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Assessment of Road Condition: Traffic Safety Requirement

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Abstract

Road deaths and injuries highly affect the lives of people worldwide. road injuries and deaths happen due to improper driving, unfit motor vehicles, traffic laws disobeying persons and poor road condition. An effort is made here to assess the factors of poor road conditions which can be improved by prioritizing. Multi criteria technique is applied to prioritize the factors. Ann technique is adopted to assess the road condition. The methodology suggested can be used to determine the level of contribution of parameters towards safety hazard. Accordingly, appropriate mitigation measures may be adopted. A further detailed study needs to be conducted on a large scale by carrying out sensitivity analysis to test the stability of the ranking obtained by the suggested methods.

Keywords: AHP, Road safety, ANN

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1. Introduction

Condition assessment of infrastructure is the evaluation of the assets throughout the period of their service validity. The condition of the asset refers to the measurement of the asset's physical state, while the performance of the asset refers to the capability of the asset to produce the required level of service to the users. These evaluations are critical for providing crucial information regarding the asset management of the asset. These evaluations forecast the remaining useful life of an asset and generate a plan for possible future outcomes and actions.

A road safety assessment is: 'An examination of the quality of traffic flow, accident potential and safety performance of a road based on a set number of key indicators to identify hazardous locations and safety deficiencies'.

The purpose of road safety assessments is:

- To evaluate the safety performance of the road network based on a set number of key indicators
- To prioritise hazardous locations on the road network to ensure that road safety audits and remedial measures can be implemented where it is the most needed

It is therefore absolutely essential that each intersection/ area or road segment is evaluated and rated with the same procedures and set of values. To promote a homogeneous rating system the performance of a road has been divided into four main areas of concern:

a) Accident History,
b) Operational Conditions,
c) Road Elements, and
d) Land-Use.

The Road Safety Index consist of two indices, namely, the Accident Index (which takes the accident history into consideration) and the Safety Index (which take Operational Conditions, Road Elements and Land-Use) into consideration.

Road infrastructure plays a vital role in supporting human activities, such as the availability of adequate road networks and the ability to more efficiently and cheaply connect the transportation flow of goods and services to enter the city or vice versa. A good road has fine surface and structural conditions The maintenance of transportation assets has become the most difficult challenge for most transportation agencies in the world. In general, road damage is usually caused by age, inundation on the road surface that cannot flow due to poor drainage, and excessive repetitive traffic loads causing the road life to be shorter than planned. Roads overloaded due to the continuous burden of volumes and traffic greater than planned will reduce the strength of the road pavement structure The road Pavement Condition Index (PCI) will decrease with the increase in traffic loads per year.

Road accident causes huge losses to the economy in terms of the cost incurred in hospitalization and treatment and damages to vehicles and property etc. There is an urgent need to reduce the number and severity of road accidents by implementing remedial measures at hazardous locations in the road network. Further, it is generally not possible to implement all remedial measures identified due to limited budget available for road safety improvement it is generally not possible to implement all remedial measures identified due to limited budget available for road safety improvement. Hence, it is needed to rank the hazardous locations so that depending on the available budget, the hazardous locations can be treated.

Often comprehensive accident data are not available. Even if accident data is available, it is difficult to analyze this data due to its poor quality. Further, some locations have high frequency of accident but fatality is less. Many locations with narrow bridges, slippery pavements, and rigid roadside obstruction have a high accident potential but may not yet have a history of high-accident occurrence. Therefore, it is important to develop a methodology for ranking road safety hazardous locations without using any accident data.

Road deaths and injuries highly affect the lives of people worldwide. Still, it is one of the neglected global problems and requires collective efforts for mitigation and prevention. According to the records of World Health Organization (WHO), about 1.25 million people die each year due to road traffic crashes. About half of these deaths are among vulnerable road users i.e., pedestrians, cyclists, and riders of motorized two-wheelers and their passengers. About 1.7% of national highways and 3.9% of state highway road network accounts for 52.4% of the reported road crashes In general, the key risk factors that cause likelihood of accident occurrence and increased severity include, increase in average speed of vehicle, drinking and driving, distracted driving, and driving without wearing helmets and seat-belts. Improved legislation, enforcement, safer roads and vehicles have achieved success in reducing the number of road deaths in high-income countries.

In India, out of the 4,64,650 road crashes, 1,47,913 fatalities and 4,70,975 injuries had resulted in the year 2017. In economic terms, the cost to the nation is an estimated 3 % of Gross Domestic Product (GDP). A majority of fatalities are in the age group of 18 to 45 years. There is need for coordinated action by all the key stakeholders to address this serious concern. Road Safety Audit on roads is one critical step in that direction. The road safety problem involves three components - the human, the vehicle and the road. International research shows that the road plays a crucial role in road crashes.

It is often stated in public discussions that more should be done to improve the behaviour of road users. There are also frequent calls for increased enforcement of the road rules. Both calls reflect the involvement of the human factor in road crashes. The roads are also in need of safety improvements and across the country, there are instances of geometric deficiencies, inconsistent pavement markings, missing (or wrong) road signs, traffic signals not operational, inadequate attention to needs of the vulnerable road users. The community expects their roads to provide clear efficient traffic management and high levels of safety, as well as to withstand the weather conditions. Pedestrians and cyclists are often left to cross high speed roads without assistance, especially in case of highway passing through urban settlements and villages. If crashes occur due to design deficiencies, the community will pay a much higher price than the initial capital cost. The cost of serious and fatal crashes can end up costing much more over the life of a road project than the initial capital cost. The engineers are not expected to “wash their hands” of the safety problems on the roads and highways. Engineers are an important part of the solution to the road safety problem. Examining how road projects cleared through the traditional system of engineering design and hence checking yields a clear answer to the question of why the road safety audit process is needed in all road authorities: Sometimes a new design may include standards inappropriate for the type of road.

- In some cases, outdated standards may be used in a design.
- Sometimes, the combination of various elements of the design may yield a result that is not the best in terms of safety.
- Compromises may be made between traffic carrying capacity and safety which lead to a lessening of safety in the finished road project.
- Sometimes changes are made during construction which does not fully consider
- operational safety factors.

A road safety audit is “a formal, systematic and detailed examination of a road project by an independent and qualified team of auditors that leads to a report of the potential safety concerns in the project”. A formal examination of design would not permit a layout shown below causing unsafe and illegitimate movement. Such potential unsafe situations would be captured in a safety audit and can be modified before implementation

Analysis of the interaction between elements of the system “driver-vehicle-road-traffic environment” and study their mutual influence help to develop methods of optimization factors of road environment and traffic as well as get solutions that meet the requirements of the safety and comfort of movement, main aim of this work is to study the impact of road conditions using AHP and ANN, which allows to assess the degree of accident risk road sections as during the operational phase and the design phase.

Table 1. Type of damage

1	Alligator cracking	Cracking with tissue-shape from many small polygons like crocodile skin
2	Bleeding	The used impact of excessive asphalt binder, expanding onto the pavement surface
3	Block cracking	A crack of beams or boxes on pavements
4	Bump and sags	Small landslides and top-down cracking displacements in the pavement layer form a basin.
5	Corrugation	Caused by plastic deformation producing transverse waves or perpendicular to the asphalt pavement
6	Depression	The deformation of pavement occurring in a limited area that may be followed by cracks
7	Edge cracking	Tins cracking occurs due to weak contraction at the edge of pavement or high-water humidity.
8	Joint reflect cracking	This distress generally occurs at asphalt pavement laid on Portland cement concrete pavement.
9	Lane/shoulder drop off	This damage occurs due to the presence of a height difference between the surface of the pavement and the surface of the roadside or the surrounding soil.
10	Longitudinal trans verse cracking	This damage consists of various damage types, as the name implies, longitudinal and transverse cracks on the pavement.
11	Patching and utility cut patching	The surface course of the pavement repaired.
12	Polished aggregate	Caused by the repeated traffic applications, which may lead to the aggregate on the pavement becomes polished.
13	Pothole	Shaped like a bowl that can hold and absorb water on the road
14	Railroad crossing	The decrease or lump around or between rails caused by differences in material characteristics.
15	Rutting	Another term used to refer to this damage is longitudinal nits or channel.
16	Shoving	The displacement of the pavement layer in certain parts caused by traffic loads.
17	Slippage cracking	A crack like a crescent moon or half a month
18	Swell	Having a characteristic of protruding out along the gradual pavement layer about 10 feet long (10m).
19	Weathering/raveling	Caused by a pavement layer losing asphalt or tar binding, and the aggregate particles are uprooted.

2. Literature Review

Saeid Jafarzadeh Ghoushchi1, et al., 2023 stated Due to the ambiguity and uncertainty of the risk assessment process, a multi-criteria decision-making technique for dealing with complex systems that involves choosing one of many options is an important strategy of assessing road safety and applied MCDM technique, they have considered 16 factors driver behavior, road condition, floods, vehicle condition, etc. and risk factors are prioritized.

Zelico, et al., 2022 stated that Road capacity utilization is causally connected with an appropriate level of efficiency and an optimal level of traffic safety The Improved Fuzzy Step-Wise Weight Assessment Ratio Analysis (IMF SWARA) method was chosen to determine the weights of criteria, while the road sections were ranked using the Evaluation based on distance from average solution (EDAS). Considered only a set of seven criteria, which are marked as follows: C1 - ascent/descent at 1000 m in %, C2 - deviation from the speed limit, C3 - AADT, C4 - traffic accidents with fatalities (TA-F), C5 - TA with seriously injured (TA-S. inj.), C6 - TA with slightly injured (TA-S. inj.) and C7 - TA with material damage (TA-MD).

Mohammad, et al., 2021 discussed the prioritization of hazardous points on the roads is discussed, using multi-criteria decision-making (MCDM) techniques considering different natural and environmental criteria affecting road accidents 20 criteria were identified in 4 different categories to prioritize the hazardous points using the literature review and the experts' opinion. In this paper, the MDL (Modified Digital Logic) and AHP (Analytical Hierarchy Process) methods are used to determine the criteria's weights.

Gianfranco, et al., 2018 have selected two further multicriteria methods (Vikor and TOPSIS), for comparison with the Concordance Analysis and for evaluating which performed best. In order to identify critical sections in a road network.

Pedro Marcelinoa, et al., 2018 stated Transport infrastructures deteriorate due to ageing, exposure to weather and traffic, and to the growing maintenance backlog the development of an improved pavement condition indicator using a machine learning algorithm, which can make more accurate predictions using less data.

Faan Chen, et al., 2015 introduced a hierarchical structure of composite Road Safety Risk Index with entropy TOPSIS–RSR methodology (RSRI) The RSRI captures a multitude of risk information in a comprehensive way for the means of road safety performance evaluation.

It has been categorized in seven main dimensions (i.e., Human factors, Vehicle factors, Road factors, Environment factors, Management factors, Personal risk, and Traffic risk. As per the authors, a change in the set of road safety performance indicators may lead to different conclusion.

Qiong Bao, et al., 2012 explained a hierarchical structure of SPIs for road safety performance evaluation as in Fig. 1. More specifically, for alcohol and drugs, the percentage of drivers disrespecting the alcohol limit is the indicator (A1); the speed indicator is the percentage of drivers exceeding the speed limit in built-up areas (S1); the protective systems are represented by the seat belt wearing rate in front and rear seats, respectively (P1 and P2); the age distribution and the composition of the vehicle fleet are the two main aspects reflecting the vehicle performance, and each of them is represented by two different indicators, which are the share of passenger cars of maximum five years old (V1), the median age of the passenger car fleet (V2), and the share of motorcycles and heavy goods vehicles (HGV) in the vehicle fleet, respectively (V3 and V4); the motorways density (R1) and the share of motorways in total road length (R2) describe the roads domain, and for trauma management the health expenditure as share of the gross domestic product (GDP) is the selected indicator (T1). Applied fuzzy TOPSIS for ranking the road section.

Vrtagic, et al., 2021 stated Traffic management is a significantly difficult and demanding task. It is necessary to know the main parameters of road networks in order to adequately meet traffic management requirements The input parameters for the given sections were as follows: section length-I1, road slope-I2, deviation from the speed limit-I3, and average annual daily traffic (AADT)-I4. The classifications of traffic accidents with fatalities, severe injuries, minor injuries, and material damage are defined as output parameters, O1, O2, O3, and O4, respectively. Future research may need to be conducted on a number of road sections with the possibility of implementing the proposed model. The existing model, with an increase of input parameters, could contribute to a much more selective level of choosing the rank of road sections.

Emil Adly, et al., 2020 stated road damage at low and high levels will not only obstruct social and economic activities but also cause accidents. Any road pavement structure will undergo a gradual destruction process since the road was first opened for traffic. Overcoming this phenomenon requires a method to determine a road maintenance program that can be prepared using the Pavement Condition Index (PCI). PCI is a numerical index from 0 to 100 in which the value of 0 indicates the worst pavement condition, and 100 represents the best condition The correlation between the PCI method and the percentage of damage is that this method utilizes three factors, such as the damage types, the damage severity, and the amount or density of damage

Mateus A. Martins, et al., 2020 defined the prioritization and criticality of roads takes on the characteristics of a multicriteria decision, given the multidimensional aspects of the risks inherent in them. Thus, this paper presents a multicriteria decision model for prioritizing road sections, based on their criticality and the risks that users face. The model was applied using the FI Trade-off method, due to its flexibility and due to it requiring less cognitive effort from the decision-maker with regard to providing information regarding his/her preferences the DM felt more confident in directing the available resources (such as financial resources, work team, vehicles, radar, and extra signage) to prevent and mitigate traffic accidents for the prioritized sections have little impact on the issues associated with the road pavement, with a view to improving road safety that assess the extent to which these objectives have been achieved: c1: accident rate (In); c2: index of accidents with fatal victims (IF); c3: index of people with serious injuries involved in traffic accidents (ISI); c4: index of people with minor injuries involved in traffic accidents (IMI); c5: index of traffic accidents with damage only to property (IDP), c6: percentage of heavy vehicles in road traffic (such as trucks, buses) (%NHV); c7: percentage of motorcycles in road traffic (%NMC); c8 Pavement characteristics/conditions (PAV); c9: Signaling characteristics/conditions (SIN); c10: Characteristics of the track geometry (GEO); c11: criminality (CRIM).

Table 2. Qualitative scales of the criteria of pavement, signage, road geometry and criminality

Level	Pavement (c_8)	Signage (c_9)	Road geometry (c_{10})	Criminality (c_{11})
1	Very bad conditions	Missing signage in all (or almost all) the section	Very bad geometric characteristics of the road section	Very high level of criminality
2	Bad conditions	Missing signage in parts of the section. Damaged or unclear signage in many parts of the section	Bad geometric characteristics of the road section	High level of criminality
3	Regular conditions	Damaged or unclear signage in many parts of the section	Regular geometric characteristics of the road section	Moderate level of criminality
4	Good conditions	Damaged or unclear signage in some few parts of the section	Good geometric characteristics of the road section	Low level of criminality
5	Very good conditions	Signage in all sections and is very clear	Very good geometric characteristics of the road section	Very low level of criminality

Xianyong Zhang, et al., 2020 studied effectiveness and the safety of road construction depend on many factors that pose the greatest risk to system safety. The aim of this study is to conduct a comprehensive assessment for these risk factors to contribute to the safety performance of road construction. To achieve this goal, this study constructs a hierarchical safety assessment framework comprising comprehensive risk indicators according to rich work experience and a relevant literature review and then proposes a group AHP-PCA (group analytic hierarchy process-principal component analysis) to calculate the weights of relevant risk factors

Zeljko Stevic, et al., 2021 entails to the development of a novel multiphase multicriteria decision-making (MCDM) model to evaluate the vulnerability of urban roads for traffic safety combining several methods such as CRiteria Importance through Intercriteria Correlation (CRITIC). The findings suggest that there are a certain number of roads that have a high level of safety for both directions, as well as a group of risky roads, which need traffic improvement measures. Thus, the results indicate that the model is sensitive to various approaches and can prioritize vulnerable roads comprehensively based on which safety measures can be taken.

Nurten Akgun-Tanbay, et al., 2022 investigate the impacts of perception of infrastructure, sociodemographic characteristics, frequency of road use, and road user perception on safety, comfort, and chaos with respect to shared spaces A face-to-face survey was conducted and the answers of 200 of the participants, who use three active travel modes, namely, walking, cycling, and micro mobility, were analysed. the results obtained from the ordered logit models suggest that one-unit higher perception of infrastructure will increase safety and comfort perceptions for both walking and cycling Shared spaces help transport planners to organize different types of modes in a certain space and to limit speeds.

Ferit Yakar, 2021 stated Accident-prone Road Section (APRS) treatment is the most effective strategy for accident reduction. Because use of multicriteria decision making (MCDM) in the decision process improves the quality of the decision, especially in problems involving multiple criteria, MCDM approach may be the appropriate approach for APRS determination Relative risk" was used as common unit for criteria standardization and past accident data is utilized to express the "relative risk Five criteria (horizontal alignment, vertical alignment, intersections, significant places, shoulder width) were used in the process. criteria set may change according to the road type: the criteria set for an in-city road will be different from the criteria set for a controlled-access highway.

Criteria, criteria classes, and relative risks of criteria classes. Criteria# Criteria Criteria values Relative risks of criteria value 1 Horizontal alignment 1- Straight 0.9630 2- Slight curve 1.1159 3- Sharp curve 0.9394 2 Vertical alignment 1- Flat 0.9224 2- Slight slope 1.1315 3- Steep slope 0.8510 3 Intersections 1- 3 leg (T shaped) 0.5802 2- 3 leg (Y shaped) – 3- 4 leg 1.1605 4- 5 leg – 5- Rotary intersection 1.1605 6- Other intersection types 1.1605 7- No intersection 1.0048 4 Significant places 1- Settlements exist around road 1.0880 2- Public facilities-buildings exist around road 1.0154 3- Other places 0.9781 5 Shoulder width 1- No shoulder 0.6738 2- 0 < Shoulder width < 100cm 1.1605 3- 101cm < Shoulder width < 300cm 1.1605 4- 301cm < Shoulder width 1.1605.

Priyank Trivedi1 and Jiten Shah, 2002 analysed road crash severity ranking by integrating all injury classified crash types using MCDM techniques TOPSIS, ranked the roads based on injuries in state wise for India. The proposed approach provided relevant results with limited classified data (i.e., injury classified crash data). Suggested for Future research in this direction is possible with fuzzy MCDM methods and different research criteria (e.g., registered vehicles, traffic volumes, etc.) for the roads.

Miroslav Rosic, et al., 2017 developed road safety index this paper offers evaluation of six different composite indexes based on popular DEA and TOPSIS methods by using proposed PROMETHEE-RS tool considering Fatalities Seriously injured Number of inhabitants, No. of registered mot vehicles, Public risk Traffic Risk Public Risk (No. of ser. inj.). Traffic Risk (No. of ser. inj. On road sections).

Antonino Tripodia, et al., 2020 conducted road safety risk assessment based on automated video image analysis and calculated risk score, the drawback of the research is Not all the road attributes can be automatically recognized from videos with enough reliability and precision. Several algorithms exist that can be used for video analysis. Not all of them are still sufficiently precise.

In order to obtain a synthetic Risk index [R], it is universally recognized that it must be the result of a combination of at least two key factors: Danger [D] (likelihood that a crash can happen) and Vulnerability [V] (risk of injury of road users given a crash occurred). Another important factor is also the Exposure [E] (i.e. the amount of "activity" a user is exposed to a risk). However, this factor is hardly available in developing countries. The resulting (general) formula used for risk assessment is as follows:

1) The risk assessment is performed for three road user categories: pedestrians, cyclists and motor-vehicles (including cars, motorcycles, trucks).

Gianfranco Fancello, et al., 2015 suggested a method for assisting public administrations in planning safety involvements on the road network applied, the multicriteria method called "Concordance Analysis", The target areas considered for ranking are: traffic accidents, road geometry and traffic flow, model does not provide information about the choice of elements with worst safety conditions. Future research will focus on:

Introducing new criteria that are able to deepen the analysis detail level, such as Road Maintenance Condition Indicators. Comparison of the results using a specific technique for "γ" problematic such as Electric III for example.

Angelica Batrakova and Olga Gredasova, 2016 studied the effect of road conditions on the functional state of the driver and found that keeping the set speed for safe driving as per the design of roads.

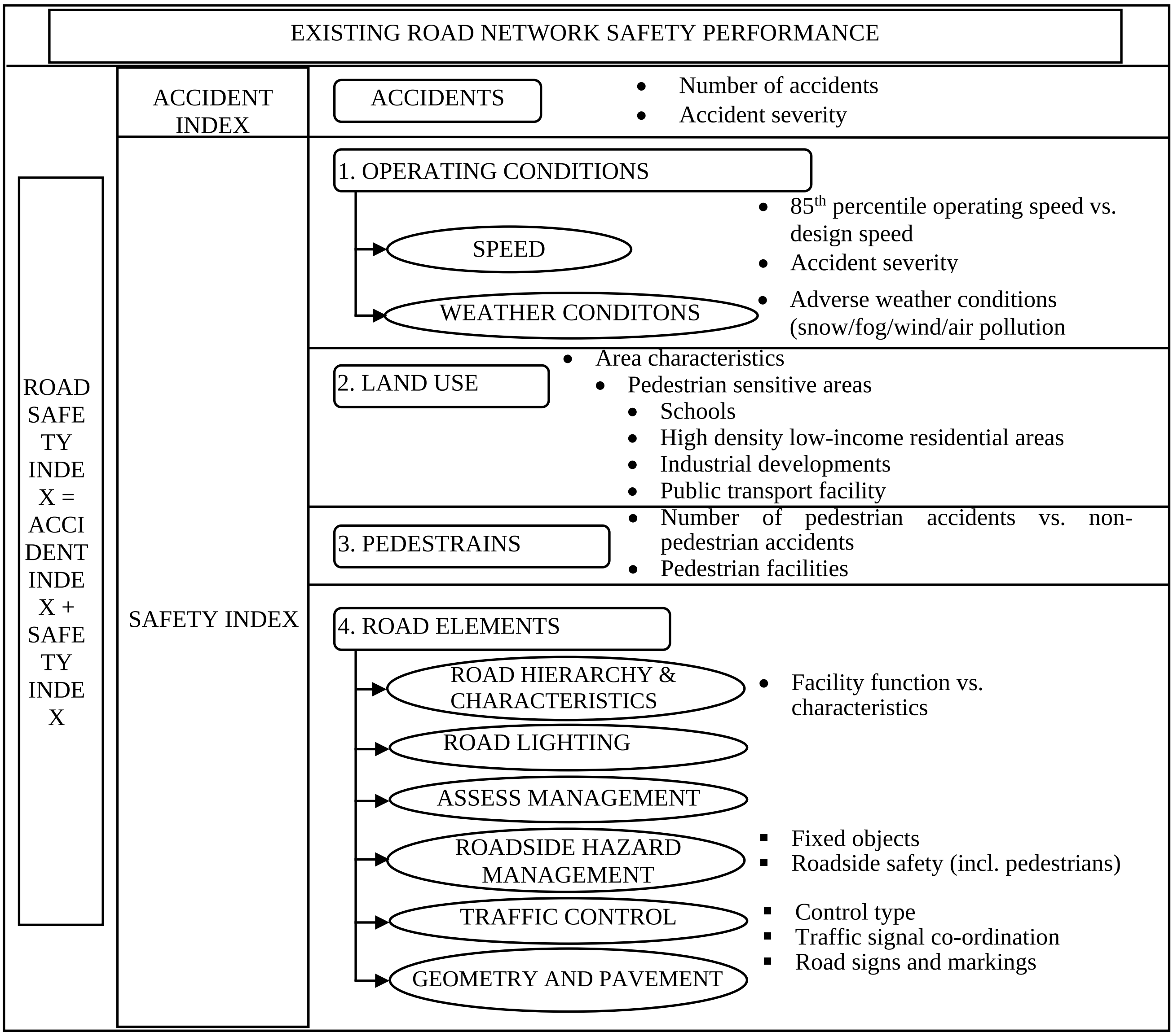
Vidhi Vyas, 2018 AHP methodology is demonstrated by taking a case study of a National Highway in India (NH-52, Sikar-Reengus) Geographic information system (GIS) is used for spatial visualization of the accident data. Four accident black spots are identified. The major reasons contributing to the accidents are found to be poor visibility, over speeding, drunk driving, etc. Suitable mitigation and preventive measures are suggested for improvement at the spots.

Ponnualuri, 2012 explained a detailed accident analysis some more relevant data is required. Information regarding driver characteristics (age, gender), road characteristics, weather conditions, and collision diagram will be very helpful (Ponnaluri 2012).

T. Agarwal, et al., 2013 developed Safety Hazardous Index using weight of safety factors and condition rating of safety factors. The Safety Hazardous Index is developed separately to evaluate safety at straight section, safety at curve section and safety at intersection. It is expected that this study will be useful in treating more hazardous locations depending on the available budget for road safety improvement

Occurrence of accident is governed by many parameters. These need to be identified and assigned relative importance, which involves decision-making. Road geometrics (pavement and shoulder width, roughness, sight distance, gradient, cross fall, super elevation, extra-widening, etc.) driver and road user characteristics (physical, mental and psychological factors), vehicular characteristics (vehicle dimensions, turning radius, weight, axle configuration, braking and acceleration characteristics, etc.), environmental factors (rain, fog, snow, etc.) are some of the factors to be considered for the study. Some researchers gave more importance to factors related to road geometrics such as surface, shoulder, drainage, lighting, marking, signs and signals and developed a safety hazardous index (Agarwal et al. 2013). Some others considered driver and road-user characteristics as important factors in their study (Najib et al., 2012; Islam and Kanitpong 2008). Environmental factors were also considered by few others (Sordyl 2015).

In this paper a study was carried out to determine the priority of safety requirements of a certain category of rural roads, viz., Pradhan Mantri Gram Sadak Yojan determine the priority of safety requirements of a certain category of rural roads, viz., Pradhan Mantri Gram Sadak Yojana (PMGSY) roads in the Jhunjhunu district of Rajasthan, India. Multi-criteria techniques were used to quantify the safety levels.



2.1. Literature gap

Many authors have considered few factors in assessing road condition, most of researches have focused on driver behavior on roads and accident history on roads. Ranking of roads is done without saying whether the road is fit for use. An effort is made here in considering all the relevant factors.

3. Methodology

a) Identification of road factors for its assessment.
b) Prioritization of each factor by AHP.
c) Checking the condition of road using ANN.

3.1. Analytic hierarchy process

The AHP is a multicriteria decision-making method proposed by Saaty [47]. In the AHP, pairwise comparison is performed to generate criteria weights. Before calculating the weights, consistency index tests are conducted to determine the ranking of the criteria and select the optimal solution. In the AHP, a series of factors (criteria) that influence the target are analyzed, and pairwise comparison is performed between factors to determine the weight and decision-making priority of each problem. The results of the AHP can assist decision makers in selecting the optimal solution. The AHP can be used to process uncertain or subjective data to develop a hierarchical structure based on logical relationships. Such a structure enables decision makers to understand the relationships between each relevant factor, which allows for the analysis of additional criteria and the calculation of factor weights.

The AHP is a multiple-attribute assessment method that can be used to divide complicated problems into attributes in a hierarchy. Accordingly, a hierarchical framework can be established on the basis of decision-making objectives, which can then be used to establish the hierarchical relationships between decision-making criteria. According to the number of factors in the hierarchy, each criterion can be further divided into subcriteria. The choices for assessment are presented at the bottom of the hierarchy. Pairwise comparison is conducted to determine the relative importance of two factors on the same layer (dimension) to a specific factor on a higher layer. The importance is rated on a scale of 1-9, and pairwise comparison matrices are developed. The eigenvectors of each comparison matrix are then obtained and multiplied with the importance rating of each factor to determine the factor weights, which are subsequently used to obtain the total score of each choice.

In the AHP, interactions between factors on the same layer (dimension) are presented using arrows arranged in a circular form. The relationships between factor priorities must exhibit the properties of transitivity (i.e., if A is better than B and B is better than C, then A must dominate C) and strength (i.e., if A is two times better than B and B is three times better than C, then A must be six times better than C). However, given that complete transitivity between factors is rare, factors that exist intransitivity are acceptable if they pass the consistency ratio test. In the AHP, the relative importance of factors in each hierarchy is calculated to establish pairwise comparison matrices. The results of the pairwise comparison of the factors are assessed on a scale of 1-9. After assessment by experts and scholars, the comparison results for the importance of each factor are presented in the pairwise comparison matrix A, which is expressed as follows:

$$A=[a_{ij}]=\begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_j & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_j & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_j/w_1 & w_j/w_2 & \cdots & w_j/w_j & \cdots & w_j/w_n \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_j & \cdots & w_n/w_n \end{bmatrix}$$

where $a_{ij} = w_i/w_j$, and w_i and w_j represent the weights of i factor and j factor, respectively. Given that $a_{ij} = 1/a_{ij}$, A is considered a positive reciprocal matrix. If all pairwise comparison values exhibit transitivity, then A is considered a consistent matrix. After establishing the pairwise comparison matrix, numerical analysis is conducted using eigenvalue solutions to obtain the eigenvector of this matrix. According to the theory of numerical analysis, if A is an n × n consistent matrix, the relationship between the eigenvector (X) and eigenvalue (λ) of matrix A can be expressed as presented in Eq. (2). Eq. (3) is obtained through the transposition of Eq. (2).

$$AX = \lambda X, \tag{2}$$
$$(A - \lambda I)\, X = 0, \tag{3}$$

When the eigenvector (X) is a nonzero vector, then det(A – λI) = 0. By solving this determinant, the n eigenvalues (λ) in matrix A are obtained. Let W be the weight vector of the n attributes; thus, $W = [w_1, w_2, \dots , w_n]^T$. The vector product of matrix A and the weight vector W is obtained using Eq. (4). Saaty [44] suggested inputting matrix A to obtain the maximum eigenvalue (λ_{max}); therefore, $AW = \lambda_{max}W$. The parameter λ_{max} is obtained using Eq. (5).

$$AW=\begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_j & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_j & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_j/w_1 & w_j/w_2 & \cdots & w_j/w_j & \cdots & w_j/w_n \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_j & \cdots & w_n/w_n \end{bmatrix}\begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} w_1' \\ w_2' \\ \vdots \\ w_j' \\ \vdots \\ w_n' \end{bmatrix} \tag{4}$$

$$\lambda_{\max}=\frac{1}{n}\left(\frac{w_1'}{w_1}+\frac{w_2'}{w_2}+\cdots+\frac{w_n'}{w_n}\right) \tag{5}$$

Because of the different levels of importance in each layer, an examination should be conducted regarding whether the layer structures exhibit consistency to ensure that the decision maker's evaluations remain consistent. In consistency testing, a consistency index (CI) is used for evaluating the overall consistency of pairwise comparison matrices. A CI of less than 0.1 indicates that the results are not completely consistent but are still within the acceptable error range. The CI is expressed in Eq. (6), in which λ_{max} represents the maximum eigenvalue of matrix A, and n represents the order of the matrix. For complicated problems involving additional pairwise comparisons, the order of the pairwise comparison matrix is increased, which increases the difficulty of determining consistency. To account for the differences in the CI of different orders, Saaty [47] proposed the calculation of the consistency ratio (CR) by using the CI and random index (RI; Table 1) The CR is calculated as follows: CR = CI/RI. When the CR is less than 0.1, the matrix is considered consistent.

$$CI=\frac{\lambda_{\max}-n}{n-1} \tag{6}$$

Table 3. RI values for different layers

Order	1	2	3	4	5	6
RI	N.A.	N.A.	0.58	0.9	1.12	1.24

3.2 ANN-based machine learning

ANNs are network structures composed of connected artificial neurons. By modifying the weights of the connections between artificial neurons, decision makers can simulate scenarios according to their perception and judgment. The output of each neuron is obtained using Eq. (7), in which x_i represents the input value, w_i represents the weight of the neuron connection, b_i represents the bias, and y_i represents the output value. By transferring the principles of biological neural networks to ANNs, scientists have enabled the use of advanced mathematical and statistical calculations to solve complex problems. ANNs can obtain information from the external environment. By using network structures and learning algorithms to train ANNs, decision makers can control the output to obtain the desired outcome.

$$y_i=\sum_{i}^{n} w_i \cdot x_i + b_i \tag{7}$$

ANNs comprise an input layer, hidden layers, and an output layer (Fig. 1). The input layer receives data from the external environment and converts the input data into suitable network signals according to the characteristics of the problem. Each neuron in the input layer only receives one input variable, which is then passed to the neuron in the next layer. The number of neurons in the input layer is equal to the number of input variables received. The hidden layers, which are located between the input and output layers, serve as an internal structure where interactions occur for solving nonlinear problems. The number of hidden layers and the numbers of neurons in these layers are fixed and can be freely adjusted according to the data complexity. The use of a higher number of hidden layers results in a longer computation time, during which local optimization might occur, which causes overfitting. When fewer neurons cannot be used for processing complicated problems, the output layer processes the data output to the external environment. The number of neurons in the output layer is determined according to the problem. In the output layer, nonlinear transfer functions are used to convert output data into output signals, which serve as a reference for predicting possibilities.

During ANN training, the input parameters are randomly initialized, and loop computation is performed to output the training results. The training results are compared with the actual results to obtain the loss function. The input parameters are constantly updated until a minimal loss function value is achieved. After the error threshold is reached, the loop computation is stopped. An ANN training model combines backpropagation (BP) and stochastic gradient descent to minimize errors. First, BP is used to compute the weight of the connections between neurons in each layer. Second, an optimized objective function is used to determine the quality of each weight. Because BP networks have excellent nonlinear mapping capabilities, the ANN can approximate continuous functions for model learning. A study on deep neural network learning indicated that stochastic gradient descent is an effective optimization method [48].

Nonlinear functions are used in ANNs as activation functions (e.g., the sigmoid and tanh functions) to approximate any function. Activation functions must be differentiable to enable the computation of the partial derivative of the loss function with respect to the weights when using BP to update the gradient. Basically, a two-layer neural network can approximate most functions. In ANN training, the input (x_i), weight (w_i), and bias (b_i) are used to calculate the weighted sum of each neuron. Therefore, the parameters of the activation function are defined as the connection weights of input layer neurons and hidden layer neurons [49]. Commonly used ANN activation functions include the rectified linear unit (ReLU), which are expressed in Eq. (8), respectively. To perform BP, a feature and a true value label are required. First, the feature is input into the neural network and processed by each hidden layer until it reaches the output layer. Subsequently, the loss function is used to compute the error between the output result and the true label. Finally, the weights and bias of the neuron connections are updated according to the error to minimize the error of the loss function (e.g., cross-entropy) and measure the per-sample training loss. The per-sample training loss is expressed in Eq. (9), in which p(y) and q(ŷ) represent the true value label and the probability distributions of predicted output, respectively.

$$\mathrm{ReLu} = \max(0, x)$$

$$\mathrm{ReLU} = \begin{cases} 0 & \text{for} \quad x < 0 \\ x & \text{for} \quad x \geq 0 \end{cases} \tag{8}$$

$$\mathrm{Loss} = -\Sigma(p(y) \cdot \log(q)(\hat{y})) \tag{9}$$

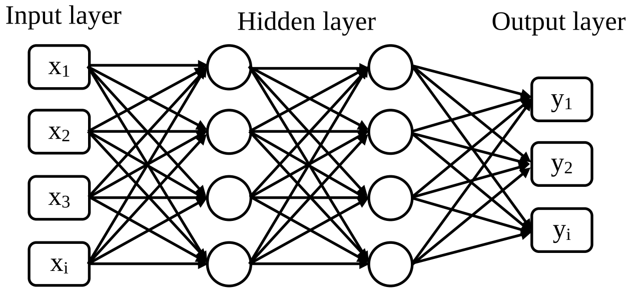


Figure 1: Architecture and computational model of an ANN

4. Case Study

Table 4. Survey questions and units

Parameters	Survey questions	Units
Gender	Please specify your gender	Female/male
Age group	Please specify your age group	18-24/25-39/40-54/55-65/over 65
Profession	Please specify your profession	Student/full time working/ retired/ others
Road use frequency	How often do you use Via Maqueda?	Rarely/once a week/two to three times a week/four times a week/ every day
Perception of infrastructure	How do you evaluate the level of service of infrastructure?	On a scale from a to F, where a corresponds to the best possible score and F to the worst
Safety perception	How safe do you think the Via Maqueda is by traveling by walking/cycling/micro mobility?	Likert scale from 1 to 5, where 1 corresponds to completely negative and 5 to completely positive
Comfort perception	How comfortable do you think is Via Maqueda by walking/ cycling/ micromobility?	Likert scale from 1 to 5, where 1 corresponds to completely negative and 5 to completely positive
Chaos perception	Maqueda by walking/ cycling/micromobility?	Likert scale from 1 to 5, where 1 corresponds to completely negative and 5 to completely positive

4.1 Measurement of parameters

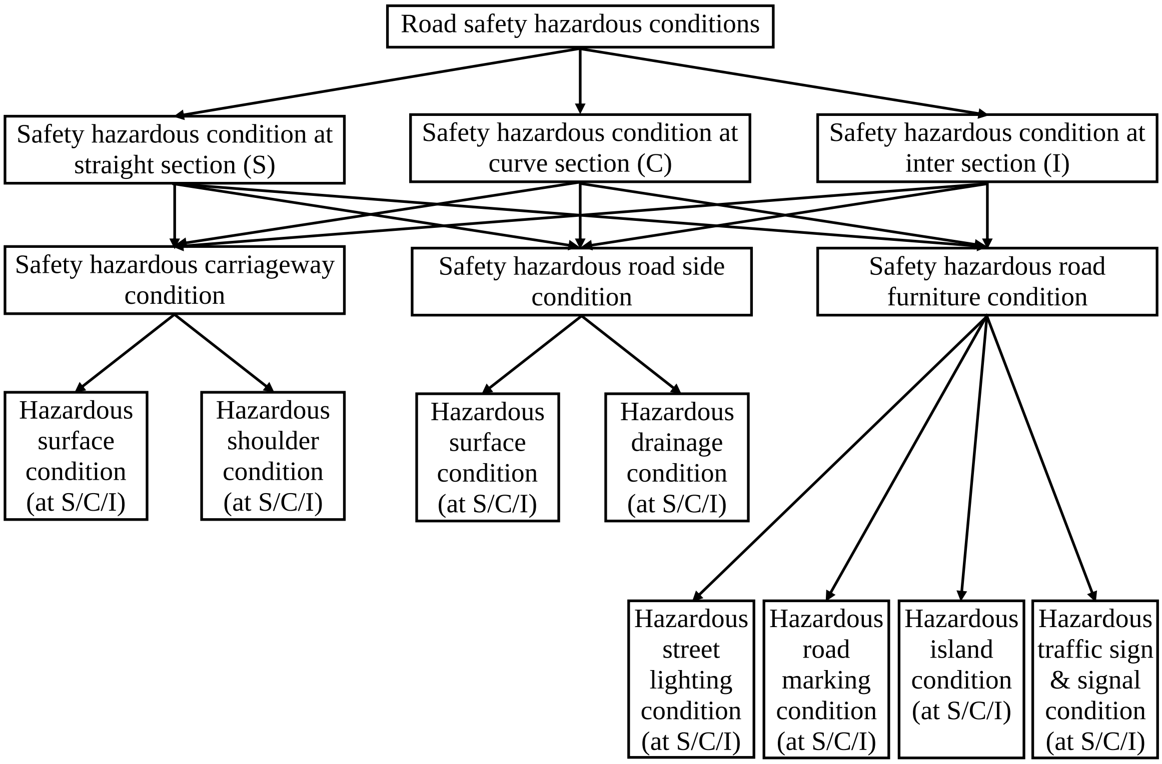
The criteria considered in the analysis are presented in column 1 of Table-1. Measurement of these criteria was done in field as per the critical dimension of the particular parameter as given below:

- The available sight distance at curves was measured as that length within which any obstruction was visible from some distance ahead.
- Sharp curve was measured as the angle of the bend of the curve.
- Super-elevation was estimated in terms of the transverse elevation difference of the centre line and edge of the road.
- Severity of roadside environment has been quantified as the length by the side of the road up to which obstruction such as tree close to the roadside, dumped material etc. affects the overall road width and visibility.

- Drainage provision has been measured as that portion of the road stretch which was not provided with sufficient drainage in terms of length.
- Shoulder width was measured in terms of the length of the road without sufficient width of shoulder.
- Shoulder drop was measured in terms of difference in elevation between the traffic lane and the shoulder
- Quality of the shoulder was measured as the length for which compacted and paved shoulder was not available.
- Pavement edge failure was taken as the length for which loss of bituminous surface material and base material was observed from the edge of the pavement.
- Potholes are bowl shaped holes propagated by traffic loads forcing the underlying materials to continually be removed from the hole. It was calculated as the area of the cavities which was measured as the depth and the maximum length of spread.
- Ravelling and spalling are the wearing of materials from the pavement surface due to dislodged aggregates. It was estimated as the length of the pavement surface with material segregation.
- The delineation was based on the availability of guide posts and warning signs at appropriate place

Severity score of the selected roads:

In this study the analysis has been done in two phases. In the first phase the prioritization of roads for safety provision was carried out considering the total length of each road as an alternative and the most critical road was identified. The parameters in the road were measured and rated (on a scale of 1-5) as explained above in Table-1. The severity level ratings of individuals were aggregated and average values were obtained as shown in Table 3. In the second phase, the road found critical from the first phase was considered for detail analysis. The entire stretch of the road was divided into stretches of 1 km and the stretch-wise prioritization of roads for safety provision was determined. The average values per km for the severity score of the parameters were obtained similar to the first phase.



Cracking implies the longitudinal cracks seen on the road surface and was calculated as the area in terms of width of the crack and length of propagation.

- Rutting is the permanent traffic associated deformation within the pavement layers. It was measured as the depth of depression on the pavement surface.
- Direct access from houses to roads was estimated by counting the number of collective houses with direct access to the road.

Table 5. Critical parameters in stretch 4-2

Parameter	Rank
Cracking	1
Sharp curves	2
Potholes	3
Sight distance	4

Super elevation	5
Quality of shoulder	6
Drainage	6
Delineation	6
Ravelling	7
Rutting	7
Shoulder drop	8
Severity of roadside environment	8
Direct access	8
Pavement edge failure	9
Insufficient shoulder width	9

Table 6. Criteria for pavement conditions classification according to the degree deterioration. Reproduced from [65]

Grade of deterioration	Cracking (%)	Aggregate shedding (%)	No potholes per km	Edge break (m^2 per km)	Average depth of ruts (mm)	Roughness (m per km)
New	0	0	0	0	0	0
Good	0	1	0	0	2	2
Fair	5	10	0	10	5	4
Poor	15	20	5	100	15	6
Bad	25	30	50	300	25	8

Table 7. Relation between maximum slope, type of terrain and project speed

Terrain	Maximum Slope (%) for Different Project Speeds (Km/h)						
	50	60	70	80	90	100	110
Flat	6	5	4	4	3	3	3
Plain	7	6	5	5	4	4	4
Mountain	9	8	7	7	6	5	5

- Mobility, i.e. that analyses those aspects associated with vehicle flow, traffic load distribution and the type of traffic recorded. This area comprises the following four objective functions (or criteria):
  - g_1, Peak-hour factor (PHF). the hourly volume during the maximum-volume hour of the day: divided by the peak 15-min flow rate within the peak hour: a measure of traffic demand fluctuation within the peak hour (HCM. 2000);
  - g_2, %hv, % heavy vehicles for lane group volume;
  - g_3, ADT. Average Daily Traffic, measured m vehicles per day;
  - g_4, degree of saturation, volume to capacity (v/c) ratio (HCM. 2000);
- Geometry, winch takes into account the geometrical characteristics of the road section. In this case we only considered one objective function:
  - g_5, adjustment factor for lane width (fW). The lane width adjustment factor, fw. accounts for the negative impact of narrow lanes on sanitation flow rate and allows for an increased flow- rate on wide lanes. Standard lane widths are 3.6 m (HCM 2000):
- Safety, that takes into account the number of accidents, m both absolute and relative terms, as well as the social consequences that these events have on society as a whole. In this case we have five objective functions:
  - g6, safety potential (SAPO). it is defined as the amount of accident costs per kilometre road length (cost density) that could be reduced if a road section would have a best practise design (European Commission. 2003);
  - g7, number of fatalities every year as the result of an accident in the section considered;
  - g8, number of persons injured every year as the result of an accident in the section considered;
  - g9, number of accidents with damage only to property:
  - g10, accident rate (Tif), the number of accidents divided by vehicle flow multiply by number of km (Elvik, et al., 2009).

Distress type	Low severity	Moderate severity	High severity
Longitudinal Wheel Path Cracking (LWP)	Single cracks with no spalling; mean unsealed crack width < 5mm	Single or multiple cracks; moderate spalling; mean unsealed crack width 5-20mm	Single or multiple cracks; severe spalling; mean unsealed crack width >20mm; alligator
Longitudinal Joint Cracking (LJC)	Single cracks with no spalling; mean unsealed crack width < 5mm	Single or multiple cracks; moderate spalling; mean unsealed crack width 5-20mm	Single or multiple cracks; severe spalling; mean unsealed crack width >20mm; alligator
Pavement Edge Cracking (PEC)	Single cracks with no spalling; mean unsealed crack width < 5mm	Single or multiple cracks; moderate spalling; mean unsealed crack width 5-20mm	Single or multiple cracks; severe spalling; mean unsealed crack width >20mm; alligator
Transverse Cracking (TC)	Single cracks with no spalling; mean unsealed crack width < 5mm	Single or multiple cracks; moderate spalling; mean unsealed crack width 5-20mm	Single or multiple cracks; severe spalling; mean unsealed crack width >20mm; alligator
Meandering Longitudinal Cracking (MLC)	Single cracks with no spalling; mean	Single or multiple cracks; moderate	Single or multiple cracks; severe spalling; mean

Distress type	Low severity	Moderate severity	High severity
Alligator Cracking (AC)	unsealed crack width < 5mm Not rated	spalling; mean unsealed crack width 5-20mm Interconnected cracks forming a complete block pattern; slight spalling and no pumping	unsealed crack width >20mm; alligator Interconnected cracks forming a complete block pattern, moderate to severe spalling, pieces may move and pumping may exist
Rutting (RUT)	Less than 10mm	10 to 20mm	Greater than 20mm
Shoving (SHV)	Barely noticeable to noticeable	Rough ride	Very rough ride
Distortion (DST)	Not rated	Noticeable swaying motion; good car control	Fair to poor car control
Bleeding (BLD)	Not rated	Distinctive appearance with free excess asphalt	Free asphalt gives pavement surface a wet look; tire marks are evident
Potholes (POT)	Less than 25mm deep and greater than 175cm^2 in area. (~15 cm Ø)	25 to 50mm deep and greater than 175cm^2 in area. (~15cm Ø)	Greater than 50mm deep and greater than 175cm^2 in area. (~15cm Ø)
Ravelling (RAV)	Not rated	Aggregate and/or binder worn away; surface texture rough and pitted; loose particles exist	Aggregate and/or binder worn away; surface texture is very rough and pitted

Table 8. Relative importance (weight) of safety factors at straight section, curve section and intersections

S.No.	Name of safety factors	Straight section (SFS)	Curve section (SFC)	Intersection (SFI)
1.	Hazardous geometrical condition	0.0270	0.0675	0.1700
2.	Hazardous surface condition	0.0330	0.0825	0.1900
3.	Hazardous shoulder condition	0.0114	0.0228	0.0700
4.	Hazardous drainage condition	0.0086	0.0172	0.0400
5.	Hazardous street light condition	0.0075	0.0175	0.0363
6.	Hazardous road marking condition	0.0051	0.0119	0.0242
7.	Hazardous island condition	0.0016	0.0140	0.0290
8.	Hazardous traffic sign and signal condition	0.0158	0.0266	0. 0705
	Total of weights	0.11	0.26	0.63

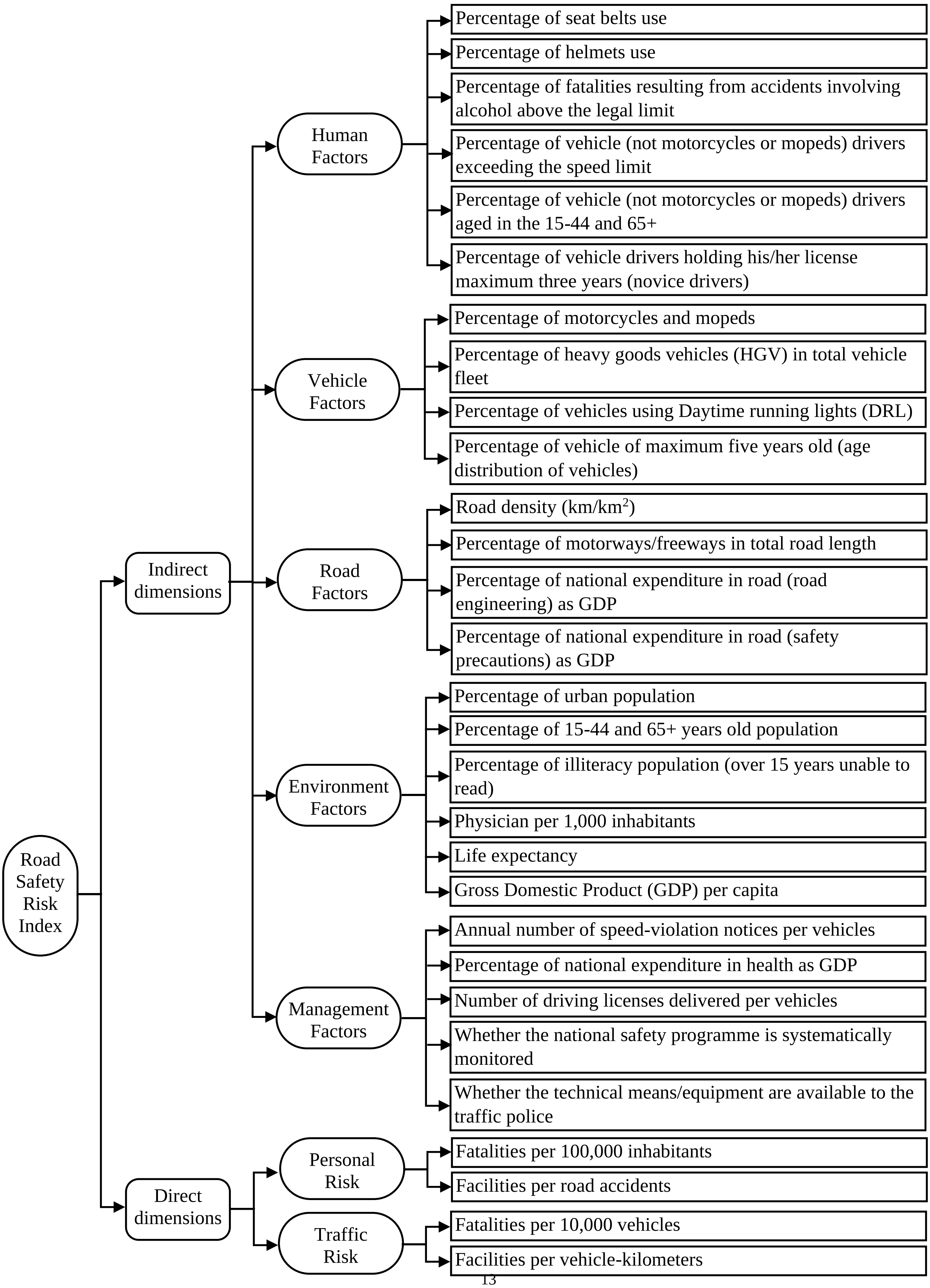
Parameters related to delay at intersections.

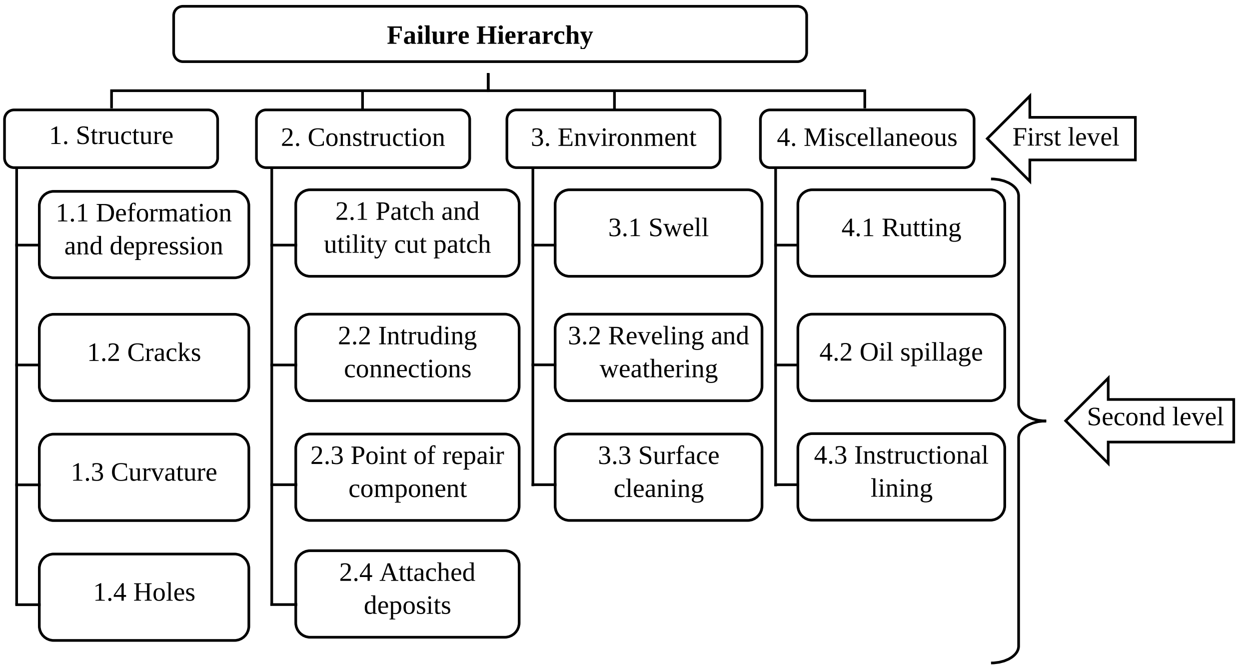
Each criteria is represented by a scalar value and by a preference direction: higher values of the criterion are preferred to lower ones if the preference direction is ascending; on the contrary, lower values of the criterion are preferred to higher ones if the preference direction is descending. The key indicators considered are described in the following:

- I1, Sight distance from access [m]. The driver approaching an intersection should have an unobstructed view of the entire intersection and an adequate view of the intersecting road to permit control of the vehicle to avoid a collision. The value of this indicator increases with sight distance from each approach: absent (1), poor (2), fair (3), good (4). This criterion is calculated by on-site measurements.

  To determine the road sections with worst safety condition, the objective is to minimize the criterion.
- I2, road signs and markings. This indicator increases as safety conditions improve: absent (1), poor (2), fair (3), good (4). This criterion is calculated by visual inspection. The objective is to minimize the criterion.
- I3, intersection lighting. The value of the level of illumination indicator increases as lighting conditions improve: absent (1), poor (2), fair (3), good (4). This criterion is calculated by visual inspections of site conditions. The objective is to minimize the criterion.
- I4, road surface maintenance. The presence of rutting, ponding, cracking, potholes, etc. increases the risk of accidents due to reduced vehicle control. The road surface indicator increases as surface conditions improve: poor (1), low (2), fair (3), good (4). The objective is to minimize the criterion. This criterion is calculated by visual inspection of site conditions. The objective is to minimize the criterion.
- I5, density of traffic conflict points. This indicator is calculated from the ratio of traffic conflict points between vehicles at intersection to intersection area.

The objective is to maximize the criterion. This criterion is calculated by analysing the trajectories generated by the traffic flows. The objective is to maximize the criterion.





- I6, number of vehicles entering the intersection area. This indicator is defined as the sum of traffic flows entering the intersection (in the analysis area "A") during the peak hour from all approaches. This criterion is determined by means of traffic counts at the intersection.
  The objective is to maximize the criterion.
- I7, heavy vehicles. This indicator is defined as the percentage of heavy vehicles entering the intersection analysis area "A". This criterion is determined by means of traffic counts at the intersection.
  The objective is to maximize the criterion.
- I8, pedestrian flow. This indicator is defined as the sum of pedestrian flows entering the intersection analysis area "A" during peak hour from all approaches. This criterion is determined by manual counts at the intersection. The objective is to maximize the criterion.

5. Conclusion

The methodology suggested can be used to determine the level of contribution of parameters towards safety hazard. Accordingly, appropriate mitigation measures may be adopted. A further detailed study needs to be conducted on a large scale by carrying out sensitivity analysis to test the stability of the ranking obtained by the suggested methods

1. Longitudinal Wheel Path
   Cracking (LWP) heavy traffic loading during spring thaw
2. Longitudinal Joint
   Cracking (LJC) poor construction, frost action, moisture changes
3. Pavement Edge Cracking
   (PEC) frost action, inadequate pavement substructure, heavy traffic loading, poor drainage, inadequate pavement width
4. Transverse Cracking (TC) low/high temperatures, frost action, reflection cracks from substructure
5. Meandering Longitudinal
   Cracking (MLC) frost action, poor construction
6. Alligator Cracking (AC) repeated traffic loading, insufficient pavement substructure, poor asphalt mix design
7. Rutting (RUT) poor construction, unsuitable pavement substructure
8. Shoving (SHV) vehicle stop/start, heavy traffic on steep grades, poor asphalt mix design, unstable pavement substructure
9. Distortion (DST) frost heaves, poor pavement substructure
10. Bleeding (BLD) poor mix design, poor construction
11. Potholes (POT) poor construction, drainage issues, poor asphalt mix design
12. Ravelling (RAV) poor asphalt production, poor construction, aging/weathering

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