thus defining the more prominent safety risk factors.

6. Results and Discussion

The weights provided by the experts were checked for their consistency and among the 12 experts who provided their pairwise comparisons only 7 were found to have consistency index within the acceptable range of ¡ 0.10.These pairwise comparisons were then computed using the relative weight matrix discussed above to determine the weights of factors. The weights thus computed from the relative weight matrices for the 7 experts were averaged to obtain average weight value for each of the factors considered. The average weight developed from experts' pairwise comparison using AHP for each road section is summarized in Table 5 below.

Table 5: Summary of weights

Straight Sections	
A. Speed limit and No overtaking signs	0.149
B. road marking	0.061
C. Pavement maintenance	0.143
D. Pedestrian crossing facilities	0.234
E. Road skid resistance	0.067
F. Vehicle flow	0.049
G. Operation speed	0.0298
Curve Sections	
A. Speed advisory signs, sharp bend, steep up/down grade warning signs	0.106
B. Combination of horizontal and vertical curves	0.142
C. Pavement maintenance condition	0.080
D. Sight distance provision	0.182
E. Super elevation in horizontal curves	0.140
F. Road safety intervention	0.099
G. Vehicle flow	0.040
H. Operation speed	0.211
Merges and intersections Sections	
A. Speed limit and warning signs	0.222
B. Road Marking	0.146
C. Visibility(sight distance)/turning radius	0.272
D. Pavement condition	0.082
E. Lighting poles and reflective signs	0.222
F. Vehicle flow	0.1222
Bridge Sections	
A. Speed limit,no overtaking and load limit signs	0.133
B. Guardrails and bridge approach protection	0.190
C. Pavement maintenance condition	0.160
D. Reduction in pavement and shoulder width	0.150
E. Operation speed	0.285
F. Vehicle flow	0.082

After obtaining the average weights for each of the factors the SHI value of all of the factors were obtained using equations (6) through (13). The SHI values for the sections obtained from the condition rating and computations are shown in Table 6 as below.

Table 6: Summary of calculated SHI

Straight Sections	
A. Speed limit and No overtaking signs	5.46
B. Road Marking	1.688
C. Pavement Maintenance	2.471
D. Pedestrian crossing facilities	6.257
E. Road Skid resistance	1.371
F. Vehicle flow	1.526
G. Operation Speed	7.751
Curve Sections	
A. Speed advisory signs, sharp bend, steep up/down grade warning signs	1.000
B. Combination of horizontal and vertical curves	1.756
C. Pavement maintenance condition	0.376
D. Sight distance provision	0.998
E. Superelevation in horizontal curves	0.723
F. Road safety intervention	1.265
G. Vehicle flow	0.567
H. Operation speed	1.192
Merges and intersection Sections	
A. Speed limit and warning signs	1.874
B. Road marking	1.434
C. Visibility(sight distance)/turning radius	2.771
D. Pavement condition	0.287
E. Lighting poles and reflective signs	3.402
F. Vehicle flow	1.488
Bridge Sections	
A. Speed limit, no overtaking and load limit signs	0.253
B. Guardrails and bridge approach protection	0.247
C. Pavement maintenance condition	0.0641
D. Reduction in pavement and shoulder width	0.0598
E. Operation speed	0.612
F. Vehicle flow	0.196

7. Conclusions and Recommendations

Based on these findings we are able to conclude that for having the higher values of SHI, Speed limit and No overtaking signs, Pedestrian crossing facilities and Operation speed are considered more important factors to be considered for straight sections for Kathmandu Ring Road(KRR). For the case of curve sections it is seen that Combination of horizontal and vertical curves, Road Safety intervention and Operation speed are considered as higher risk factors. For the Case of Merges and intersection, speed limit and warning signs, Visibility(sight distance)/turning radius and Lighting and reflective signs should be considered as higher risk factors. Finally for the case of bridges Operation speed, Speed limit, no overtaking signs and load limit signs and Guardrails and bridge approach protection are taken as high risk factors.

The staggering number of crash records in KRR shows the urgency for employing preventive measures. Since, all the road safety measures may not be possible to be implemented throughout the KRR section due to the insufficient availability of budget so the methodology developed in this study can be firstly useful for the implementing agencies to detect the hazardous locations more quickly; secondly, diagnose the difficulties of these locations more in detail, and finally be helpful to assign the limited budget to improve road safety condition and decrease the road crash numbers and severities.

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