DEVELOPMENT OF A METHODOLOGY TO EVALUATE SAFETY PERFORMANCE IN LOW VOLUME ROADS

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Degree of Master of Philosophy

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DECLARATION OF THE CANDIDATURE & SUPERVISOR

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R.K.T.K. Ranawaka

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Dr. H.R. Pasindu

DEDICATION

I dedicate this dissertation to Dr. H. R. Pasindu and Dr. T.W.K.I.M. Dias, my supervisors, and mentors who encouraged and guided me to complete this study successfully.

Also, I dedicate this dissertation to my parents and sister who supported me and stayed with me throughout all the good and hard times.

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ABSTRACT

Road safety is a vital element of the road's overall function, which is often neglected in decision-making for road maintenance management. As a result, the safety issues, especially in rural roads, remain without funding to implement the necessary countermeasures. One constraint faced by local authorities is the lack of analysis tools to select appropriate safety treatments within the available budget.

Low-volume roads provide connectivity between residential/commercial areas and the national road network. They are especially critical in rural areas to provide accessibility to the community for social and economic needs. Low volume roads account for nearly 61% of the road network length in Sri Lanka. With the rapid motorization taking place in Sri Lanka, it is expected that traffic on these roads will increase significantly in the future. However, some of these roads have not been developed according to the standard design guidelines and raise major safety issues on such roads as a result. Considering the expected growth in traffic and prevailing issues concerning roadway design, the safety level decrease in these roads raises risk to the road user. Therefore, it is essential to evaluate the safety performance of low volume roads. Existing safety evaluation methodologies rely on traffic data, and accident statistics, which may not be readily available for the low volume road network. Therefore, it is necessary to develop a non-subjective methodology to evaluate the safety performance of low-volume roads, considering the data limitations present in developing countries. This study analyses the main casual factors of low volume road accidents and a novel approach, i.e., Cumulative Safety Index: CSI, designed to evaluate the safety performance of low volume roads considering the data limitations present in developing countries.

This study also proposes a methodology to incorporate road safety performance in rural roads in maintenance planning using a multi-objective optimization approach. Road safety performance is defined in terms of the CSI, which is computed based on the severity, exposure, frequency of safety issues that road safety audits have identified. The safety performance and pavement condition-related indices, such as International Roughness Index: IRI, pothole number, etc., are included in the Multi-Objective Optimization: MOO decision criteria analysis. It comprises two objectives: minimize network IRI, and minimize network CSI. Applicability of the developed model has been demonstrated from the illustrative example of a rural road network. Results have shown that roads with safety issues can also be prioritized in budget allocation while ensuring the network-level pavement condition can be maintained at a reasonable level. This methodology offers a simplified approach to incorporate road safety issues in rural road maintenance planning.

This study presents a methodology to logically determine the safety treatment criteria for a selected road to increase the safety performance at the project level. The safety treatments are taken based on a linear programming model that optimizes the safety performance of the selected road. CSI represents the safety performance of the road, which is determined based on the prevailing issues on that road. The model comprises the objective function that maximizes the safety performance of the selected road concerning the number of prevailing safety issue types. This model is used to identify the optimal safety treatment scheme for the road chosen, ensuring prevailing road safety issues are effectively addressed. The objective function consists of the Initial CSI of the selected road and the safety improvement after treating relevant issue type coupled with a binary decision variable.

Keywords: Low-volume roads, Safety, Safety Performance Evaluation, Optimization Techniques, Pavement Management System, Network and Project Level Analysis

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LIST OF ABBREVIATIONS

Abbreviation	Description
RDA	Road Development Authority
PRDA	Provincial Road Development Authority
AADT	Annual Average Daily Traffic
CAREC	Central Asia Regional Economic Cooperation Program
ADB	Asian Development Bank
EPDO	Equivalent Property Damage Only
CSI	Cumulative Safety Index
MOO	Multi Objective Optimization
HSM	Highway Safety Manual

1 INTRODUCTION

1.1 Research Background

Safety performance of road infrastructure is one of the critical factors to ensuring the road network is safe for all road users. Issues in road infrastructures have been identified as a significant causal factor to road crashes, especially in developing countries. Improper safety management and road maintenance strategies have worsened this scenario in developing countries.

Various causal factors can be related with the occurrence of a road crash. Issues related to geometrical design errors, issues with pavement, improper delineation, improper road management schemes have the potential to increase the crashes of a road. Drivers are always exposed to commit an error during their travel due to condition of their mental state at the moment, reaction speeds, fatigue, negligence and other psychological factors. But, if the safety standards of a road can reduce the risk of the error committed by the driver, the probability of the crash occurring can be reduced. This is identified as the concept behind forgiving roads [1]. Such a road forgives the driver on his/ her mistake rather than punishing for the mistake. Proper road safety performance evaluation, proper safety management schemes and proper road management are the key factors to achieve forgiving roads [2]. For the purpose of achieving cost-optimized safety treatment decision criteria, well established safety management systems have to be used [3]. When considering the problems related to budget allocations for low-volume roads in developing countries, obtaining adequate safety treatment countermeasures have become a serious consideration.

At present, Sri Lanka is responsible for an average of 8 deaths per a day, which means one death nearly in every 3 hours taken place due to a road crash. When the period of 20 years back is considered, the rate of deaths due to the crashes was around three deaths per day, (i.e., one death per eight hours). Within the period of this 20 years (1998-2018), it can be seen that the magnitude of the crashes that happen daily, have been increased by 167%, largely due growth in motorization as well as the expansion of the road network.

When a significant number of deaths occur in a country due to roadway crashes, the country will have to spend more for health, especially on handicapped or partially disabled people from its economy.

Table 1.1 is an overview of crashes in Sri Lanka for the years 2008 - 2019 [4].

Table 1.1. Road Crashes in 2008 - 2019

Year	Accident Severity		
	Fatal	Grievous	Non-grievous
2008	2176	4941	11288
2009	2263	5379	10945
2010	2579	6124	12560
2011	2498	6966	13196
2012	2317	7209	14680
2013	2190	6872	13526
2014	2261	7071	12782
2015	2601	8187	13595
2016	2838	8933	14050
2017	2963	8667	13102
2018	2949	8475	12264
2019	2641	7693	10691

Table 1.1 illustrates that there is an increasing trend of crashes in all severity levels over past 10 years. Especially with the current economic status of Sri Lanka, it is not a convenient task for the government to spend a huge money on casualties due to roadway crashes.

Sri Lankan roads are now becoming deadlier than never before with the highest recorded number of traffic deaths in year 2017, 3101 [4]. It is an increase of 98 deaths when compared to 2016.

Within a period of 10 years, over 23,000 people have been killed due to road crashes and over 50,000 people are left with serious injuries.

Table 1.2 present a comparison of the element types involved in road crashes for the year 2017and 2018 [4].

Table 1.2. Involvement of different vehicle types in crashes

Vehicle Type	Fatal Crashes		Deaths in 2017	Critical crashes in 2018
	2017	2018		
Motor Cycles	1228	1227	1269	3382
Lorry	371	344	397	843
Dual Purpose Vehicles	315	318	346	977
Private Buses	191	237	214	498
Three-Wheelers	357	365	383	1354
SLTB Buses	56	62	64	189
Motor Cars	207	210	225	952
Cycles	41	42	41	71

These scenarios arise the requirement` of addressing the road safety in Sri Lanka more than in the previous decades.

Roads in Sri Lanka can be mainly divided as urban and rural roads. In a research carried out by S.A.T Dhananjaya and M.C Alibuhtto (2016) regarding the Factors affecting the road crashes in Sri Lanka, shows that most of the road crashes are taken place in the rural road network in Sri Lanka [5].

Table 1.3 illustrates the variation of occurrence of crashes in different severities in urban and rural roads. As it can be seen, a majority of crashes have taken place in rural roads. From the total fatal crashes, 66% of crashes have taken place in rural roads, while 59% of the total grievous and non-grievous crashes have also taken place in rural roads.

Table 1.3. Occurrence of crashes in urban and rural roads

Year	Fatal crashes in		Grievous and Non grievous crahses	
	Urban roads	Rural roads	Urban roads	Rural roads
2008	813	1363	7259	8970
2009	803	1460	7187	9137
2010	861	1718	7805	10879
2011	868	1630	8570	11592
2012	782	1535	9079	12810
2013	692	1498	8341	12057
2014	725	1536	7782	12071
2015	830	1771	8251	13531
2016	946	1892	8493	14490
2017	984	1979	8629	13140

When it further comes to rural low-volume roads, it can be observed that a comparatively low priority is given to their upgrades than the national roads. Even the Sri Lanka Police crash database does not contain information regarding minor roads in rural areas. Low-volume road safety assessments may raise concerns about the general lack of reliable accident statistics. That small crash data may not always provide the information needed to prevent them. [6].

In 2017, Sri Lanka had a classified road network of 31,303 covering all the provinces in the country [7]. Among them, 18,923km of roads could be categorized as low volume roads, which accounts nearly 61% of the total road network in Sri Lanka [7]. Classified roads here include expressways, national roads (Class A and B) and provincial roads (Class C and D).

1.2 Problem Statement

With the increase in vehicle usage, especially three-wheelers and motorcycles, which account for more than 60% of the total vehicle population [8], the number of vehicles using the local roads is expected to increase. Sustainable development goal (SDG) 11.2 stands to providing a safe, affordable, and accessible by any user, and sustainable transport system for all, by 2030 [9]. According to the five pillars, all countries are encouraged to implement the Global Plan for the Decade of Action for Road Safety 2011-2020. Pillar 2 stands for safer roads and mobility. It is expected to achieve safer roads and mobility by “raising the safety and protective quality of road networks for the benefit of all road users, especially the most vulnerable (pedestrians, bicyclists and motorcyclists)” [10]. It highlights that, achieving safer roads is a key element in SDG. Also, the safe systems approach adopted by in the next decade of action identifies road improvement as a primary concern in improving road safety.

Majority of the low volume roads are not planned highways, but have been gradually evolved from dirt tracks leading to villages. The road upgrading that has taken place in low volume roads over the years are primarily involved road paving to asphalt concrete or concrete pavements but have not always incorporated safety standard improvements through improved geometric design. Thus, road users such as motorcycles, three wheelers perceive that road conditions are suitable for higher travel speeds whereas the geometric characteristics does not warrant it. This would increase the crash risk not only for them, but for the other users especially the vulnerable road users such as pedestrians and cyclists. Apart from that, other infrastructure that increases the safety performance of a road such as proper delineation, roadside barriers etc., may also have not been provided in the low-volume road network.

When considering about the available safety evaluation tools, most of the existing methodologies rely on accurate crash data and traffic data which are not readily available in developing countries [11]. Therefore, road agencies in developing countries face many difficulties when trying to adopt those methodologies. These scenarios highlight the requirement of developing a proper logical and non-subjective framework which is less data extensive to evaluate the safety performance of a considered road.

On the other hand, road agencies and authorities use Pavement Management Systems (PMS) to make decisions regarding individual projects or an entire pavement network [12]. Most of the existing PMSs consider only about the pavement maintenance strategies within their management schemes. Although ensuring a safe travel is a primary objective of a road, safety performance has not been addressed in most of the multiple decision-making criteria of pavement management systems. Low-volume roads are more exposed to this scenario due to the lack of accurate crash, traffic data, crash cost parameters, and safety performance indicators especially in developing countries [11]. Therefore, there is a requirement to develop alternative approaches to incorporate safety performance in PMSs and decision making that can address the data limitations prevailing in developing countries [13]. Then, relevant road agencies and authorities will decide on the safe treatment strategies they can adopt based on their budgetary restrictions.

Above scenarios indicate that, to create a safer environment for all road users, it is vital to identify the roadway characteristics in low volume roads that are critical to ensure the safety performance of these roads. On the other hand, it is essential to develop proper mechanism to evaluate the safety performance of low-volume road.

1.3 Research Objectives

Major Objective

- To develop a safety performance evaluation methodology for low volume roads

Sub Objectives

- Evaluate road crashes and its relationship to causal factors relevant to road infrastructure
- Develop guideline to rate road safety related characteristics based on their contribution to safety risk

1.4 Scope

In this research, low volume roads are defined as the roads in which AADT <2000 and that are not categorized under A class and B class roads according to the road classification of Sri Lanka. To ensure the safety of -volume roads in Sri Lanka, it is essential to identify the roadway characteristics which contribute to those roads' safety, which this research address. Crash data obtained from Sri Lanka Police are used for this study to study the facts related to the crashes.

2 LITERATURE REVIEW

Definition for a low volume road

Definition by Dominique van de Walle (2009) - Local roads and rural roads with little or no traffic connecting villages to other villages or road networks. [14]

According to Coghlan (1999), two-lane asphalt paved roads where below 2,000 vehicles travel per day at the high end can be considered a low-volume road. They facilitate transportation for agricultural, material items from their origins to relevant markets and destinations. It is critical for both local and national economies. Low-volume roads provide access to public health, education, civic and recreational facilities. [15]

2.1 Safety Issues in Low Volume Roads

Table 2.1 provides an analysis of the safety issues related to roadway characteristics as they have been concerned in different studies.

Table 2.1. Analysis of roadway issues in different studies

Safety Issue	Addressed in			
	[6]	[16]	[17]	[18]
Lack of roadside space	√	√	√	√
Issues at curve alignments			√	√
Signalized intersections	√	√		√
Entrance from by roads	√		√	
Road side edges				√
Pavement marking	√		√	√
Roadway issues	√	√	√	
Roadside slopes and edges				√
Pedestrian facilities			√	
Improper signage			√	

According to the above analysis, lack of roadside space and presence of roadway issues such as cross section, lane width, alignment etc. can be identified as the highly concerned safety issues related to roadway characteristics. Issues at intersections, pavement markings have been highly concerned after the above two issues mentioned. That demonstrates those issues should be prioritized when applying safety treatments for a particular road.

Ten general safety issues that can have direct influence in causing crashes have been identified by different authors [6] [17] as follows: alignment of the road, the cross-section of the road, road markings, longitudinal rumble strips, pedestrian walkways, delineation, warning signs, road condition, roadside features, and access density. Based on the above issues, a set of complex problems have been generated. It is noticeable that the effect of the above-mentioned issues also depends on the existence of other roads, traffic on the considered road, features related to environment, etc. [17]. From the above safety issues, road alignment has been identified as the road factor that has the highest impact on the road safety. When a severe curve realignment is needed, the risk may be increased severely at the end of the realignment process. Further, Montella (2005) states that widths of lanes and shoulders affect vehicle run-off-the-road and head-on and opposite direction collisions of multiple vehicles.

Two other safety issues that have not been mentioned in the above list are lane and shoulder widths. Lane and shoulder widths do not effect on the road safety alone. Their effect depends on traffic volume of the road [17].

Missing passing lanes and climbing lanes can be identified as other factors that can lead to roadway crashes. Improper road marking also has a contribution to the increase of crash risk. Inadequacy of edge lines, inadequacy of centrelines, and improper overtaking lines where passing sight distance is not provided have their own contribution for the increase of the crash risk [17].

Causal factors to roadway crashes are not always roadway related issues. There are other governing factors that affect the safety risk on roadways. Abbas (2004) [19] has further undertaken an analysis to identify the causes related to crashes on a set of rural roads. Previously collected crash data have been performed. He could obtain four other main reasons which can lead up to a collision, apart from roadway related issues.

- Problems associated with drivers
- Problems associated with pedestrians

- Vehicle faults
- Problems associated with surrounding environments

As mentioned in the previous chapter, rural roads account for a higher percentage of crashes. When the fatality rate of urban and rural roads is considered, the rural roads have a 1.5 times higher fatality rate than the urban road network. It may be the final result of the occurrence of the below factors [18].

- The physical characteristics of roadways including inadequate roadside space that provide recovery areas for vehicle run-offs from roads, issues at curve alignments, etc.
- Inappropriate practices of drivers such as over speeding, not using seat belts.
- The higher reaction time taken for the medical treatments during a crash.
- Issues with the lack of availability of data, funding and safety expertise for future implementations

Safety improvement on low volume roads manual [18] has provided safety treatment methods in a vast range that can be applied for the high-risk low volume roads. Those treatment methods can be directly applied to both rural collectors and rural local roads.

Table 2.2, Table 2.3, Table 2.4, and Table 2.5 illustrate the safety treatments suggested by the manual as follows.

1. Horizontal Curves

Table 2.2. Safety treatments for horizontal curves

Safety Treatment	Crash modification factor	Crash reduction factor
Install curve warning signs	0.7	0.3
Install or upgrade warning signs with fluorescent yellow sheeting	0.66	0.34
Use of optical speed bars	-	-
Installation of chevron signs	0.75	0.25
Providing rumble strips	0.85	0.15

2. For the issues at non-signalized intersections

Table 2.3. Safety treatments for the issues at non-signalized intersections

Safety Treatment	Crash modification factor	Crash reduction factor
Stop ahead pavement markings	0.44-0.69	0.31-0.66
Install stop bars at minor road access		
Improving sight distance	0.44-0.89	0.11-0.66
Providing upcoming road names on advanced warning signs	0.9-0.99	0.01-0.1
Installing dynamic, advanced intersection warning system	0.1-0.76	0.24-0.9
Improving hardware and visibility on railroad crossings	0.55	0.45
Implement lane narrowing	0.6-0.8	0.2-0.4
Convert minor road stop control to all-way stop control	0.3	0.7

3. Pavement and shoulder resurfacing

Table 2.4. Safety treatments for the issues related to pavement and shoulders

Safety Treatment	Crash modification factor	Crash reduction factor
Installing safety edges	0.85-0.92	0.08-0.15
Installing centerline rumble strips	0.75-0.85	0.15-0.25
Installing edge lines/shoulder rumble strips	0.78-0.9	0.1-0.22
Installing transverse rumble strips	0.76-0.91	0.09-0.24
Providing graded shoulders	0.52	0.48
Increasing skid resistance	0.25-0.6	0.4-0.75
Providing paved shoulders	0.86	0.14
Widen the width of travel lanes	0.95	0.05
Increasing the width of shoulder	0.9-0.97	0.03-0.1

4. Pavement marking

Table 2.5. Safety treatments related to pavement markings

Safety Treatment	Crash modification factor	Crash reduction factor
Marking the centerline	0.67	0.33
Installing wider pavement markings	0.65-0.96	0.04-0.35

5. Roadside safety treatments

- Control roadside vegetation to improve sight distance
- Convert culvert headwalls to traversable end treatments
- Relocation of selected hazardous utility poles
- Install centre-median guardrail
- Provide impact attenuation devices at selected roadside hazard locations
- Widening current centre-median or constructing new physical separation
- Flattening roadside slopes
- Creating clear-zones
- Installing concrete median barriers

Other possible treatments

- Mitigation of groundwater to prevent ponding
- Widening of functionally obsolete bridges

2.2 Safety Evaluation in Low Volume Roads

There are different classifications and terminologies used to indicate the severity levels of crashes. In "CAREC Road Safety Engineering Manual" published by Asia Development Bank, crash severity has been estimated as shown in

Table 2.6 [20].

Table 2.6. Estimates of Crash Severity

Severity	Description	Examples
Catastrophic	Multiple deaths are likely.	High-speed, multivehicle crashes on expressways A bus collision at high speed with a bridge abutment
Serious	Death and serious injuries are likely.	High- and/or medium-speed vehicle/vehicle collisions High- and/or medium-speed collisions with a fixed roadside object Pedestrian crashes on rural highways
Minor	Minor injuries only are likely.	Low-speed collisions, such as a rear-end crash in a slip lane or a pedestrian struck in a car park

Limited	Trivial injuries or property damage only are likely.	Very low-speed vehicle collisions A pedestrian trips on an uneven footpath A car collides with a median island in a car park

But the crash severity classification followed by the Sri Lanka Police is different to this. The highest severity level is classified as fatal, followed by grievous, non-grievous, and damage only crashes.

A key tool which is followed all over the world for safety evaluation, is safety performance functions (SPF). SPFs estimate the number of crashes on a particular road segment in a given year. Confirming that, The Highway Safety Manual (HSM) (2010) has also suggested using SPF to evaluate the safety in road segments. HSM has developed the following equation as the safety performance function to predict crashes in rural two-lane two-way road segments [13]

$$N_{spf} = ADT \times L \times 365 \times 10^{-6} \times e^{-0.312} \qquad 2.1$$

Where,

N_{spf} - Predicted number of annual crashes

L - Lane width

AADT - Annual Average Daily Traffic

Although HSM has developed safety performance functions, researchers and relevant transportation agencies are always encouraged to develop country-specific or state-specific methodologies to evaluate the safety. Main reason for that is, traffic conditions and road conditions are different from country to country. And the base conditions where one tool is developed may be quite different than the conditions where the model is going to be applied.

After the review of SPFs developments all over the world, four models have been used to investigate the safety performance in Alabama State. [16]

Model 1 – Model one is generally based on the HSM, and the data required to perform the model is very low. The coefficient for the segment length is fixed here since AADT greatly influence crash prediction models [16].

$$\mu_i = \beta_0 \times AADT_i^{\beta_i} \times SL_i \qquad 2.2$$

μ_i - Estimated expected number of crashes per year for site i

$AADT_i^{\beta i}$ - Annual Average Daily Traffic

SL_i - Segment length for the site i

β_0 & β_I are parameters to be determined.

Model 02 is in the form of SPF, which is developed in the UK. In addition to the required data mentioned in model 01 and in model 02, the minor junctions within the site are quired [16].

$$\mu_i = \beta_0 \times AADT_i^{\beta_1} \times SL_i^{\beta_2} \times exp\left(\frac{bn_i}{SL_i}\right) \qquad 2.3$$

n_i - Number of minor intersections in site i

β_0,β_1, β_2 & b are parameters to be determined.

Model 03 is in the form developed by the Connecticut Transportation Institute. It requires additional data such as dummy variables to account for the effects of a year on the intercept, lane width, and the speed limit [16].

$$\mu_i = \exp(\beta_0 + \beta_1 DY_i + (\beta_2 \ln \times AADT_i) + (\beta_3 \ln \times SL_i) + \beta_4 LW_i + \beta_5 S_i) \qquad 2.4$$

DY_i - Dummy variable to account for effects on a year on the intercepts

LW_i - Lane Width

S_i - Speed Limit (mph)

Model 04 has been developed by the Council & Stewart based on the data of some regions in USA. Shoulder width has been additionally introduced in this model [16].

$$\mu_i = \exp(\beta_0 + \beta_1 SW_i + \beta_2 LW_i) \times AADT_i^{\beta_s} \times SL_i \qquad 2.5$$

- SW_i - Shoulder Width

Adopting of these models for the low volume road network has a major limitation. Specially in developing countries like Sri Lanka, the availability of traffic data for the low volume and rural road network is very low. Therefore, models based on the traffic data cannot be directly used in the Sri Lankan context.

The New Zealand Transport Agency has developed “Road infrastructure safety assessment” procedure to screen road controlling authority’s performance in road safety. Road safety audits are the basis of the development of this procedure. Based on “What If” scenarios, the effect of different road safety treatments has been explored under this procedure. Each identified issue at road safety audits has been assigned to risk relative to a similar issue of the benchmark road, which has a risk of 1.0 for ease of arithmetic. The relative risk is then multiplied by the exposure to obtain the actual risk [21]. In the method proposed in this study, every identified safety issue is assigned a value between 1-5 based on three risk parameters namely exposure, probability and severity.

Cafiso et al., (2006) and Montella (2005) has proposed a similar approach. According to Cafiso et al., only a few crash data will not always provide enough measurements to predict future crashes and safety [6]. So, a methodological approach has been implemented to address the safety of two-lane – rural roads based on analytical procedures and safety inspections. The research has been carried out by performing a road safety inspection. The main objective of the road safety inspection is to identify the hazardous roadway characteristics that are prevailing on a particular road. Previous research has proved that safety inspections are effective and now it’s becoming an accepted practice all over the world [6] [17]. Safety index was used to address the causes which were found at the road safety inspection in the study. It generally consists of three factors:

- How much a road user is exposed to a crash (Exposure factor)
- How probable a road user to get involved in a crash (Crash Frequency factor)
- How severe the casualty resulting from a crash (Crash Severity factor)

Finally, the safety index can be stated as follows.

$$\mathrm{SI} = \text{Exposure factor} \times \text{Accident frequency factor} \times \text{Accident severity factor} \qquad 2.6$$

Based on a similar approach, Road Safety Risk Index (RSRI) has been used by Leur and Sayed (2002) to evaluate the safety risks of roads. RSRI is obtained as follows [22].

$$\mathrm{RSRI} = \mathrm{Exposure} \times \mathrm{Probability} \times \mathrm{Consequence} \qquad 2.7$$

Calculation of the parameters mentioned in previous two equations is based on the attributes impacting different safety issues and crash types. Karndacharuk et al. (2019) [23] identified following factors as the contributing factors that affect exposure, probability and severity related to roadway issues as shown in

Table 2.7.

Table 2.7. Parameters to decide safety parameters

	Run-off-road	Head-on	Intersection	Other	Pedestrian
Exposure	AADT; segment length	AADT; segment length	AADT for each approach; intersection size	AADT; segment length	AADT; pedestrian count; crossing width; segment length
Probability	Speed; road geometry; shoulders; barriers; hazard offset; guidance and delineation	Geometry; separation; guidance and delineation; speed	Type of control; speed; design, visibility; conflict points	Speed; sight distance; number of lanes; surface friction	Design of facilities; separation; number of conflicting directions; speed
Severity	Speed; roadside features and design (e.g., barriers)	Speed	Impact angles; speed	Speed	Speed

Use of different indexes to identify the safety risk of a road has been a common practice. Loprencipe et al. (2018) have proposed Hazard Index (I): a numerical index to quantify overall roadside risk assessment. “I” has an inverse relationship with safety provided by the roadside features, i.e., the more the I value, the less the safety offered by roadside features is. I depend on the risk factor of the examined distance (V_{pj}), where the product of six individual factors obtains v_{pj} as follows [24]

- B_i - base value associated to each of n elements i
- K_{1i} - priority factor of the category to which the aspect i belongs
- K_{2i} - extent factor of each of n elements i which are along the roadside
- K_3 - accident factor (considers the accident rate)
- K_4 - traffic factor of the determined road (derived from AADT)
- K_5 - design consistency factor of examined road

Four defect types i.e., safety barriers, discrete, rigid obstacles, continuous obstacles, and water drainage have been considered for the above evaluation. The crash rate proposed in this method is reliable only in homogeneous stretches, which is not experienced at rural roads in developing countries [24].

Identifying the prevailing risk of a road segment is essential. The method proposed in this study also focuses on identifying the overall risk of a road. As per the method proposed by Appleton (2009), the risk is generally calculated per 1km section of the road, for the easiness of comparing risks of issues in roads with unequal lengths [21]. As per the observations, rural low volume roads have higher relative risks when compared to urban roads. The relative risk is generally the risk to individual drivers. They are multiplied by the traffic volume to calculate the risk related to all drivers (collective risk). Based on the results of collective risks, they are scaled up as they can be used for the entire road network. Identification of issues will be based on cross section, alignment and road surface. The given equation is used to calculate the risk of a particular band in a sample of roads [21].

$$Band\ risk = \sum Collective\ risks \times \frac{\sum VKT\ in\ band}{\sum VKT\ in\ sample} \qquad 2.8$$

Where,

VKT - Vehicle kilometres travelled

New Zealand Transport Agency also follows the risk parameters mentioned early. They have evaluated the safety performance in low volume roads using several risk metrics: collective risk, personal risk, road protection score, star rating, RISA (discussed previously) [25].

Collective risk is defined as a “measure of fatal and grievous crashes happed per km of a road in a year” [25]. It is calculated as follows.

$$Collective\ risk\ =\ \frac{(Fatal\ crashes + Grievous\ crashes)}{(Number\ of\ years\ of\ data \times length\ of\ road\ section)} \qquad 2.9$$

Personal risk is defined as the "number of fatal and grievous crashes happened per 100 million VKT on the road" [25]. It is calculated as follows.

$$Personal\ risk\ =\ \frac{(Fatal\ crashes + Grievous\ crashes)\times 10^{8}}{(Length\ of\ road\ in\ km \times Number\ of\ years\ of\ data \times 365 \times AADT)} \qquad 2.10$$

Road protection score and start rating measure low-volume roads' safety performance based on the presence or absence of road infrastructure issues [25]. All three equations mentioned previously indicate the importance of capturing exposure to the road users.

Nalaka and Sivakumar (2016) have developed a model to address the relationship between traffic volume, crash count, and road infrastructure improvements. A section of the A4 road inside Colombo District having a length of 20km has been used to carry out the case study. The road safety audit was converted into an infrastructure improvement index value for each identified hazardous location along the selected road section by allocating weights for each feature according to perceived weightage, as shown in Table 2.8 [26].

Table 2.8. Infrastructure improvement index

No	Road Infrastructure Improvement	Weight
1	Transport mode segregation	5
2	Adequate lighting conditions	5
3	Imposed speed limits/ Prohibitions of overtaking at critical sections	10
4	Adequate turning circles by design (at junctions and bends)	10
5	Increasing skid resistance (Junctions and Bends)	10
6	Provided shoulders/ Pedestrian walkways/ Drainage system	10
7	Proper delineation	15
8	Islands/ Centre Medians/ Guard Rails	15
9	Improved visibility	20
Total infrastructure improvement index value		100

The proposed model is as follows.

$$\mathrm{I}_{(\mathrm{F})} = 5.98 + 0.9841\mathrm{I}_{(\mathrm{P})} + 5.18\mathrm{A}_{(\mathrm{F,P})} \qquad 2.11$$

$A_{(F,P)}$ - Number of fatal crashes during the past year

- $I_{(P)}$ - Infrastructure improvement index value for the present year
- $I_{(F)}$ - Infrastructure improvement index value for the future year
- The component of the traffic volume has been removed based on the correlation check.

Equation 2.11 indicates that the infrastructure improvements have a direct influence on guaranteeing the safety performance of a road.

Infrastructure Risk Rating (IRR) Manual for Australian roads is a methodology developed by Zia, Harris and Smith (2019), for road safety risk assessment. Like the start rating measures, each inspected road is given an IRR value concerning the roadside infrastructure arrangement. “IRR value is calculated by coding the following road and roadside features: land use of the area, the stereotype of the road, lane width, shoulder width, horizontal alignment, hazards from the roadside environment, intersection density, access points, traffic volume, operating and posted speed limits (rural roads only)” [27]. Each of these features is assigned to a score based on their prevalence.

Abbas has used two exposure measures to compute the risks related to crashes, injuries, fatalities, and casualties to analyse traffic safety indicators for a sample of rural roads in Egypt. The first measure was a static measure that represents the road lengths. The second measure was a dynamic measure that represents the vehicle kilometres travelled on a particular road. To fulfil the purpose, he has selected five rural roads in Egypt connected to the country’s capital. Using the first exposure measure, Cairo–Alexandria agriculture road proved that it has the highest safety risk indicator compared to the other four roads. With the use of the 2^{nd} exposure measure, Cairo–Suez desert road was identified as the highest safety risk indicator when compared to other four roads [19].

Demasi, et al. (2018) proposed quantitative approaches to obtain Branch Index Risk (BIR) and Section Index Risk (SIR). The BIR evaluates the absolute danger of road crashes on urban roads, where the SIR assesses the risk of a specific road segment. The Safety Risk Factor for each defect identified in the segment is calculated considering the vulnerability of road users, traffic flow, danger generated by the defect and the expected deaths resulting from it. Defects were identified by carrying out road safety inspections similar to the methodology proposed in this study [28].

International Road Assessment Program (iRAP) has introduced "Star Rating" criteria to evaluate the safety performance of roads. It is a five-scaled rating system where only one star represents the roads with adverse safety conditions. Five stars stand for roads with excellent safety conditions. Star rating is calculated separately for pedestrians, motor vehicles, bicycles, and motorcycles. Star rating provides an objective measure of the likelihood of a crash and the severity of the possible outcome [29]. European Roads Assessment Program [30] and United States Road Assessment Program [31] have also used the start rating system to evaluate the safety performance of European roads. Based on the road inspection data, star rating methodology provides an objective and a simple measure regarding the safety level of a given road segment. Crash data are not essential for this methodology.

Another limitation that developing countries has is the lack of crash data. Availability of crash data in Sri Lankan rural roads is comparatively lower than the urban roads. Although details about fatal crashes are entered in the database, no focus is given to the other types of crashes happened in minor roads in rural areas. Therefore, there is a limitation in using models based on the crash data for safety performance evaluation. That highlights the need for a novel approach to evaluate the safety performance by a methodology that does not require crash and traffic data.

The HSM always encourages local transport agencies and researchers to develop state-specific methodologies concerning data availability. Not only for crash predictions but state-specific methodologies can also be used for network screening and engineering treatment evaluation at project and site level [13]. Most of the above-discussed methodologies, including HSM's SPFs, are based on AADT. In Sri Lankan context, AADT is not always available for the low volume roads. But infrastructure features that can lead users up to a crash, can be easily identified by performing road safety audits. That is why it is decided to carry out the study based on actual field inspections. These issues can be rated based on the exposure, probability, and severity factors to obtain a safety index. By combining the individual indexes, the combined risk index evaluates the entire risk of a road according to Montella (2005), Cafiso et al. (2006) and Leur and Sayed (2002).

Table 2.9 provides an overview of the different safety evaluation methods and their applicability to the Sri Lankan context.

Table 2.9. Applicability of different safety evaluation methods in Sri Lankan Context

Proposer	Risk Assessment Method	Applicability in Sri Lankan Context
Highway Safety Manual	$N_{spf} = AADT \times L \times 365 \times 10^{-6} \times e^{-0.312}$	AADT is not readily available for Low volume roads in Sri Lanka
Calibrated models of HSM's safety performance function	$\mu_i = \beta_0 \times AADT_i^{\beta_i} \times SL_i$ $\mu_i = \beta_0 \times AADT_i^{\beta_1} \times SL_i^{\beta_2} \times \exp\left(\frac{bn_i}{SL_i}\right)$ $\mu_i = \exp(\beta_0 + \beta_1 DY_i + (\beta_2 \ln \times AADT_i) + (\beta_3 \ln \times SL_i) + \beta_4 LW_i + \beta_5 S_i)$ $\mu_i = \exp(\beta_0 + \beta_1 SW_i + \beta_2 LW_i) \times AADT_i^{\beta_s} \times SL_i$	AADT is not readily available for Low volume roads in Sri Lanka
New Zealand Transport Agency	$\text{Band risk} = \sum \text{Collective risks} \times \frac{\sum \text{VKT in band}}{\sum \text{VKT in sample}}$	Traffic data and crash data are not readily available for Sri Lankan low-volume roads
Zia, Harris and Smith	Infrastructure Risk Rating (IRR) Manual for Australian roads	Traffic data and speed data are not available for Sri Lankan low-volume roads
Abbas, A. K	Predictive models for accidents in rural roads in Egypt	Traffic data are not available for Sri Lankan low-volume roads
Sharma and Landge	Model to predict heavy vehicle crashes in Indian rural highways $\frac{\frac{Accident}{year}}{km} = 2.913 + (0.326 \times AD) - (0.478 \times SW) - (0.173LW)$	This does not capture the safety issues prevailing on Sri Lankan low-volume roads
Loprencipe et al	Hazard Index (I)	Traffic and Crash data are not available for Sri Lankan low-volume roads
International Road Assessment Program (iRAP)	Star Rating	The coefficients used in star ratings have to be calibrated for the Sri Lankan context, which is highly data extensive.

		So, customizing model to represent the local conditions is complicated.

2.3 Incorporating Safety in Decision Making and Pavement Management Systems (PMS)

A systemic approach for the safety treatments in low volume roads is always preferable rather than focusing on specific crash locations because they tend to be dispersed widely geographically. The advantage in using a systemic approach is that, it targets common safety issues and risk factors throughout a road network rather than being limited only to spot locations.

Following are the tools stated by the Manual for Selecting Safety Improvements on High-Risk Rural Roads in identifying the safety issues in low volume roads [18].

- HSM
- Safety analyst tool
- Crash modification factor clearinghouse
- Road safety audits
- Training for road safety improvement

There are three major types of road safety countermeasures that are being used in road safety management schemes [32]

- Engineering countermeasures: These types of countermeasures include roadway treatments. The scope of these countermeasures varies from installation of warning signs, up to road re-alignments. Although it is not possible to upgrade all roads to highway standards, there are various countermeasure that can be implemented achieve a higher level of safety guarantee for the existing low-volume roads. The decision makers can focus on the most frequent crash types of the road network and implement strategies to overcome that.

  Table 2.10 analyses the crash reduction capabilities of different engineering road safety countermeasures [32].

Table 2.10. Crash Reduction Percentages by Different Countermeasures

Countermeasure	% crash reduction
Installing intersection, curve, pedestrian warning signs	25
Proper delineation	15
Indicating no-passing zones	40
Lighting of at grade intersections (overall)	30
Lighting of at grade intersections (night)	50
Installing right-turning lanes	35
Installing rumble strips	25
Road surface improvements	25
Providing crash barriers (fatal crashes)	65
Visibility improvements	30
Horizontal alignment improvements	40
Construct grade-separated interchange	55

- Enforcement countermeasures: Enforcement has a significant impact on reducing roadway crashes [32]. As per the estimations of The European Transit Safety Council, a reduction of 50% of crashes can be obtained if all the road users comply with the road traffic regulations [32]. If authorities can eliminate traffic violations, it will lead up to achieve a reduction of 63% on fatalities [32]. Table 2.11 summarizes different effects of speed enforcements.

Table 2.11. Effect of manual and automatic speed enforcements

Effect	Manual enforcement	Automatic enforcement
% Reduction in crash frequency	2 – 4	20 – 24
% Reduction in no. KSI* crashes	14 – 58	17 – 38
% Reduction in mean speed	3.6 – 4.5	4
Average speed reduction (km/h)	3.6	2.9 – 6.9
Distance halo (km)	1.6 – 3.5	1 – 10
Time halo (days)	1 – 63	not applicable

*KSI = Killed and Seriously Injured

- Education countermeasures: This varies from advocacy campaigns regarding rod safety to driver simulation training.

According to Alfronsi et al., (2016), there are five different schemes related to road safety planning, method of funding and the process of finance monitoring. They are as follows.

- With a centralized financing system in the treasury, budget for the road safety program is estimated. The process is monitored regularly.
- Same as the above, but no regular monitoring is involved.
- Budget for the road safety programs is not estimated. funding is independent from treasury.
- Budget for the road safety programs is not estimated, but funding is from both dependent and independent structure from treasury. This scheme includes regular monitoring activities.
- Budget for the road safety programs is estimated. Funding is independent from treasury. Does not conduct regular monitoring activities [33].

Pavement management systems can be identified as effective tools when the authorities need to take cost effective decision [3]. In order to obtain a logical conclusion regarding the safety improvement strategies, authorities can adopt different approaches. Specialized algorithms, logistics regressions, manual rules, multi-objective optimizations models, and linear programming are frequently used to obtain proper analytical solutions [34].

Different approaches have been developed by the researchers in the world to incorporate safety performance in Pavement Management Systems (PMS). Table 2.12 describes some of those methods and their applicability in PMS for low volume roads.

Table 2.12. Different approaches to incorporate safety performance in pavement management systems

Methodology	Parameters Used	Applicability for Rural Road PMS
Life cycle cost analysis-based methods	Agency cost and user cost (incorporating crash cost) [35], [36]	Rural roads in developing countries do not have reliable crash data, crash modification factors and accurate crash cost estimates to make consistent analysis
Crash parameters used in optimization models	Crash rate [35] [36], [37] Crash frequency [35]	
Considering skid resistance parameters	Skid number [37] Skid resistance [36]	Skid resistance data not readily available in a rural low-volume road network.

or other distress related to safety		
Optimization approach incorporating IRI and safety performance ratings	IRI [38] Safety risk based on the probability and consequence of an event [39]	Options for Measuring IRI will be cost-effective and easy to be adapted for developing countries. Considering safety issues for the optimization approach will be a viable methodology. Since crash data is not available, the safety risk can be obtained from the roadway issues prevailing on rural roads due to road user impacts.

Not having a proper knowledge on the crash reduction capabilities of available countermeasures is one of the major drawbacks that authorities have regarding incorporating safety in decision making processes. Identifying the causes of crashes and using that information on safety treatment selection processes is a key fundamental act [40].

In order to incorporate safety performance evaluation in pavement management systems for rural low-volume roads, the adopted methodology needs to be a simplified approach, which is less data-intensive. As an example, a system that require accurate crash data, accurate crash cost parameters, accurate traffic data would not be suitable for rural road agencies, especially in developing countries like Sri Lanka. Furthermore, such a network has limited adaptability for security performance functions that require extensive calibration and road design parameters. Therefore, by concerning all above facts, the most reliable safety performance evaluation method to incorporate safety in PMS would be do develop a risk indicator by carrying out on-time field inspections and using it in an optimization model along with relevant road condition parameters.

[33] proposed an integrated approach to road safety financing performance. It can be integrated at all national, regional / provincial and regional levels. Users of the proposed methodology should review specific actions and have the parties responsible for implementing them. Once a specific measurement has been selected for

investigation, the resource path must be recreated inversely. The quantitative performance index proposed in the study is as follows:

Speed of disbursement processing: average time (days) elapsing between official resource allocation and liquidation [33]

Loprencipe et al., (2018) proposed a cost-benefit analysis to prioritize possible safety actions for a considered road. The cost analysis was carried out taking into account the road prices adopted in the present for the Italian road network. The cost of renovating a road is obtained from the sum of all individual works applicable to the road. The benefit analysis took into account the average crash cost density (ADAC) before and after safety risk implementations. In the later period, only collisions and their consequences related to side barriers were considered, assuming that all other roadside deficiencies have been managed and solved [24].

$$\text{Benefit }(\mathrm{B_R}) = (\mathrm{ADAC_{After}}) - (\mathrm{ADAC_{Before}}) \qquad 2.12$$

Such type of methodologies is required specially for countries like Sri Lanka since we are always working on limited budgets and resources.

The role of a pavement management system is to obtain optimum strategies to maintain pavements. Now, the focus has been given to incorporate safety performance in pavement management systems too. This study also proposes an application to incorporate both safety performance and road condition in pavement management systems through a MOO model. Skid resistance measured in terms of skid number (SN) would be an ideal parameter for safety assessment, especially for primary roads where operating speeds are higher. The skid number is obtained by full scale friction measuring equipment - interlocked tester, SCRIM machine etc. Using the British Pendulum Number (BPN) does not necessarily provide representative values for skid resistance that would be useful for managing road surface friction. Typically, minimum friction values for these test methods are specified for speeds of 64 km/h or higher. Most rural roads considered in the study operate at speeds below 50 km/h, where it may not be possible to obtain consistent friction data. In addition, the identified parameters mainly came from the observations made during the safety audits. Therefore, friction performance is not considered as a main factor contributing to the pavement management of the rural road network. If necessary, friction measurement can be performed on a case-by-case basis in segments where causality has been established and included as a parameter [41]. On highways, the main concern is the skid resistance of pavements at normal driving speeds, typically between 40 mph (65 km/h) and 70 mph (112 km/h) [42]. The effect of skid resistance is minimal, especially if the speed is lower than 50 km/h, according to a study by (Shafi, 2009). Most rural low-volume roads are operated at a speed of less than 50 km/h. The above finding also proved that the Skid Number measured on such a road network is not as significant as for a national road network.

The World Bank has introduced a new toolkit to assess the safety of World Bank funded roads. The Road Safety Screening and Appraisal Tool (RSST) compares the old and new road in terms of road fatalities. Based on existing circumstances, the project team can assess the safety performance and look for possible improvement opportunities concerning the road [43]. One of the limitations of this toolkit when applying low volume rural roads is the lack of reliable crash reference data, which can be observed especially in developing countries. Although the safety improvement is obtained in terms of Project Safety Impact (PSI), the toolkit focuses on the relative reduction of fatalities. Estimating the reduction of crashes/ casualties has been a key element in highway planning. In order to estimate the safety effectiveness for a given safety treatment strategy, safety performance functions have been used in an empirical-bayes (EB) methodology [44]. The following equation provides the estimation of the change in the safety for a given crash type.

$$\Delta \text{Safety} = \lambda - \pi \tag{2.13}$$

λ represents the expected number of crashes that would occur in the after period without the safety treatment strategy obtained by the developed SPF. Π represents the number of crashes reported in the after period. This methodology was used to estimate safety improvements after the addition of the centerline plus shoulder rumble strips for different types of collisions in three different US states. SPFs were calibrated for each state to meet the actual conditions [44].

2.4 Optimization Approaches used in Pavement Management Systems

Recent research related to Pavement Management Systems indicates that many studies have been carried out regarding incorporating optimization techniques in pavement management systems [45].

The main goal of maintenance, rehabilitation and reconstruction strategies should be to maximize the overall benefits based on available resources [46]. The complexity of modern design problems in PMS is increasing every day, leading to disagreement between goals. Several objectives need to be optimized in the decision-making process, such as budget optimization, maximum overall condition, maximum reliability, maximum performance, etc. Achieving a maximum remaining service life has been identified as the most important goal in optimization strategies [46].

Therefore, Multi Objective Optimization (MOO) approaches can be adopted to overcome the conflicts between objectives. MOO can be categorized under three methods as follows [12].

- A prior articulation of preference,
- Methods with a posterior articulation of preference,
- Interactive methods.

Three different condition levels have been identified by Hafez et al., (2017) where the funds should be assessed [46].

- Worst segments,
- Rapidly deteriorating segments,
- Segments requiring routine maintenance

The weighted sum method (WSM) is a common approach that incorporates preferences into an earlier or posterior process. This method combines several objective functions into an objective function and defines the optimal solution as one that corresponds to the best value of the weighted sum. This method facilitates the simplicity of implementation in a MOO process [47], [48]. However, this method has several drawbacks, such as difficulties in solving multidimensional problems and subjectivity in assigning weights to objective functions. The application of the theory of utility of multiple attributes is another method that represents a mathematical framework for the analysis of choices with multiple outcomes. The main advantage is the ability to quantify decision makers' preferences [49]. In cases where a lot of data is needed and the choice has to be correct, building a utility function can be a challenge.

The Analytical Hierarchy Process (AHP) is another method based on gaining preferences or weights of importance for alternatives. The pair compares the alternatives to assess the weight of the criteria. This method is effective because it uses comparative comparison that allows the decision maker to relatively compare alternatives. However, complex and time-consuming calculations are required to obtain results when many alternatives are involved and can produce biased results.

The current research mainly focuses on developing alternative optimization strategies, rather than on obtaining an overall road condition forecasting strategy to identify sections of the road that require maintenance each year. For example, Garcia Segura et al., (2020) proposed an optimization model that uses Markov chains and Monte Carlo simulations in the MOO. Optimization objectives include life-cycle costs, life-cycle cost deviation, and mean benefit [50].

The number of treatments available can have a significant impact on the complexity of the optimization problem. Therefore, it is recommended to start the model with a moderate number of treatment regimens. In order to reduce the complexity, individual types of treatment can be presented as a group when different treatments affect the same distresses. Individual forms of treatment can be included in the decision tree [51]. Decision trees are highly recommended to define treatment strategies in a selected roadway [46]. Agencies can determine required treatment schemes that have a direct benefit on the road network based on the structural data, maintenance history and traffic data. Surface repair has been identified as the most common treatment type in low-volume roads. Although the respective agencies focus on a budget optimization, it is not always suitable to adopt low-cost treatment methodologies as it can impact the structural behavior of the road [46]. Therefore, adopting optimization strategies is essential because it suggests the most feasible treatment types in terms of both safety and pavement condition.

Apart from MOO models, there are other mathematical tools used in pavement management systems. Linear programming, integer linear programming, dynamic programming, and heuristics are considered to be powerful mathematical programming techniques that have been used in pavement management systems apart from MOO models.

In situations where the solution space includes discrete and continuous variables to solve complex problems, researchers apply mix-integer programming (MIP) techniques. In mix integer programming, decision variables are considered to be integer values [52], [53], [54]. MIP has a good effect on problems with isolated or invisible variables [55]. But integer linear programming has not been identified as an ideal tool for solving problems exposed to combinatorial explosions [56]. While many engineers prefer MIP to linear programming to make decisions about available solutions, MIP is not considered very useful in providing solutions to the challenges of everyday problems [57].

Problem solving mechanism associated with linear programming is solutions are provided by maximizing a linear objective subjected to one or more constraints. Producing optimal maintenance and rehabilitation strategies are the primary objective of incorporating linear programming models in pavement management systems [34], [58]

[34] has developed a linear programming model for pavement management systems: The multi-year pavement maintenance problem. This model has been developed to obtain the treatment strategies in a network-level safety analysis. Therefore, the model's objective function maximizes the condition of the overall network over the planning horizon. The illustration of the model is as follows.

$$\boldsymbol{\sum_{t=1}^{T} \sum_{s=1}^{S} \sum_{l=1}^{L} Z_{tsl} \ x \ l} \tag{2.14}$$

$$X_{tsr} = \begin{cases} 1, if\ maintenance\ alternative\ r\ is\ selected\ for\ segment\ s\ in\ year\ t; \\ 0, otherwise \end{cases}$$

$$Z_{tsl} = \begin{cases} 1, if\ at\ year\ t\ the\ segment\ s\ is\ in\ condition\ l; \\ 0, otherwise, \end{cases}$$

$$Y_{tslr} = \begin{cases} 1, if\ maintenance\ alternative\ r\ is\ selected\ for\ segment\ s\ which\ is\ in \\ condition\ l\ in\ year\ t; \\ 0, otherwise, \end{cases}$$

In this study by [34], the safety performance of the road is maximized considering the constraint of the available budget. When taking decisions on either safety or pavement maintenance strategies for a given road or a road network, relevant authorities have to pay much attention of the availability of budgets. Therefore, in most of the optimization models designed for pavement management systems, availability of funding has been considered as a primary constraint.

Budget allocation can be implemented considering two major budget periods: single-period budgets and multi-period budgets. Multi-period allocations always lead to inconsistencies related to inflation, traffic growth rate, crash moderation etc. Therefore, if maintenance operations can be completed within a given short period of time, researchers prefer adopting single-period budget allocations in pavement management systems. [40] has proposed another linear programming model to execute safety improvement projects for a given road network.

$$\text{Minimize } \left[\sum_{i=1}^{N}\sum_{j=1}^{N_i} b_{ij}X_{ij} + \sum_{k=1}^{K}\sum_{j=1}^{n_k} B_{kj}Y_{kj}\right] \qquad 2.15$$

Where,

- b_{ij} - number of crashes at location i after execution of project *j*
- B_{kj} - number of crashes along road stretch k after execution of project j
- N, k - number of black spots and road stretches, respectively
- X_{ij}, Y_{ki} - integer O-1 decision variables indicating whether project j related to "black spot" or road stretch is executed.

Constraints used in the model

- The total sum spent on improving "black spots" or road stretch is smaller than the entire budget available.
- Authorities can select only one improvement level at each location.
- The exact location will not be improved twice, once a "black spot" and once a part of a road stretch.

2.5 Development of State-specific Methodologies to Evaluate Safety Performance

Concerning crash frequency to be a function of several variables, state specific safety performance methodologies can be developed adopting regression analysis models using localized data [59]. Highway Safety annual always encourage local transport agencies, academia and researchers to develop state-specific safety evaluation methods concerning the data availability as they fit with the local conditions of the respective country. Moreover, one of the major concerns that Alfronsi et al., (2016) suggested is that Road Safety Management (RSM) systems of two countries cannot be compared since the base conditions of one country will never be same with another country [33]. Two countries might have similar RSM schemes. But they might behave very differently because existing internal mechanisms have a considerable effect on task performance [33]. Therefore, it is always advisable to develop state-specific safety performance evaluation schemes. In situations where that is not achievable, researchers can concern on a methodology developed for another country and calibrate it as it fits the base conditions of the local context. So, the researchers can how the models can be calibrated concerning the characteristics of the surroundings and impacting safety issues.

For rural road networks, especially in developing countries, the applicability of most of these methods is limited. A fundamental limitation is the lack of reliable data on the crash. There are some restrictions on adapting the safety performance models developed to local contexts because they require extensive calibration. Furthermore, these road agencies are unlikely to have a regular road monitoring regime to update this information regularly. Therefore, the method of evaluating safety performance must be simplified while reflecting critical road safety issues.

A comprehensive comparison carried out between the proposed model and Australia National Risk Assessment model is presented in ANNEX 0.

3 EVALUATION OF ROADWAY FACTORS RELATING TO CRASHES ON LOW VOLUME ROADS

In this chapter, the first step of the safety performance evaluation process is discussed; i.e. The risk identification criteria.

3.1 Identification of Road Infrastructure-Related Safety Issues

The methodology of the study starts with the identification of causal factors related to crashes in the selected low volume road network. A systematic approach was needed to identify all the relevant risks which can pose a safety risk on the road users. A Road safety audit is a systemic approach that incorporates traffic safety knowledge into road planning and designs to prevent future roadway crashes.

Safety issues that can pose a risk towards the road users in the selected road network, were identified by carrying out road safety audits. Road safety audits were carried out by a well experienced multidisciplinary team. A road safety audit team should consist of independent professionals who have expertise on road safety, traffic operations, road design, and human factors. The team audited the road segment and identified all the road infrastructure issues prevailing on the roads. The Central Asia Regional Economic Cooperation (CAREC) guideline published by the Asian Development Bank (ADB) was used as the basic tool to identify the roadway related safety issues. All the identified safety issues were recorded with photographs and their respective GPS coordinates. GPS coordinates help to compare the locations of safety issues with locations where crashes have occurred as per the information provided by Sri Lanka Police in order to check whether there is an effect on real time crashes from these issues. The road safety audits were carried out in both day and night times. Road safety audits were conducted in 125 roads.

Each identified safety issue was rated on a 1-5 scale on three risk parameters: exposure, probability, and severity, based on the attributes impacting each issue described in the next chapter. The purpose of carrying out safety audits and rating them is to develop the Cumulative Safety Index (CSI) of the road (CSI_k) and the specific issue types (CSI_i) as described in “Findings of the Road Safety Audit” in the following section. The CSI indicates the safety risk level of a road or a particular issue type. The CSI is an abstract value and it needs to be validated with a parameter that represents the safety risk level on the road as perceived by the road users. Therefore, the developed CSI values are then used to evaluate the relationship between the crash number on the particular road segment. The crash data, which includes fatal, grievous, and non-grievous crashes on the selected roads were considered in the analysis. Due to under-reported behaviour of property damage only crashes in developing countries, damage only crashes are not considered for the development of model. The regression model developed between the CSI and the Equivalent Property Damage Only (EPDO) crashes is presented in the next chapter.

The CSI value is also an input parameter in the both Multi Objective Optimization (MOO) and Linear Programming models proposed as applications of this methodology. Moreover, the EPDO can be added as a constraint in the optimization models if the agency has specific crash reduction targets.

3.2 Crash Data Collection

Sri Lanka Police Department has the authority of maintaining the crash database in Sri Lanka. Crashes are reported under three categories: crash details, element details and casualty details of a crash. The data provided under each category are described in Table 3.1

Table 3.1. Data Provided by Crash Database of Sri Lanka Police

Crash Details	Element Details	Casualty Details
Date and time of crash Class of crash Status of environment (urban/rural) Status of the day (workday/holiday) Day of week Road number Road name Nearest lower km post	Element type Vehicle ownership Driver/ rider/ pedestrian sex Validity of driving license Pre-crash factors contributing to accident (human, pedestrian, road, vehicle, crash factors, other factors)	Traffic element number Severity according to penal code Category Sex Information about protection Whether hospitalized

Distance from nearest lower km post Coordinates of the location Collision type Information on a secondary collision Road surface condition Weather Light condition Type of location Traffic control Speed limit Action taken by police Number of casualties	Alcohol test Whether driver/ rider/ pedestrian at fault	

To study the crashes that have taken place on the surveyed roads, crash data for three years were considered. It is ascertained that; the relevant roadway characteristics have remained constant during the considered period. Three years of crash data (2015, 2016, and 2017) were used such that each road segment would have a significant volume of crash data for the analysis. When studying the crashes that have happened on audited roads, it was found that crash data are available only for 42 roads. Therefore, only these roads were selected for further analysis. Locations of the crashes happened on those roads were compared with the locations where safety issues were identified. Crashes that have happened on locations where safety issues were identified, then used for crash mapping activity. The purpose of crash mapping is to identify casual factors for crashes.

3.3 Roughness Data Collections

The other type of data required for the model is roughness data. It is an expression of irregularities in a pavement surface that can affect the quality of a ride. Roughness data were collected in terms of the International Roughness Index (IRI). IRI data were collected based on a smartphone-based approach proposed by Gamage et al., (2016) [60]. The applicability of the smartphone-based data collection approach has been evaluated by Sandamal and Pasindu (2020) and identified as a cost-effective and less time-consuming approach to be used in rural road pavement condition evaluation (Sandamal and Pasindu (2020)). Pavement condition is a suitable parameter, especially for network-level condition assessments. IRI data was used as an objective in the MOO model. The objective function of the MOO model is defined as it minimizes the overall

CSI and IRI value of the network based on the available treatment schemes adhering to the available budget.

3.4 Crash Mapping

Since this methodology is based on onsite inspections, the influence of the safety issues towards the cause of crashes can be identified. Locations where safety issues were prevalent were identified at road safety audits. Based on information collected from Sri Lanka Police database regarding crashes that happened on those roads and information such as crash type, vehicles involved, etc., a brief overview could be obtained whether crashes have happened on the identified hazardous locations. If crashes have happened on the identified hazardous locations, the next step was studying the collision type to check whether the safety issue may have caused that type of collision. From this approach, possible influence of roadside safety issues to cause crashes can be assessed. If the collision type of a crash at a particular location can be related to the identified safety issue prevailing on that location, that issue was identified as a causal factor for the crash in the crash mapping process.

Once the safety issues related to crashes by location are identified, these crashes were mapped to the relevant issue identified through the road safety audit.

While comparing the collision types with the safety issue at hazardous locations, there were collision types that did not match with the prevalent issue at the location. That indicates these collisions were random occurrences that did not have any relationship with the safety issue prevailing at those locations. Those types of crashes were not considered for accident mapping activity.

The summary of the methodology is shown below in Figure 3.1.

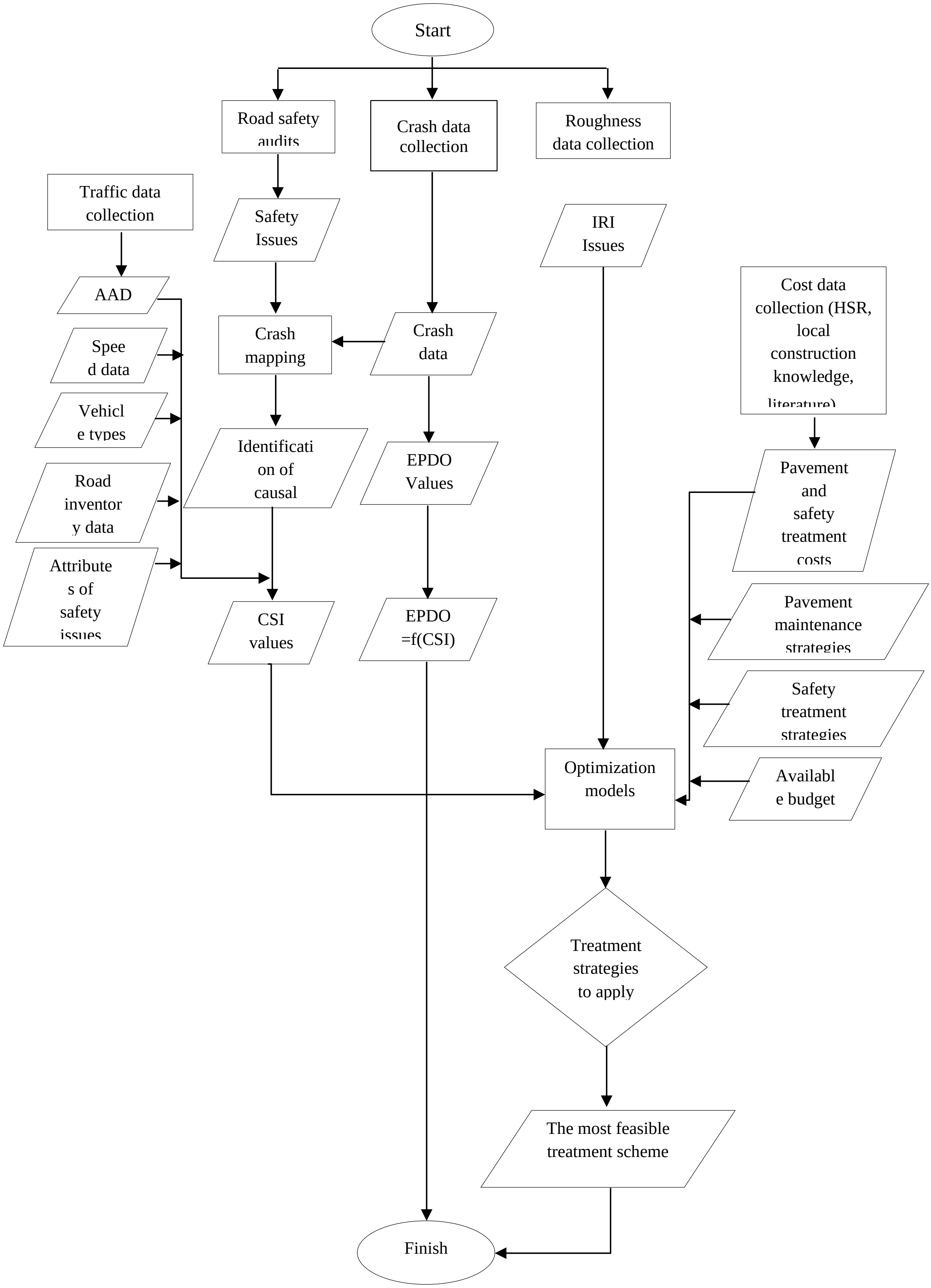


Figure 3.1. Overview of the methodology

4 DEVELOPMENT OF A RISK ASSESSMENT GUIDELINE

This chapter describes the second step of safety performance evaluation process process, i.e., Risk Assessment. As it has was discussed about the procedure of the risk identification in the previous chapter, there should be a proper guideline to direct the road safety practitioners to analyze and evaluate the identified risks. A subjective risk evaluation method would not be beneficial for a reliable risk evaluation process as it captures the risk levels based on the person who carries out the process.

Major objectives of risk assessment can be concluded as follows:

•Create awareness of hazards and risks.
•Identify who may be at risk.
•Determine whether a control program is required for a particular hazard.
•Determine if existing control measures are adequate.
•Prevent injuries or illnesses, especially when done at the design or planning stage.
•Prioritize hazards and control measures.
•Meet legal requirements where applicable.

There is a lack of crash data in the low volume roads in developing countries [11]. Therefore, when evaluating the safety performance and deciding safety treatment strategies for the low volume roads, most of the decisions are made based on the road safety audits [20]. Currently, road safety audits are done by a well-experienced multi-disciplinary team. All their decisions about the risk factors are made on their experience and subject knowledge. When considering the above situation, two professionals can end up with two different safety ratings and/or two different safety improvement for a considered same road. Therefore, the current practice has identified to be a subjective approach since there is a tendency of producing different results based on the person who is involved in it. But, when decision-making is required in national level projects, this kind of a subjective approach would end up producing unreliable results. This scenario raises the need of developing a standardized framework to evaluate the safety performance of low volume roads. So, when there is a proper framework available to be used during safety performance rating, the results will not be subjective. Also, when there is such framework available, the decision makers will not always be needed to look for external expertise support. They can engage their own engineers or relevant professionals in the evaluation process, optimizing their own resources.

Purpose of risk analysis is to understand the level of risk posed to the road users by prevailing safety issues. That sets the basis for decision making on how or whether to treat the risk. Analysis can be done quantitatively, semi-quantitatively or qualitatively. For the purpose of standardizing the risk assessment procedure, risk analysis will be proposed as a quantitative approach.

In order to analyze the safety risks identified during road safety audits, “Safety Index” approach is used. Safety index is obtained through the product of three factors namely: exposure, probability and severity.

4.1 Currently Available Safety Assessment Methodologies

Different countries use different methodologies to assess the safety performance of roads. Table 4.1 provides a comparison between safety assessment methodologies of different countries.

Table 4.1. Comparison of Different Safety Assessment Methodologies

Methodology	Data	Procedure	Output	Remarks
iRAP	Issues prevailing on roads are identified by carrying out road inspections	Identified safety issues on a road segment are then coded based on the attributes impacting safety issues	Star Rating for vehicle occupants, motorcyclists, bicyclists and pedestrians	“Can be completed without reference to detailed crash data, which is often unavailable in low-income and middle-income countries” [11]
Australian National Risk Assessment Model (ANRAM)	Data related to road infrastructure, speed, traffic flows, fatal and serious crash history	The severe crash risk is estimated based on road infrastructure, speed, traffic flow, potentially conflicting	Fatal and serious injury (severe) crash risk across all parts of the road network	Requires data which are not readily available in low-income and middle-income countries.

		vehicle movements, and on severe crash history [61]. Provides a flexible toolkit so as jurisdictions are able to prioritize road sections with high-risk and implement treatment options as they comply with the context of jurisdiction.		Most importantly, ANRAM provides tools to implement nationally consistent risk-based road assessment programs as they fit the local context. [61]
World Bank Safety Assessment Tool: Road safety performance and appraisal tool (RSAAT)	Annual fatalities in segment Serious injury/ fatality ratio Vehicle fleet mean speed Segment characteristics Presence of roadside objects Speed management/ traffic calming methods Pedestrian facilities Traffic flows	Safety performance is evaluated based on the existing condition. Based on that, project teams can screen for safety improvement strategies with respect to toad and roadside infrastructure [62]	RSAAT project safety impact index (PSI 0-1) is determined for all road segments with and without the project [62].	Fatality rates, associated economic costs are estimated under scenarios with and without the project [62].
Road Infrastructure Safety Assessment: New Zealand	Issues on road segments are identified by carrying out road safety audits	Each identified safety issue is assigned a risk value relative to a similar issue on a benchmark road which has a risk of 1.0. Relative risk is then multiplied by traffic volume to obtain the risk	Relative risk Collective risk	It is no convenient to adapt to this methodology to calculate overall risk where traffic volumes are not available. “What if” scenarios are used to

		relative to all drivers (collective risk)		evaluate the effect of different road safety treatments.
Methodology in this study	Safety issues prevailing on road are identified by road safety audits	Safety index (SI) is calculated for each safety issue identified based on the attributes impacting risk parameters i.e., exposure, probability and severity.	Calculation of SI leads to obtain the Cumulative Safety Index for a road (CSI_k), and Cumulative Safety Index of a particular issue type (CSI_i)	The methodology can be performed without crash data and speed data which are not readily available in middle-income and low-income countries. Since the relationship between Equivalent Property Damage Only Crashes and CSI is developed, it helped to prioritize road segments/ issue types for treatment that have significant impact on crashes. Subjected to a safety treatment projects, before and after analysis on safety performance can be done in terms of CSI or EPDO.

4.2 Attributes Impacting Safety Issues

When analyzing the risk level of identified safety issues, the attributes that affect the risk parameters mentioned previously are considered. For each identified safety issue, the attributes that impact exposure, probability and severity were studied separately in order to determine the risk imposed towards the road users.

To determine the attributes impacting safety issues, several resources were considered in the study. They are International Road Assessment Program (iRAP) [29], United States Road Assessment Program (usRAP) [31], and European Road Assessment Program (EuroRAP) [30]. Apart from that, local knowledge on safety hazards and the best available literature were used to determine the attributes impacting on safety issues. All those resources were also used to measure the risk imposed by each attribute quantitively according to the framework that is proposed in this study.

Since the risk imposed by each attribute should be demonstrated as per the proposing framework, each attribute is assigned a value (1-5 scale) based on its impact on the exposure, probability, or severity at a location. Effect of a considered attribute may have an effect of another attribute. Since combining the effect of several attributes is not convenient always, it is assumed that they impact individually and the attribute with the highest impact is considered.

The values were assigned based on iRAP fact sheets, usRAP, EuroRAP, the best available research evidence, and considering pre-crash factors available crash data.

- Exposure - Estimated as a measure of how much the risk is exposed to traffic conflicts.

Scale: 1 – Rare exposure, 2 – Minor exposure, 3 – Moderate exposure, 4 – Major exposure, 5 – High exposure

- Probability - A measure of the likelihood of traffic conflict resulting in a crash. It is quantified separately for each road issue to assess its potential to cause crashes.

Scale: 1 - Rare, 2- Unlikely, 3 – Moderate, 4 – Likely, 5 – Highly probable

- Severity - Estimated level for the severity of the casualty that can cause by a crash.

Scale: 1 – Property damages only, 2 – Non-grievous injuries, 3 – Minor injuries, 4 – Deaths/ serious injuries are probable, 5 – Multiple deaths are probable

Table 4.2 illustrates the attributes impacting each safety issue that are considered in determining the risk imposed by each issue.

Table 4.2. Attributes Impacting Safety Issues

Issue ID	Issue	Factors Affecting Exposure	Factors Affecting Probability	Factors Affecting Severity
1	Lack of signage, road markings at intersections	AADT Surrounding pedestrian facilities	Improper pavement markings Obstructions to the sight distance Improper signage Intersection configuration Lane width (m) Skew angle Development within 100m (Presence of schools, houses, film theatres, liquor shops, religious places, recreational activities, sports centres, public transport terminals, commercial areas, industrial areas, etc.)	Poor pedestrian facilities Presence of buildings and other fixed objects
2	Poor visibility at Access Roads	AADT Land use of the area	Improper pavement markings Obstructions to the sight distance Improper signage Skew angle	The operating speed of vehicles (kmph) Presence of fixed objects
3	Limited Roadside Space Availability	AADT Segment Length (m)	Growth of vegetation Characteristics of the shoulder (Availability, type, width (m)) Road geometry (Curve or straight)	Presence of fixed objects The operating speed of vehicles (kmph) Presence of drainage systems Presence of soil banks, walls

4	Road alignment, Sight distance Issues, and Lack of Warning signs at Curves	AADT Segment Length (m)	Curve radius (m) Superelevation rate Provided side friction Sight distance The requirement of speed reduction (kmph) Unavailability of warning signs Growth of roadside vegetation Lane Width (m) Outside shoulder width (m)	Presence of fixed objects The operating speed of vehicles (kmph) Presence of un-protected slopes Presence of drainage systems Presence of soil banks, walls
5	Inadequate Pedestrian Facilities near Schools, Town Areas	Land use of the area (Educational, recreation, residential, commercial, religious) AADT	Traffic condition Inadequate notifications to drivers Pedestrian manoeuvre (i.e., walking along the roadway or crossing the street) Lack of visibility (For both pedestrians and drivers)	The operating speed of vehicles (kmph) Distressed pavements at pedestrian manoeuvres
6	Issues at Railroad Crossings	Land use of the area (Educational, recreation, residential, commercial, religious) AADT	Sight distance Availability of rail crossing hardware and warning system The operating speed of trains (kmph) Whether the track is equipped with signals	*In this matter, severity is always at the highest
7	Roadside Vertical Drops – Unprotected Steep Roadside Slope	AADT The length, a driver is exposed to a vertical drop (m)	Distance from outside shoulder (m) Characteristics of the shoulder (Availability, type, width (m)) Road geometry (Curve or straight)	Unavailability of guardrails The operating speed of vehicles (kmph) Depth of the slope (By visual inspections) (m) Presence of structures the slope end Presence of water bodies at slope end
8	Unprotected Bridges and Culverts	AADT Length of the culvert/bridge (m)	Number of lanes Lane width (m) Improper signage	The operating speed of vehicles (kmph) Depth to the water body (m)

				Nature of the water flow
9	Open Drains	AADT Length of the drain/ditch opening (m)	Availability of protection Distance from outside shoulder edge (m) Characteristics of the shoulder	Depth of the ditch/ drainage (m) The operating speed of vehicles (kmph)
10	Excessive Pavement Edge Drop-Offs (A significant elevation change experienced at the lane edge, which occurs as a result of shoulder erosion, poor construction practices, edge breaks as a result of sever edge cracking)	AADT Length of the distressed road section (m)	Characteristics of the pavement edge	The operating speed of vehicles (kmph)

Following sections provide clear illustration about how the attributes are rated within the 1-5 scale. Rating of each attribute is done based on the prioritization schemes provided at iRAP fact sheets, opinions of professionals and best available literature.

4.2.1 Common attributes impacting risk parameters

Table 4.3 illustrates the variation of exposure score based on AADT and pedestrian activities.

Table 4.3. Exposure based on AADT and Pedestrian activities

AADT	Pedestrian Activities		
	Religious	Residential	Recreational, Educational, Commercial
<1000	1	2	2
1000-2000	3	3	4
>2000	4	5	5

Table 4.4 illustrates the variation of probability score based on total paved length.

Table 4.4. Probability of a crash based on total paved length

Lane Width	Shoulder Width			
	0-0.5	0.5-1	1-2	2-3
2.5-3	4	3	2	2
3-3.5	3	3	2	1
3.5+	3	2	2	0

Table 4.5 illustrates the variation of probability score based on road condition.

Table 4.5. Probability of a crash based on Road Condition

Condition Option	Description	Probability score
Poor	Road has serious defects, likely to have frequent and unpredictable impact on vehicle control	2
Medium	Road has some minor defects which result in occasional impact on vehicle control	1
Good	Road has very few or no defects providing no potential impact on vehicle control	-

Note - While there has been fairly substantial evidence of the benefits of adding shoulders to nearly all lane widths, there is evidence that for two-lane two-way rural road, the optimal safety benefit is obtained by considering the total pavement width (combined lane-shoulder configuration).

Table 4.6 illustrates the variation of severity score based on operating speed.

Table 4.6. Severity based on operating speeds

Factor: Operating speed of vehicles	Severity Score				
	1	2	3	4	5
>=60kmph					√
50kmph to <60kmph				√	
40kmph to <50kmph			√		
30kmph to <40kmph		√			
<30kmph	√				

4.2.2 Attributes impacting No advance knowledge of hazards at intersections

- Exposure – Addressed in Table 4.3. Exposure based on AADT and Pedestrian activities

Table 4.7 illustrates the influence of attributes impacting the probability of a crash for no advance knowledge of hazards at intersections.

Table 4.7. Attributes impacting probability of crash for no advance knowledge of hazards at intersections

Factor	Probability Score				
	1	2	3	4	5
Not having stop ahead pavement markings			√		
Obstructions to the sight distance					
Adequate	√				
Poor			√		
Improper signage			√		
Intersection configuration					
3 legs intersections		√			
4 legs intersections			√		
Lane width					
Wide (>= 3.25m)	√				
Medium (>= 2.75m to < 3.25m)		√			
Narrow (>= 0m to < 2.75m)			√		
Arrangement around 100m					
Presence of educational facilities	√				
Presence of bus stops		√			
Presence of alcohol sales establishments			√		

Table 4.8 illustrates the influence of attributes impacting the severity of a crash for no advance knowledge of hazards at intersections.

Table 4.8. Attributes impacting severity of a crash for no advance knowledge of hazards at intersections

Factor	Severity Score				
	1	2	3	4	5
Pedestrian Maneuver					
Crossing at crosswalks		√			

Walking against traffic		√			
Walking on Road			√		
If crossings are not provided			√		
Walking within traffic				√	
Darting into traffic				√	
Presence of buildings and other fixed objects					
Frangible Structures		√			
Rigid Structures				√	

4.2.3 Attributes impacting No advance knowledge of hazards at access roads

- Exposure – Addressed in Table 4.3

Table 4.9 illustrates the influence of attributes impacting the probability of a crash for no advance knowledge of hazards at access roads.

Table 4.9. Attributes affecting probability of a crash for no advance knowledge of hazards at access roads

Factor	Probability Score				
	1	2	3	4	5
Not having stop ahead pavement markings			√		
Obstructions to the sight distance Adequate Poor	 √ 		 √		
Improper signage			√		
Intersection configuration 3 legs intersections 4 legs intersections		 √ 	 √		
Lane width Wide (>= 3.25m) Medium (>= 2.75m to < 3.25m) Narrow (>= 0m to < 2.75m)	 √ 	 √ 	 √		

Table 4.10 illustrates the influence of attributes impacting the severity of a crash for no advance knowledge of hazards at access roads.

Table 4.10. Attributes affecting severity of a crash for no advance knowledge of hazards at access roads

Factor	Severity Score				
	1	2	3	4	5
Operating speed of vehicles	Addressed in “Table 5.4”				
Presence of buildings and other fixed objects		√			
Frangible Structures				√	
Rigid Structures					

4.2.4 Attributes affecting Limited roadside space availability

Table 4.11 illustrates the influence of attributes impacting the exposure to a crash for Limited roadside space availability.

Table 4.11. Attributes affecting exposure for Limited roadside space availability

Factor	Exposure				
	1	2	3	4	5
AADT	As addressed in Table 4.3				
Segment Length					
<20m	√				
20m-50m		√			
>50m			√		

Table 4.12 illustrates the influence of attributes impacting the probability of a crash for Limited roadside space availability.

Table 4.12. Attributes affecting probability of a crash for Limited roadside space availability

Factor	Probability Score				
	1	2	3	4	5
Not having proper lane markings		√			
Sight distance due to growth of vegetation					
Adequate	√				
Poor			√		
Road geometry					
Straight		√			
Curved			√		
Grade of the road					
0% to < 7.5%	√				

7.5% to < 10%		√			
>= 10%			√		
Lane and shoulder width	Addressed in Table 4.4				

Table 4.13 illustrates the influence of attributes impacting the severity of a crash for Limited roadside space availability.

Table 4.13. Attributes affecting severity of a crash for Limited roadside space availability

Factor	Severity Score				
	1	2	3	4	5
Operating speed of vehicles	Addressed in Table 4.6				
Presence of buildings and other fixed objects					
Frangible Structures		√			
Rigid Structures				√	
Aggressive vertical face			√		
Upward slope (150-750)		√			
Upward steep slope (>750)		√			
Deep drainage ditch			√		
Downward slope (Unprotected)			√		
Cliff (Unprotected)					√
Tree (>=10cm diameter)			√		
Non-frangible sign/post/pole (>=10cm diameter)			√		
Unprotected barrier end			√		
Large boulders (>=20cm tall)			√		
Safety barrier – metal	√				
Safety barrier – concrete	√				
Safety barrier – motorcycle friendly	√				
Safety barrier – wire rope	√				

4.2.5 Road alignment, Sight distance Issues and Lack of Warning signs at Curves

Table 4.14 illustrates the influence of attributes impacting the exposure to a crash for road alignment, sight distance issues and lack of warning signs at curves.

Table 4.14. Attributes affecting exposure for Road alignment, Sight distance Issues and Lack of Warning signs at Curves

Factor	Exposure				
	1	2	3	4	5
AADT	As addressed in Table 4.3				
Segment Length					
<20m	√				
20m-50m		√			
>50m			√		

Table 4.15 illustrates the influence of attributes impacting the probability of a crash for road alignment, sight distance issues and lack of warning signs at curves.

Table 4.15. Attributes affecting probability of a crash for Road alignment, Sight distance Issues and Lack of Warning signs at Curves

Factor	Probability Score				
	1	2	3	4	5
Curve Radius					
>900m	√				
500m-900m		√			
200m-500m			√		
0m-200m				√	
Obstructions to the sight distance					
Adequate	√				
Poor			√		
Provided Side friction					
Sealed - adequate	√				
Sealed - medium	√				
Sealed – poor		√			
Unsealed - adequate			√		
Unsealed - poor				√	
Required speed reduction					
<8kmph	√				
8-16kmph		√			
16-32kmph			√		
>32kmph				√	
Unavailability of warning signs			√		
Getting collided with a fixed object if the distance to the object is,					
0<1m					√
1m<5m				√	
5m<7M			√		
7m<10m		√			
>=10m	√				

Grade of the road 0% to < 7.5% 7.5% to < 10% >= 10%	 √	 √	 √		
Lane and shoulder width	Addressed in Table 4.4				

Table 4.16 illustrates the influence of attributes impacting the severity of a crash for road alignment, sight distance issues and lack of warning signs at curves.

Table 4.16. Attributes affecting severity of a crash for Road alignment, Sight distance Issues and Lack of Warning signs at Curves

Factor	Severity Score				
	1	2	3	4	5
Operating speed of vehicles	Addressed in Table 4.6				
Presence of buildings and other fixed objects					
Frangible Structures		√			
Rigid Structures				√	
Aggressive vertical face			√		
Upward slope (150-750)		√			
Upward steep slope (>750)		√			
Deep drainage ditch			√		
Downward slope (Unprotected)			√		
Cliff (Unprotected)					√
Tree (>=10cm diameter)			√		
Non-frangible sign/post/pole (>=10cm diameter)			√		
Unprotected barrier end			√		
Large boulders (>=20cm tall)			√		
Safety barrier – metal	√				
Safety barrier – concrete	√				
Safety barrier – motorcycle friendly	√				
Safety barrier – wire rope	√				

4.2.6 Poor Pedestrian Facilities near Schools, Town Areas

Table 4.17 illustrates the influence of attributes impacting the exposure to a crash for poor pedestrian facilities near schools, town areas.

Table 4.17. Attributes affecting exposure for Poor Pedestrian Facilities near Schools, Town Areas

Factor	Exposure				
	1	2	3	4	5
AADT	As addressed in Table 4.3				
Lane width where the pedestrian is exposed				√	
Wide (>= 3.25m)			√		
Medium (>= 2.75m to < 3.25m)		√			
Narrow (>= 0m to < 2.75m)					

Table 4.18 illustrates the influence of attributes impacting the probability a crash for poor pedestrian facilities near schools, town areas.

Table 4.18. Attributes affecting probability of a crash for Poor Pedestrian Facilities near Schools, Town Areas

Factor	Probability Score				
	1	2	3	4	5
Inadequate notifications to drivers			√		
Obstructions to the sight distance					
Adequate	√				
Poor			√		
Unavailability of warning signs to warn drivers			√		
Pedestrian crossing facilities					
Grade separated facility	√				
Marked crossing with a refuge		√			
Marked crossing without a refuge		√			
Refuge only			√		
No facility				√	
Sidewalk Provision					
Physical barrier	√				
Non-physical separation >3m	√				
Non-physical separation >1m		√			
Adjacent to traffic		√			
Paved Shoulder >1m			√		
Total shoulder >1 m			√		
Informal Path			√		
None and 0 < shoulder < = 1m				√	

Table 4.19 illustrates the influence of attributes impacting the severity of a crash for poor pedestrian facilities near schools, town areas.

Table 4.19. Attributes affecting severity of a crash for Poor Pedestrian Facilities near Schools, Town Areas

Factor	Severity Score

	1	2	3	4	5
Operating speed of vehicles	Addressed in Table 4.6				
Pedestrian Manoeuvre					
Crossing at crosswalks		√			
Walking against traffic		√			
Walking on Road			√		
If crossings are not provided			√		
Walking within traffic				√	
Darting into traffic				√	
Presence of buildings and other fixed objects					
Frangible Structures		√			
Rigid Structures				√	

4.2.7 Issues at Railroad Crossings

- Exposure - Addressed in Table 4.3

Table 4.20 illustrates the influence of attributes impacting the probability of a crash for issues at railroad crossings.

Table 4.20. Attributes affecting probability of a crash for Issues at Railroad Crossings

Factor	Probability Score				
	1	2	3	4	5
Inadequate notifications to drivers			√		
Sight distance					
Adequate	√				
Poor			√		
Unavailability of warning signs to warn drivers			√		
Pedestrian crossing facilities					
Grade separated facility	√				
Marked crossing with a refuge		√			
Marked crossing without a refuge		√			
Refuge only			√		
No facility				√	

Sidewalk Provision					
Physical barrier	√				
Non-physical separation >3m	√				
Non-physical separation >1m		√			
Adjacent to traffic		√			
Paved Shoulder >1m			√		
Total shoulder >1 m			√		
Informal Path			√		
None and 0 < shoulder < = 1m				√	

- Severity - Severity is always at the maximum in this matter

4.2.8 Road Side Vertical Drops and Unprotected Steep Road Side Slope

Table 4.21 illustrates the influence of attributes impacting the exposure a crash for road side vertical drops and unprotected steep road side slope.

Table 4.21. Attributes affecting exposure for Road Side Vertical Drops – Unprotected Steep Road Side Slope

Factor	Exposure				
	1	2	3	4	5
AADT	As addressed in Table 4.3				
Segment Length					
<20m	√				
20m-50m		√			
>50m			√		

Table 4.22 illustrates the influence of attributes impacting the probability of a crash for road side vertical drops and unprotected steep road side slope.

Table 4.22. Attributes affecting probability of a crash for Road Side Vertical Drops and Unprotected Steep Road Side Slope

Factor	Probability Score				
	1	2	3	4	5
Sight distance					
Adequate	√				
Poor			√		

Provided Side friction					
Sealed - adequate	√				
Sealed - medium	√				
Sealed – poor		√			
Unsealed - adequate			√		
Unsealed - poor				√	
Unavailability of warning signs			√		
Distance from outer shoulder edge to the side slope,					
0<1m					√
1m<5m				√	
5m<7M			√		
7m<10m		√			
>=10m	√				
Grade of the road					
0% to < 7.5%	√				
7.5% to < 10%		√			
>= 10%			√		
Road geometry					
Straight		√			
Curved			√		
Lane and shoulder width	Addressed in Table 4.4				

Table 4.23 illustrates the influence of attributes impacting the severity of a crash for road side vertical drops and unprotected steep road side slope.

Table 4.23. Attributes affecting severity of a crash for Road Side Vertical Drops and Unprotected Steep Road Side Slope

Factor	Severity Score				
	1	2	3	4	5
Operating speed of vehicles	Addressed in Table 4.6				
Type of safety barrier (if provided)					
Safety barrier – metal	√				
Safety barrier – concrete	√				
Safety barrier – motorcycle friendly	√				
Safety barrier – wire rope	√				
Unavailability of guardrails for a,					
Downward slope			√		
Downward steep slope (Cliff)					√
Presence of buildings and other fixed objects at the end of slope					
Frangible Structures		√			
Rigid Structures				√	
Aggressive vertical face				√	
Upward slope (150-750)		√			

Upward steep slope (>750)		√			
Water body			√		
Tree (>=10cm diameter)				√	
Non-frangible sign/post/pole (>=10cm diameter)				√	
Unprotected barrier end					√
Large boulders (>=20cm tall)					√

4.2.9 Unprotected Bridges and Culverts

Table 4.24 illustrates the influence of attributes impacting the exposure to a crash for unprotected bridges and culverts.

Table 4.24. Attributes affecting exposure for Unprotected Bridges and Culverts

Factor	Exposure				
	1	2	3	4	5
AADT	As addressed in Table 4.3				
Length of the culvert/bridge					
<10m	√				
10m-20m		√			
>20m			√		

Table 4.25 illustrates the influence of attributes impacting the probability of a crash for unprotected bridges and culverts.

Table 4.25. Attributes affecting probability of a crash for Unprotected Bridges and Culverts

Factor	Probability Score				
	1	2	3	4	5
Improper signage			√		
Number of lanes					
2		√			
4			√		
Lane width					
Wide (>= 3.25m)	√				
Medium (>= 2.75m to < 3.25m)		√			
Narrow (>= 0m to < 2.75m)			√		

Table 4.26 illustrates the influence of attributes impacting the severity of a crash for unprotected bridges and culverts.

Table 4.26. Attributes affecting severity of a crash for Unprotected Bridges and Culverts

Factor	Severity Score				
	1	2	3	4	5
Operating speed of vehicles	Addressed in Table 4.6				
Depth to the water body					
<5m	√				
5m-10m		√			
10-15m			√		
15m-20m				√	
>20m					√
Nature of the water flow					
Stream			√		
River				√	

4.2.10 Issues at Open Drains

Table 4.27 illustrates the influence of attributes impacting the exposure to a crash for issues at open drains.

Table 4.27. Attributes affecting exposure for issues as open drains

Factor	Exposure				
	1	2	3	4	5
AADT	As addressed in Table 4.3				
Length of the drain/ditch opening					
<10m	√				
10m-20m		√			
>20m			√		

Table 4.28 illustrates the influence of attributes impacting the probability of a crash for issues at open drains.

Table 4.28. Attributes affecting probability of a crash for issues as open drains

Factor	Probability Score				
	1	2	3	4	5
Unavailability of warning signs			√		

Type of safety protection (if provided)					
Safety barrier – metal (NA)					
Safety barrier – concrete	√				
Safety barrier – motorcycle friendly		√			
Safety barrier – wire rope			√		
Distance from outer shoulder edge to the ditch/drainage					
0<1m					√
1m<5m				√	
5m<7M			√		
7m<10m		√			
>=10m	√				
Road geometry					
Straight		√			
Curved			√		
Lane and shoulder width	Addressed in Table 4.4				

Table 4.29 illustrates the influence of attributes impacting the severity of a crash for issues at open drains.

Table 4.29. Attributes affecting severity of a crash for issues as open drains

Factor	Severity Score				
	1	2	3	4	5
Operating speed of vehicles	Addressed in “Table 5.4”				
Depth of the drainage					
<1m		√			
>1m			√		

4.2.11 Excessive Pavement Edge Drop Offs

Table 4.30 illustrates the influence of attributes impacting the exposure to a crash for excessive pavement edge drop offs.

Table 4.30. Attributes affecting exposure for excessive pavement edge drop offs

Factor	Exposure				
	1	2	3	4	5
AADT	As addressed in Table 4.3				
Length of the distressed road section					
<10m	√				
10m-20m		√			
>20m			√		

Table 4.31 illustrates the influence of attributes impacting the probability of a crash for excessive pavement edge drop offs

Table 4.31. Attributes affecting probability of a crash for excessive pavement edge drop offs

Factor	Probability Score				
	1	2	3	4	5
Road geometry					
Straight		√			
Curved			√		
Characteristics of the pavement edge					
Edge cracking present		√			
Edge drop-off present			√		
Lane and shoulder width	Addressed in Table 4.4				

Table 4.32 illustrates the influence of attributes impacting the severity of a crash for excessive pavement edge drop offs

Table 4.32. Attributes affecting severity of a crash for excessive pavement edge drop offs

Factor	Severity Score				
	1	2	3	4	5
Operating speed of vehicles	Addressed in Table 4.6				
Presence of buildings and other fixed objects		√			
Frangible Structures				√	
Rigid Structures			√		
Aggressive vertical face		√			
Upward slope (150-750)		√			
Upward steep slope (>750)			√		
Deep drainage ditch			√		
Downward slope (Unprotected)					√
Cliff (Unprotected)			√		
Tree (>=10cm diameter)			√		
Non-frangible sign/post/pole (>=10cm diameter)			√		
Unprotected barrier end			√		
Large boulders (>=20cm tall)			√		
Safety barrier – metal	√				
Safety barrier – concrete	√				
Safety barrier – motorcycle friendly	√				
Safety barrier – wire rope	√				

These findings have been consistent with the road safety issues that has been identified by several other researchers [17], [6], [18], and [63]

4.3 Development of the Safety Index

The purpose of developing a scoring system as mentioned in the previous chapter is to evaluate the identified risks quantitively. When there is a pre-defined framework, risk evaluation can be carried out without subjectivity. The purpose of developing the scoring system based on exposure, probability and severity is to use the values in developing the Safety Index (SI). When deciding the score of exposure, probability and severity at a particular hazardous location, it would be reasonable to select the attribute with the highest impact on the risk factor.

Ex: - When there are several roadside safety issues, it is fair to consider the safety issue with the highest impact rather than considering all features to impact in a single crash.

Based on the above considerations, the safety index of a particular issue is calculated as follows.

$$\mathbf{SI_i = e_i \times p_i \times c_i} \qquad 4.1$$

where,

SI_i	=	Safety Index of issue *i*
e_i	=	Exposure of issue *i*
p_i	=	Probability of issue *i*
c_i	=	Consequence of issue *i*

Based on the safety index developed for a particular hazardous location, two approaches were proposed in this study.

I. Evaluating the risk level of an entire road section considering all safety issues
II. Evaluating the risk level caused by a selected issue type

4.3.1 Evaluating the risk level of an entire road section considering all safety issues

This approach evaluates the risk of the whole road section by the Cumulative Safety Index (CSI) developed for the whole road. One of the advantages of this approach is to identify the roads that require safety treatments when allocating funds.

Therefore, the safety index for a road segment *k* where road safety issue *i* would occur for the n^{th} time is denoted by $(SI_{in})_k$. The (CSI) for a road is computed by summing the safety indexes of all the issues occurring on the road, given by Equation (4-2).

$$\mathrm{CSI_k} = \sum_1^{I} \sum_0^{N} (\mathrm{SI_{in}})_k \qquad 4.2$$

Where,

CSI_k	=	Cumulative safety index for road *k*
SI_{ink}	=	safety index for the n^{th} occurrence of the i^{th} safety issue in road *k*
I	=	number of road safety issue types
N	=	Number of occurrences for each type of safety issue

4.3.2 Evaluating the risk level caused by a selected issue type

This approach evaluates the risk caused by a specific safety issue. That helps to understand the impact of each issue type over a considered road or a considered road network. That allows the authorities to identify the safety issue types that require treatment in network level and project level safety treatment.

Cumulative safety index (CSI) for a road safety issue type *i* is given by Equation (4-3).

$$\mathrm{CSI_i} = \sum_1^{K} \sum_0^{N} (\mathrm{SI_{nk}})_i \qquad 4.3$$

Where,

CSI_i	=	Cumulative safety index for road safety issue *i*
SI_{ink}	=	safety index for the n^{th} occurrence of the i^{th} safety issue in road *k*
K	=	number of roads in the network
N	=	Number of occurrences for each type of safety issue

Table 5.3 provides ranking of road infrastructure issues based on the impact on crash severity levels along with their cumulative safety indexes. Cumulative Safety Index for each issue type was calculated as mentioned previously. The addition of individual safety indexes to obtain the cumulative effect is carried out with the assumption that attributes are impacting individually.

4.3.3 Validation of Cumulative Safety Index Based on Number of Crashes

The applicability of using CSI in risk analysis process can be evaluated based on a correlation between CSI and number of crashes. CSI_k and CSI_i provides an indication about the safety risk of a road and safety risk of a particular issue type on road(s) respectively. But CSI alone cannot demarcate the magnitude of the crash risk associated with a road or an issue type. Therefore, it is required to validate CSI as a safety performance function. The correlation developed by this approach proves the validity of using CSI to represent the crash risk of a road. Therefore, this section describes developing a correlation between CSI of a road and number of crashes in each road. Crashes have been identified under three severity level: fatal crashes, grievous crashes, and non-grievous crashes. But for a considered road, if the crashes are presented in a total basis for the analysis purpose, that might not represent the actual risk. Therefore, it was required to convert all the crashes to a common standard scale. To address this, all the crashes were converted into Equivalent Property Damage Only (EPDO) crashes. EPDO factor assigns greater importance, or weight, to crashes resulting in a severe injury or a fatality, lesser importance to crashes resulting in a moderate or slight injury, and minor importance to property-damage-only crashes. As Highway Safety Manual (HSM 2010) suggests, EPDO factor is calculated by using the societal cost of crashes for each severity over the societal cost of a property damage only crash to calculate the EPDO [64].

Weightages obtained for other countries require a proper calibration if they are about to be used for the local context. The main reason for that is the surrounding conditions where they have been developed are completely diverted from the surrounding conditions in the local context. Therefore, unique weightages were obtained each severity type considering local sources. The weightages for different crash severity types were obtained based on the economic cost estimated for fatal, grievous (a crash ends up causing severe injuries), non-grievous (a crash ends up causing a minor injury) crashes in Sri Lanka by [65], and [66] as given in equation (4-4). Due to under-reported behavior of property damage only crashes in developing countries, damage only crashes are not considered for the development of model.

$$\mathrm{EPDO} = (\mathrm{F} \times 14.6) + (\mathrm{G} \times 8) + (\mathrm{N} \times 1.14) + (\mathrm{D} \times 1) \qquad 4.4$$

Where,

F = Number of fatal crashes

G = Number of grievous crashes
N = Number of non-grievous crashes
D = Number of property damage only crashes

While the number of crashes of the road is addressed by the EPDO, the impact of safety issues towards causing crashess is addressed by the CSI_i. as discussed in the previous step.

In order to study the correlation between CSI and EPDO, a step-wise multiple linear regression analysis was used where the results are presented in the next chapter.

5 CASE STUDIES

5.1 Identification of Causal Factors Related to Crashes

This section describes the findings of road safety audits and evaluating the impact of those factors towards crashes.

5.1.1 Introduction to Study Area

Roads which are having an average daily traffic volume of less than 2,000 vehicles were considered as low volume roads in this study. Collector type roads and local roads are the main types of roads in Sri Lanka which fall under the category of low volume roads. These roads are administered by Provincial Road Development Authorities (PRDAs), municipalities, or local councils. Apart from the collector type roads and local roads, there is a considerable amount of A and B class of roads too which are within the defined traffic volume category. A and B class roads are administered by the Road Development Authority (RDA) of Sri Lanka. Classification of Sri Lankan road network is presented at ANNEX 01. Low volume roads in Sri Lanka mainly connect the low-density population areas and agricultural lands where commercial activities are limited. The land use and population density within the study area remain similar. A sample of low volume roads having a length of around 800km was selected for this study. Roads in the sample are single carriageways limited to a maximum width of 6m. All the roads considered in this study have an asphalt concrete pavement surface. Selected roads in the sample have an Annual Average Daily Traffic (AADT) of less than 2,000 veh/day. When considering the modal share on the selected roads, motorcycles and three-wheelers are accounted for the highest percentage of road usage. Also, motorcycles and three-wheelers have been involved in the highest number of crashes on these roads, having a combined percentage of 57%. Most crashes were found to be grievous and non-grievous. The selected sample of roads for the study also cover different geographic regions from flat terrain, rolling terrain, and mountainous terrain roads. The posted speed limit of the considered road type is 70 kmph in Sri Lanka.

5.1.2 Findings of the Road Safety Audit

This section describes the findings of Road Safety Audits carried out on a sample of the roads in four provinces in Sri Lanka; Northern, Eastern, Uva, and Southern Provinces. All the hazards identified during the road safety audits were grouped into common issue types with 10 different categories identified as listed below.

1. No advance knowledge of hazards at intersections
2. No advance knowledge of hazards at access roads
3. Limited roadside space availability
4. Road alignment, sight distance issues and lack of warning signs at curves
5. Poor pedestrian facilities near schools, town areas
6. Issues at rail crossings
7. Excessive pavement edge drop-offs
8. Roadside vertical drops and steep roadside slope
9. Unprotected bridges and culverts
10. Open drains

5.1.2.1 No advance knowledge of hazards at intersections

Improper signage and improper lane markings for the riders near main intersections in local road network where two or more local roads connect could be observed in most of the audited roads. This can create major safety issues due to intersection crashes that are probable to result after the improvements are done allowing the drivers to drive speedily.

Figure 5.1. No advance knowledge of hazards at intersections

5.1.2.2 No advance knowledge of hazards at access roads

Improper signage and improper lane markings cannot warn vehicles traveling on access roads about the major local roads connecting ahead. Also, users of main roads are also not warned when there are no delineations about upcoming access roads. These are not intersections where two or more local roads connect, but places where a connecting road and a local road meet. Such warning signs are especially important where there is poor visibility.


Figure 5.2. No advance knowledge of hazards at access roads

5.1.2.3 Limited roadside space availability

The growth of vegetation at the sides of the road and limited carriageway width are the main reasons for limited roadside space availability. Having an adequate shoulder provides space for emergency use by traffic. It also facilitates a safe path for pedestrian activities too. It also improves the visibility of the connecting roads and horizontal curves ahead.


Figure 5.3. Limited roadside space availability

5.1.2.4 Road alignment, Sight distance Issues and Lack of Warning signs at Curves

Absence of required signage to warn the drivers about upcoming curves were highly observed during the road safety audits. Lack of lane markings at horizontal and vertical curves was observed during the audits too. Unexpected horizontal curves, where the turning radius is small on narrow roads have a high crash risk for road users. Similarly, poor sight distance due to vertical alignment can have safety issues, especially where there are high pedestrian movements and access roads.

Figure 5.4. Road alignment, sight distance issues and lack of warning signs at curves

5.1.2.5 Poor pedestrian facilities near schools and, town areas

Unavailability of road signs and pedestrian crossings near schools was noted during the road safety audits. Similarly, near towns where there is a high pedestrian activity, the same issue could be identified which can increase pedestrian-related crashes.

Figure 5.5. Poor pedestrian facilities near schools, town areas

5.1.2.6 Issues at rail crossings

The major issues that could be observed at railway crossings were the improper alignment, unavailability of railway gates and poor signage.

Figure 5.6. Issues at rail crossings

5.1.2.7 Excessive pavement edge drop-offs

Due to improper construction practices, excessive pavement edge drop-offs were created at the roadsides. Another reason for this can be identified as soil erosion. Pavement edge drop-offs are a major safety hazard to motorists and would mostly affect motorcyclists and cyclists.

Figure 5.7. Excessive pavement edge drop-offs

5.1.2.8 Roadside vertical drops and steep roadside slope

The existence of high roadside slope / vertical drops may result in high severity crashes due to vehicle rollover in run-off road crashes. This issue could be identified mostly in Uva province those have mountainous terrains.

Figure 5.8. Roadside vertical drops and steep roadside slopes

5.1.2.9 Unprotected Bridges and Culverts

The lack of warning signs to indicate a "narrow bridge/ culvert ahead" was observed in several locations. Two big vehicles do not have sufficient space to cross. Rather than colliding with each other, vehicles may topple over the edge of the road. There was an additional risk to drivers in the tapering section where the roadside is exposed

and has a steep drop.

Figure 5.9. Unprotected bridges and culverts

5.1.2.10 Open Drains

There were deep open drains next to the road where the cover slabs were damaged or absent. This primarily poses a hazard to motorcyclists, cyclists, and pedestrians.

Figure 5.10. Open drains

The findings mentioned here related to road infrastructure safety issues are consistent with those identified by studies done for low volume roads by Montella (2005) [17], Cafiso et al., (2006) [6], Appleton (2009) [21], Sharma and Landge(2013) [67], Atkinson et al., (2014) [18], Wu et al., (2017) [63].

5.1.3 Examples for Crash Mapping

This section provides examples for crash mapping carried out based on the identified safety issues and crash records.

Table 5.1 provides the legend for crash mapping demonstrations.

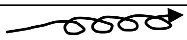
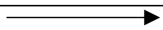
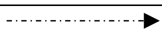
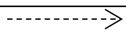
Figure 5.11 (a) illustrates safety issues in at Poonagala Road in Badulla District with horizontal curves and a roadside slope. There was moderate traffic in this area. Warning signs were not provided on the road to indicate the horizontal curve ahead. Also, no guardrails were provided at the steep side slope. The curvature of the curve was also high. Vehicle operating speed was low in this area due to the presence of curves. This scenario poses a high probability to cause a crash. The road adjustment can lead up to a single-vehicle running off the road to a steep slope which can end up as a fatal crash. For this location, crash data provides details about a fatal crash that happened at the location by a vehicle running off the road.

Figure 5.11 (b) illustrates a safety issue on Demodara – Rockhill Road in Badulla District near a junction. There were no warning signs and lane markings provided to indicate the upcoming intersection. Sight distance was also blocked for the vehicles on the minor road due to thick vegetation. Intersection arrangement can lead up to collisions which can lead up to minor injuries. Crash data analysis shows that a slightly injured collision has been taken place at the location between a cyclist and a private car.

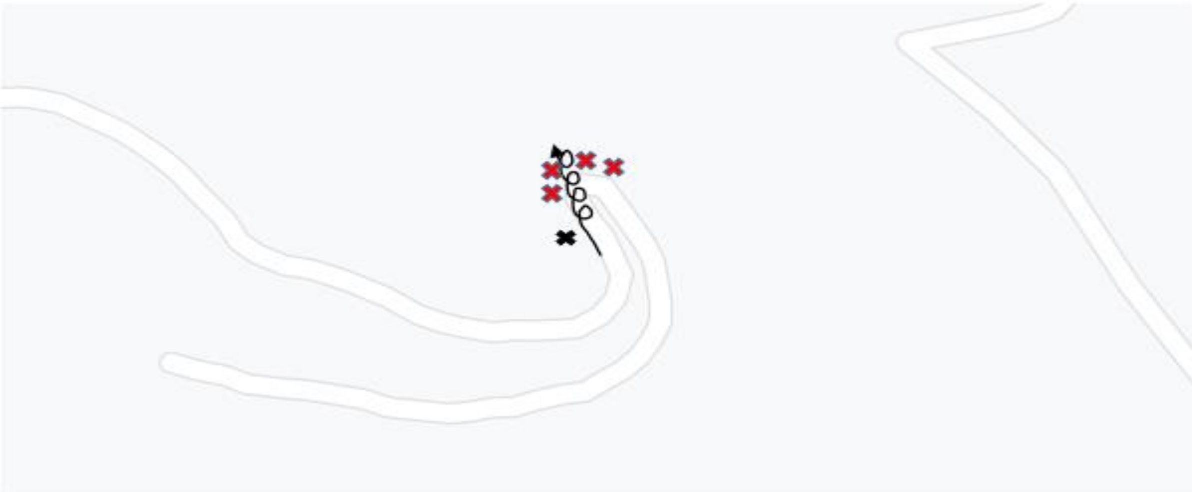
Figure 5.11 (c) illustrates a crash occurred at Wakwella – Dodangoda Road at Wakwella, where an unprotected side slope is present adjacent to the travel lane. No guardrails have been provided at the stated location. Also there have been no warning signs to warn the drivers about upcoming features. The traffic flow is moderate in this area. This scenario poses a high probability to cause a crash. The road adjustment can lead up to a single-vehicle running off the road to a steep slope which can end up as a fatal crash. Crash data provides details about a fatal crash happened at the location by a vehicle running off the road.

Figure 5.11 (d) illustrates a crash near a school on a Vempurai – Varani Road at Kodikamam. No warning signs were provided to warn the drivers about the school ahead. Also, there were no pedestrian crossings provided near the school. Since there is a straight road section and there is low traffic in this area, drivers tend to drive at a higher speed. All these factors pose a risk for a pedestrian-vehicle collision, especially children related crashes. Crash data provide details about a fatal pedestrian-vehicle crash happened at the stated location.

Table 5.1. Legend for crash mapping examples

Legend	
	Vehicle veer off the road
	No guardrails provided at the steep slope
	No warning signs to indicate the bend ahead
	Path of a private vehicle
	Path of a motorcycle
	No warning signs and lane markings at the junction
	Path of pedestrian
	Pedestrian crossings not provided
	Fatal crash
	Non-grievous crash

(a)



(b)

(c)

(d)

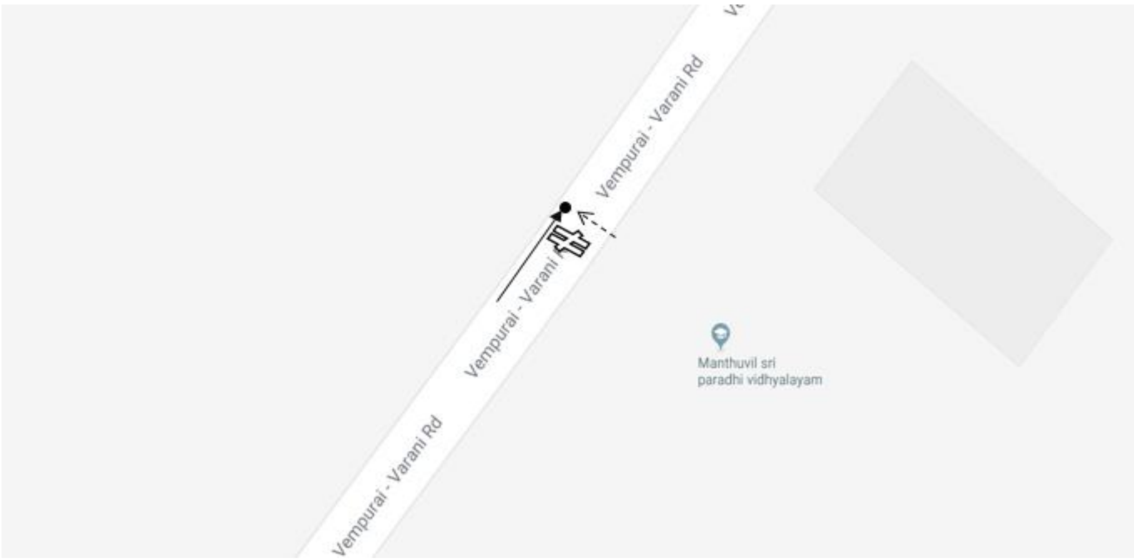


Figure 5.11. Examples for Crash Mapping

Figure 5.11 (a-d) presents details about the crashes that happened in those particular places where the prevailing issues were identified as causal factors for the particular crash. Table 5.1 illustrates the notations used for crash mapping.

5.1.4 Road infrastructure issues as causal factors for road crashes

Information obtained regarding the crash locations were compared with the locations of the prevailing road safety issues. Out of 181 crashes recorded in the three considered years (fatal, grievous and non-grievous categories only) identified in the study area, road infrastructure issue was identified as a causal factor for 163 crashes during the mapping process. It accounts to more than 90% of the serious crashes having road infrastructure issue as a contributory factor. The mapping process also enables to identify the road infrastructure issues that were relatively more significant with respect to causal factors for road crashes.

Table 5.2 shows the involvement of issues related to roadway characteristics. They were obtained from the crash mapping exercise as discussed previously. According to Table 5.2, issues at intersections and poor pedestrian facilities near schools and town areas have affected a greater number of crashes. However, when only the fatal crashes are considered, the alignment issues at curves are ranked 1st, mainly due to the fact that in the event of a crash, the consequences at those locations are more severe.

Moreover, it clearly shows that, out of 181 crashes that were considered, only 18 crashes have occurred in roads where a safety issue was not identified where a relevant risk factor could not be mapped to the crash. This is nearly 10% of all the major crashes, which is different to the observations made in the crash data records. Roadway related factors accounted for 90% of all crashes, 91% of fatal crashes, 89% of grievous crashes and 90% of non-grievous crashes on low volume roads. Based on the number of crashes, these above risk factors were then ranked.

Table 5.2. Roadway issues related to crashess in low volume roads

Issues related to roadway characteristics that were mapped to each crash	Number of crashes where identified issue was present			Total
	Fatal	Grievous	Non-grievous	
Lack of signage, road markings at intersections	3	14	19	36
Poor visibility at access roads	3	5	8	16
Limited roadside space availability	3	5	13	21
Road alignment, sight distance issues and lack of warning signs at curves	4	9	16	29

Poor pedestrian facilities near schools, town areas	3	8	19	30
Issues at railroad crossings		1		1
Road side vertical drops and unprotected steep road side slope	2	2	9	13
Unprotected bridges and culverts	3	4	6	13
Open drains		2	1	3
Excessive pavement edge drops off			1	1
NA	2	6	10	18
Total	23	56	102	181

All the identified safety issues have been ranked based on two criteria,

I. Based on the effect to cause the crash under each severity level (Fatal, Grievous, Non-grievous, Total) i.e., the issue which affected the occurrence of the greatest number of crashes was ranked as no 01 (The issue which has affected the greatest number of crashes in total was ranked as 1)

II. Based on the Cumulative Safety Index i.e., the issue with has the highest CSI was ranked as no 01.

Table 5.3. Ranking of Road Infrastructure Issues based on the Impact on Crash Severity Levels

Risk factor	Rank Based on crash severity				CSIi
	Fatal	Grievous	Non - Grievous	Total	
Lack of signage, road markings at intersections	2	1	1	1	452
Poor Pedestrian Facilities near Schools, Town Areas	2	3	1	2	731
Issues at horizontal and vertical curves	1	2	2	3	1161
Limited Road Side Space Availability	2	4	3	4	271
Poor visibility at Access Roads	2	4	5	5	520
Road Side Vertical Drops – Unprotected Steep Road Side Slope	3	6	4	6	307
Unprotected Bridges and Culverts	2	5	6	6	88
Open Drains	-	6	7	7	94

Excessive Pavement Edge Drop Offs	-	-	7	8	34
Issues at Railroad Crossings	-	7		8	40

Issues at curves have the highest cumulative safety index, yet it has been ranked number 03, which suggest that although the risk factor is prevailing in most roads, it does not contribute to the crash occurrence in the same risk level as for example lack of signage at intersections. This could be possible due to the fact that the exposure level at intersections is higher due to larger traffic volume and other road users compared to roadway segment near a curve. Although the lack of signage, road markings at intersections has been ranked as No. 01 when considering all crash severity types. But it does not have the highest Cumulative Safety Index.

Cumulative safety index (CSI_i) addresses the prevalence of each issue type. Table 5.3 suggests that, it does not always address the involvement of each safety issue in occurring a crash. Therefore, another parameter was required to validate the use of CSI in risk analysis.

5.2 Development of a Correlation Between CSI and EPDO

As stated in the previous chapter, in order to validate the use of CSI in safety performance measurement, CSI should be identified as a parameter that can predict magnitude of the prevailing crash risk. Therefore, this section discusses the development of correlation between CSI and EPDO using a stepwise multiple regression analysis.

Table 5.4 describes the data used in the multiple linear regression analysis.

Table 5.4. Variation of CSIi and EPDO

Road Name	Issue type represented by the issue ID as described in Table 4.2										EPDO
	1	2	3	4	5	6	7	8	9	10	
Putter - Meesalai Rd	0	0	0	234	192	0	0	0	0	0	140

Old Higurana Road - Village 07 To Padagoda road 40 Junction	27	48	43	63	58	0	0	0	0	0	80
Dombagahalwewa - Dematabedda - Mariarawa Rd	40	33	34	96	47	0	0	8	10	17	71
Mavilaru Junction to Seruvila Main road	64	20	20	30	25	0	0	8	36	0	68
Eravur Punnakudah Road	54	68	0	0	27	16	0	0	0	0	55
Wakwella-Dodangoda Road	14	22	14	40	35	0	40	0	0	0	41
Kurukalmadam Amplanthurai Athuchenai Road sec. i	16	4	0	18	47	0	0	2	36	0	41
Vallai - Telippalai - Araly	8	16	12	54	32	8	8	27	8	9	39
Vantharumoolai Kaluwankeny Road	54	54	18	20	12	16	0	0	0	0	39
Murukandy - Akkarayankulam Rd	28	0	0	45	30	0	0	0	0	0	34
Waturawila Road	10	18	10	34	30	0	36	0	0	0	34
Poonagala Road	0	0	0	62	68	0	66	0	0	0	33
Demodera - Spring Valley - Badulla	12	12	10	15	18	0	93	0	0	0	32
Point Pedro - Maruthankerny Road	9	20	8	16	14	0	0	8	2	8	28
Kekirihena-Kalupenibedda road	6	6	17	30	8	0	0	3	0	0	23
Konavil Skanthapuram Road	4	6	8	24	0	0	0	3	0	0	23
Porativu Palugamam Thumpankerny Road	22	2	0	12	20	0	0	0	0	0	19
Keselpotha - Aada Ulpatha Road	0	24	24	24	0	0	0	0	0	0	19
Heeloya - Makulella Rd	0	0	0	26	0	0	30	0	0	0	18
Karbala Palamunai Road, New Kaththankudy	8	8	16	26	26	0	0	0	0	0	18
Thopur Kaddaparichan Iddimanthurai Road	8	6	0	20	8	0	0	8	2	0	18
Adampan - Kandal Road	20	16	0	44	0	0	0	0	0	0	16
Kahawa-Galduwa Road	6	6	0	30	8	0	0	0	0	0	16

Maligathanna Liyaddagoda Road	10	26	0	0	0	0	12	0	0	0	16
Ginimallagaha-Dodangoda Road	10	30	8	45	0	0	0	0	0	0	16
Vishnu Kovil Road, Kalkuda	0	26	0	0	0	0	0	0	0	0	11
Gonagolla dorapaha to bandaradoowa village end	4	8	0	20	12	0	0	21	0	0	11
Ethiliwewa - Aluthela Rd	6	20	0	20	0	0	0	0	0	0	9
Manampita-Dehigahabedda	6	9	0	22	8	0	0	0	0	0	9
Uyilankulam - Nanattan Road	6	9	9	0	4	0	0	0	0	0	9
Kiri Amunakole - Mawathawewa Road	0	0	16	16	0	0	0	0	0	0	8
Borapola Samagipura internal Road	0	0	0	4	0	0	0	0	0	0	8
Ambalangoda-Dewagoda Road	0	0	0	0	0	0	14	0	0	0	3
Banwelgodalla Road	0	0	0	14	0	0	0	0	0	0	3
Goluwamulla-Atakohata Road	0	0	0	8	0	0	0	0	0	0	3
Vannerikulam Jeyapuram	0	3	0	8	0	0	0	0	0	0	3
Kanagarayankulam District Boundary Road	0	0	0	10	0	0	0	0	0	0	2
Dodampe-Padinnoruwa Road	0	0	0	6	0	0	0	0	0	0	1
Erukkalampiddy Rd	0	0	4	4	0	0	0	0	0	0	1
Halatutenna - Idalgashinna Rd	0	0	0	0	0	0	8	0	0	0	1
Pituwalgoda Road	0	0	0	6	0	0	0	0	0	0	1
Thanniyoottu Kumulamunai Alampil Road	0	0	0	6	0	0	0	0	0	0	1
Uyilankulam - Adampan Road	0	0	0	7	0	0	0	0	0	0	1
Ambagasdowagama Road	0	0	0	2	2	0	0	0	0	0	1

Table 5.5 provides the information related to crashes occurred on the selected road network.

Table 5.5. Crash data of the selected roads

Road Name	Fatal crashes	Grievous crashes	Non-grievous crashes	EPDO
15th Mile Post – Kiri Amunakole - Mawathawewa Road		1		8
Adampan - Kandal Road		1	7	16
Ambagasdowagama Road			1	1
Ambalangoda- Dewagoda Road			3	3
Banwelgodalla Road			3	3
Borapola Samagipura internal Road		1		8
Demodera - Spring Valley - Badulla	1	2	1	32
Dodampe-Padinnoruwa Road			1	1
Dombagahalwewa - Dematabedda - Mariarawa Rd	3	3	3	71
Eravur Punnakudah Road	2	3	2	55
Erukkalampiddy Rd			1	1
Ethiliwewa - Aluthela Rd		1	1	9
Ginimallagaha-Dodangoda Road	1		1	16
Goluwamulla-Atakohata Road			3	3
Gonagolla dorapaha to bandaradoowa village end		1	3	11
Halatutenna - Idalgashinna Rd			1	1
Heeloya - Makulella Rd	1		3	18
Kahawa-Galduwa Road		2		16
Kanagarayankulam District Boundary Road			2	2
Karbala Palamunai Road, New Kaththankudy		2	2	18
Kekirihena-Kalupenibedda road	1	1	0	23
Keselpotha - Aada Ulpatha Road		2	2	18
Konavil Skanthapuram Road		2	6	23
Kurukalmadam Amplanthurai Athuchenai Road sec. i		5	1	41
Maligathanna Liyaddagoda Road		2		16
Manampita-Dehigahabedda		1	1	9
Mavilaru Junction to Seruvila Main road	3	3		68
Murukandy - Akkarayankulam Rd		4	2	34
Old Higurana Road -Village 07 To Padagoda road 40 Junction	4	2	5	80
Pituwalgoda Road			1	1
Point Pedro - Maruthankerny Road		3	4	29
Poonagala Road	1	2	2	33
Porativu Palugamam Thumpankerny Road		2	3	19
Puttur - Meesalai Rd	7	4	5	140

Thanniyoottu Kumulamunai Alampil Road			1	1
Thopur Kaddaparichan Iddimanthurai Road		2	1	17
Uyilankulam - Adampan Road			1	1
Uyilankulam - Nanattan Road		1	1	9
Vallai - Telippalai - Araly		4	6	39
Vannerikulam Jeyapuram			2	2
Vantharumoolai Kaluwankeny Road		4	6	39
Vishnu Kovil Road, Kalkuda		1	3	11
Wakwella-Dodangoda Road	1	2	9	41
Waturawila Road	1	2	3	34
Total	26	66	103	

The following notations were used to define the independent variables in the regression analysis.

EPDO = Estimated EPDO for a road

CSI_a = Cumulative safety index for “No advance knowledge of hazards at intersections.”

CSI_b = Cumulative safety index for “No advance knowledge of hazards at access roads.”

CSI_c = Cumulative safety index for “Limited roadside space availability.”

CSI_d = Cumulative safety index for “Issues at horizontal and vertical curves.”

CSI_e = Cumulative safety index for “Poor pedestrian facilities near schools, town areas.”

CSI_f = Cumulative safety index for “Issues at rail crossings.”

CSI_g = Cumulative safety index for “Roadside vertical drops - steep roadside slope.”

CSI_h = Cumulative safety index for “Unprotected Bridges and Culverts.”

CSI_j = Cumulative safety index for “Open Drains.”

CSI_m = Cumulative safety index for “Excessive pavement edge drop-offs.”

The regression analysis incorporated six individual models in six steps. The results of each model are presented in Table 5.6

Table 5.6. Summary of stepwise regression models

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.886[a]	.785	.780	12.556914473911306
2	.960[b]	.922	.918	7.648063446152908
3	.974[c]	.948	.944	6.311590963247718
4	.977[d]	.954	.949	6.034839347668475
5	.979[e]	.959	.953	5.799863525342182
6	.982[f]	.964	.958	5.499605385725451

a. Predictors: (Constant), CSIe
b. Predictors: (Constant), CSIe, CSIa
c. Predictors: (Constant), CSIe, CSIa, CSIc
d. Predictors: (Constant), CSIe, CSIa, CSIc, CSId
e. Predictors: (Constant), CSIe, CSIa, CSIc, CSId, CSIb
f. Predictors: (Constant), CSIe, CSIa, CSIc, CSId, CSIb, CSIj

Table 5.7 illustrates the results of Analysis of Variance Test

Table 5.7. Results of ANOVA test

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	24187.410	1	24187.410	153.399	.000[b]
	Residual	6622.396	42	157.676		
	Total	30809.806	43			
2	Regression	28411.599	2	14205.799	242.864	.000[c]
	Residual	2398.208	41	58.493		
	Total	30809.806	43			
3	Regression	29216.359	3	9738.786	244.471	.000[d]
	Residual	1593.447	40	39.836		
	Total	30809.806	43			
4	Regression	29389.454	4	7347.364	201.744	.000[e]
	Residual	1420.352	39	36.419		
	Total	30809.806	43			
5	Regression	29531.547	5	5906.309	175.582	.000[f]
	Residual	1278.260	38	33.638		
	Total	30809.806	43			
6	Regression	29690.717	6	4948.453	163.609	.000[g]
	Residual	1119.089	37	30.246		
	Total	30809.806	43			
a. Dependent Variable: EPDO						
b. Predictors: (Constant), CSIe						
c. Predictors: (Constant), CSIe, CSIa						
d. Predictors: (Constant), CSIe, CSIa, CSIc						
e. Predictors: (Constant), CSIe, CSIa, CSIc, CSId						
f. Predictors: (Constant), CSIe, CSIa, CSIc, CSId, CSIb						
g. Predictors: (Constant), CSIe, CSIa, CSIc, CSId, CSIb, CSIj						

From the six models used in the regression analysis, the last model (6^{th} model) accounts for the highest correlation and model fit. Therefore, the 6^{th} model was selected as the best model to explain the data.

Table 5.8 illustrates the coefficients of variables obtained from the Model No. 06.

Table 5.8. Coefficients of the variables

Model		Coefficients		t	Sig.
		B	Std. Error		
6	(Constant)	1.659	1.239	1.339	.189
	CSIe	.484	.067	7.172	.000
	CSIa	.316	.094	3.362	.002
	CSIc	.296	.107	2.778	.009
	CSId	.175	.058	3.021	.005
	CSIb	.269	.090	2.989	.005
	CSIj	.327	.142	2.294	.028

Table 5.9 illustrates the excluded variables in the Model No. 06.

Table 5.9. Excluded Variables

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
6	CSIf	-.048g	-.965	.341	-.159	.398
	CSIg	.026g	.776	.443	.128	.888
	CSIh	.003g	.087	.931	.015	.870
	CSIm	-.017g	-.456	.651	-.076	.730
a. Dependent Variable: EPDO						
g. Predictors in the Model: (Constant), CSIe, CSIa, CSIc, CSId, CSIb, CSIj						

Finally, with the results obtained from the step-wise multiple linear regression analysis, the regression equation can be written as follows.

$$EPDO = 1.659 + 0.316CSI_a + 0.269CSI_b + 0.296CSI_c + 0.175CSI_d + 0.484CSI_e + 0.327CSI_j \quad 5.1$$

Once the model was obtained, Root Mean Square Error (RMSE) was calculated to measure the fit of the estimated EPDO value to the data set.

$$\mathbf{RMSE} = \sqrt{\frac{\sum(\textbf{Actual EPDO} - \textbf{Estimated EPDO})^2}{\mathbf{44}}} \quad 5.2$$

The correlation between the estimated and actual EPDO value was obtained to be 0.96 while the RMSE was obtained as 5.04. Table 5.10 describes the calculation of RMSE for the estimator.

Table 5.10. Calculation of RMSE

Road Name	EPDO	Estimated	(Actual EPDO-Estimated EPDO)^2
15th Mile Post – Kiri Amunakole - Mawathawewa Road	8	9.195	1.428025
Adampan - Kandal Road	16	19.983	15.86429
Ambagasdowagama Road	1	2.977	3.908529
Ambalangoda- Dewagoda Road	2.8	1.659	1.301881
Banwelgodalla Road	2.8	4.109	1.713481
Borapola Samagipura internal Road	8	2.359	31.82088
Demodera - Spring Valley - Badulla	32	22.976	81.43258
Dodampe-Padinnoruwa Road	1.4	2.709	1.713481
Dombagahalwewa - Dematabedda - Mariarawa Rd	71.2	76.058	23.60016
Eravur Punnakudah Road	55	50.083	24.17689
Erukkalampiddy Rd	1.4	3.543	4.592449
Ethiliwewa - Aluthela Rd	9.4	12.435	9.211225
Ginimallagaha-Dodangoda Road	15.6	23.132	56.73102
Goluwamulla-Atakohata Road	2.8	3.059	0.067081
Gonagolla dorapaha to bandaradoowa village end	10.8	14.383	12.83789
Halatutenna - Idalgashinna Rd	1.4	1.659	0.067081
Heeloya - Makulella Rd	18	6.209	139.0277
Kahawa-Galduwa Road	16	14.291	2.920681
Kanagarayankulam District Boundary Road	2.4	3.409	1.018081
Karbala Palamunai Road, New Kaththankudy	17.8	28.209	108.3473
Kekirihena-Kalupenibedda road	23	19.323	13.52033
Keselpotha - Aada Ulpatha Road	18.4	19.419	1.038361
Konavil Skanthapuram Road	22.6	11.105	132.135
Kurukalmadam Amplanthurai Athuchenai Road sec. i	41	45.461	19.90052
Maligathanna Liyaddagoda Road	16	11.813	17.53097
Manampita-Dehigahabedda	9.4	13.698	18.4728
Mavilaru Junction to Seruvila Main road	67.8	62.305	30.19503
Murukandy - Akkarayankulam Rd	34.4	32.902	2.244004
Old Higurana Road -Village 07 To Padagoda road 40 Junction	79.6	74.928	21.82758
Pituwalgoda Road	1.4	2.709	1.713481
Point Pedro - Maruthankerny Road	28.4	22.481	35.03456
Poonagala Road	32.6	45.421	164.378
Porativu Palugamam Thumpankerny Road	18.8	20.929	4.532641
Puttur - Meesalai Rd	139.9	135.537	19.03577
Thanniyoottu Kumulamunai Alampil Road	1.4	2.709	1.713481
Thopur Kaddaparichan Iddimanthurai Road	17.4	13.827	12.76633
Uyilankulam - Adampan Road	1.4	2.884	2.202256
Uyilankulam - Nanattan Road	9.4	10.576	1.382976
Vallai - Telippalai - Araly	38.6	39.597	0.994009

Vannerikulam Jeyapuram	2.8	3.866	1.136356
Vantharumoolai Kaluwankeny Road	38.6	47.885	86.21123
Vishnu Kovil Road, Kalkuda	11	8.653	5.508409
Wakwella-Dodangoda Road	41.2	40.085	1.243225
Waturawila Road	34.4	33.091	1.713481
$\sum$ (Actual EPDO-Estimated EPDO)^2			1118.212
RMSE			5.09

Figure 5.12 illustrates the plot of the multiple linear regression analysis.

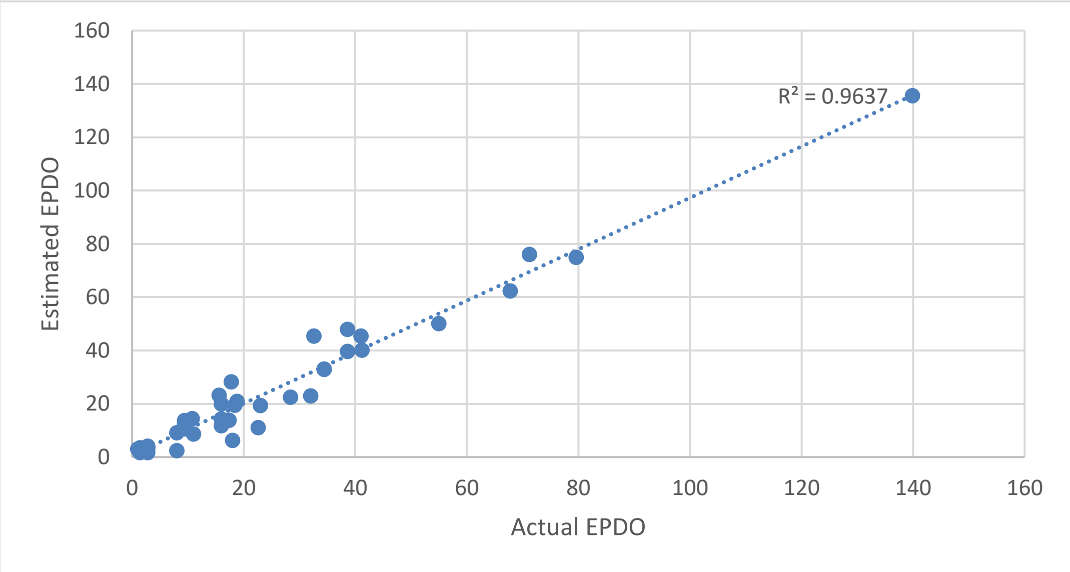


Figure 5.12. Plot between Actual and Estimated EPDO Values

Results show that, CSI can be considered as a parameter to indicate the risk of a road segment. This is a demonstration with the available data for the local context. But when the same methodology is applied in another country, coefficient of the parameters might be changed with relevant data. The purpose of this approach is to validate that CSI represents the perceived crash risk on a road and the contributory factors based on road characteristics which affect the overall risk of the road. Not having crash data on low-volume roads is a significant problem in developing countries. Therefore, using CSI enables relevant authorities to perform safety performance evaluations on low-volume roads even without crash data. The basis of iRAP methodology to calculate safety performance and safety performance improvements after mitigatory measures is the same. Without reference to detailed crash data, which is often unavailable in low-income and middle-income countries, iRAP methodology also can be used to evaluate the safety performance [11].

5.3 Model Validation

Once a regression model was developed using the available data, a model validation was carried out to determine whether the model estimates satisfy the actual data. Model validation was carried out using 10 randomly selected roads where the crash data are available.

Selected roads represent two regions of Sri Lanka. Table 5.11 illustrates the calculation of EPDO of the selected roads based on prevailing safety issues.

Table 5.11. Calculation of EPDO

Road Name	Issue type represented by the issue ID as described in Table 4.2										EPDO
	1	2	3	4	5	6	7	8	9	10	
Lower Pundaluoya-upper Sheengama road	27	18	16	54	27		63				42
Kandapola Concordia Road			18		27		54				20
Kirigalwewa-Unagaswewa-Moragoda School Road	45	18	36	45	18						48
Palugaswewa-Mahakekirawa Road	18	18	18	36	27						37
Thalawa - hangurankethagam a Road	27	27		45							25
Mahakanadarawa-welioya	18			24	18				18		26
Ihalagama-Diulwewa	36		18	60					36		41
Pihibiyagollewa Road (Kebitigollewa)	48	45	27	72							50
Kapugollewa Maradanmaduwa Wegollewa	27	36	51	114	45				27		86

Kalawewa Road	18			24	36						29

Estimated EPDO values were then compared with the actual EPDO values of the selected roads. Further, Root Mean Square Error (RMSE) was calculated to measure the fit of the estimated EPDO value to the data set. The correlation between the estimated and actual EPDO value was obtained to be 0.93 while the RMSE was obtained as 9.21. Table 5.12 describes the calculation of actual EPDO values and RMSE for the estimator.

Table 5.12. Calculation of RMSE for validation

Road Name	Numbers of					(Actual EPDO-Estimated EPDO)^2
	Fatal crashes	Grievous crashes	Non-grievous crashes	Actual EPDO	Estimated EPDO	
Lowe Pundaluoya-upper Sheengama Road	1	1	6	29	51	484
Kandapola Concordia Road			8	9	23	196
Kirigalwewa-Unagaswewa-Moragoda School Road	1	3	6	45	51	36
Palugaswewa-Mahakekirawa Road		4		32	37	25
Thalawa - hangurankethagama Road		2	1	17	25	64
Mahakanadarawa-welioya Road		3	3	27	26	1
Ihalagama-Diulwewa Road	1	3	4	43	40	9
Pihibiyagollewa Road (Kebitigollewa)	3	1	1	53	50	9
Kapugollewa Maradanmaduwa Wegollewa Road	2	6	11	90	86	16
Kalawewa Road	1	2	1	32	29	9
∑ (Actual EPDO-Estimated EPDO)^2						849
RMSE						9.21

Figure 5.13 illustrates the plot between estimated and actual EPDO values.

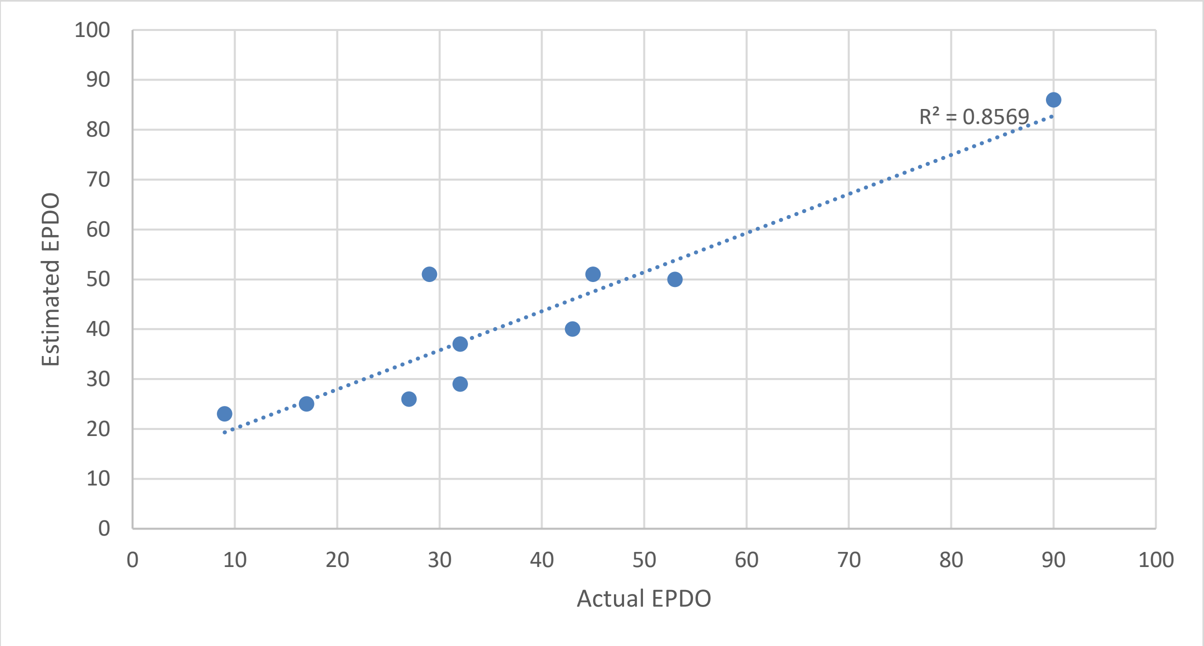


Figure 5.13. Plot between actual and estimated EPDO values

5.4 Incorporating Road Safety in Rural Road Network Level Pavement Management

For developing countries, application of most of the current safety evaluation methods are limited. The main reason for that is lack of reliable crash data. According to the World Health Organization statistics, 90% of the world's traffic deaths are occurred in developing countries [68]. Therefore, there is a need of a novel approach to incorporate safety performance in decision making in developing countries. Therefore, this methodology was proposed adhering to the safety issues, roadway issues, social conditions and environmental conditions in rural roads in developing countries.

As this methodology is proposed considering the social and environmental conditions of rural roads in developing countries, if any user needs to adapt this to an environment and/or to a developed country, the respective user can calibrate the model as it suits the new roadway conditions, roadside features, socio-economic parameters etc.

In order to optimize a set of objectives systematically at the same time, Multi Objective Optimization (MOO) can be adopted. The proposed approach under this methodology uses two optimization models to improve the road safety and road condition at the same time.

5.4.1 The framework of the Proposed System

The MOO framework proposed in this approach minimizes two criteria to select the treatment types for a given road segment as follows,

- Average network IRI
- Average network CSI for single-year analysis

The above-mentioned criteria are minimized under the constraints of allocated budget for the road improvements in the respective financial year and the restrictions defined by the decision tree. Fitness values of the above-mentioned objective functions are calculated from the results of the optimization models.

The first objective function minimizes the average network IRI value expressed in equation (5-3), while the second objective function minimizes the average network CSI value and defines it as equation (5-4).

$$\text{Minimize } (\mathrm{Q}) = \frac{\sum_{\mathrm{k}=1}^{\mathrm{K}} \sum_{\mathrm{r}=1}^{\mathrm{R}} \mathrm{Q}_{\mathrm{rk}} \mathrm{L}_{\mathrm{k}}}{\sum_{\mathrm{k}=1}^{\mathrm{K}} \mathrm{L}_{\mathrm{k}}} \qquad 5.3$$

$$\text{Minimize } (\mathrm{S}) = \frac{\sum_{\mathrm{k}=1}^{\mathrm{K}} \sum_{\mathrm{s}=1}^{\mathrm{S}} \mathrm{CSI}_{\mathrm{sk}}}{\sum_{\mathrm{k}=1}^{\mathrm{K}} \mathrm{L}_{\mathrm{k}}} \qquad 5.4$$

Subjected to:

$$Budget\ (B) \geq \sum_{k=1}^{K} \sum_{r=1}^{R} C_{rk} L_k + \sum_{k=1}^{K} \sum_{s=1}^{S} C_{sk} \qquad 5.5$$

Where,

Q - Average network IRI value in m/km

Q_{rk} - IRI of road section ‘k’ after applying the operation ‘r’ in m/km

L_k - Length of road section ‘k’ in km

K - Number of road sections in the network

R - Number of maintenance operations used for road section ‘k’

S - Average network CSI value

CSI_{sk} - CSI of road section ‘k’ after applying the safety improvement strategy ‘s’

S - Number of safety improvement operations used for road section ‘k’

B - Total budget available for the financial year

C_{rk} - Cost per km for applying procedure '*r*' to road section '*k*'

C_{sk} - Cost for using safety improvement strategy '*s*' to road section '*k*'

In order to satisfy the second objective of the model, the chromosome element has three mutually exclusive safety treatment strategies as described below.

- Strategy 1 (s=1) - Clearing of roadside obstructions, lane marking, installing warning signs, and marking pedestrian crossings.
- Strategy 2 (s=2) - Superelevation adjustments, curve geometry arrangements, constructing pedestrian walkways, installing guardrails, covering open drains, and edge corrections.
- Strategy 3 (s=3) - A combination of strategy 1 and strategy 2, where all defined safety improvement strategies are included.

Table 5.13 below illustrates the safety treatment types used under each strategy to improve safety levels of the safety issues identified in Table 5.2.

Table 5.13. Safety treatment strategies

Safety Issue	Required safety treatment strategy		
	S=1	S=2	S=3
Lack of signage, road markings at intersections	Yes	Yes	Yes - based on the requirement
Poor visibility at Access Roads	Yes	Yes	Yes - based on the requirement
Limited Roadside Space Availability	Yes	-	-
Road alignment, Sight distance Issues, and Lack of Warning signs at Curves	Yes	Yes	Yes - based on the requirement
Poor Pedestrian Facilities near Schools, Town Areas	Yes	Yes	Yes - based on the requirement
Issues at Railroad Crossings	Yes	Yes	Yes - based on the requirement
Roadside Vertical Drops – Unprotected Steep Roadside Slope	-	Yes	-
Unprotected Bridges and Culverts	-	Yes	-
Open Drains	-	Yes	-
Excessive Pavement Edge Drop-Offs	-	Yes	-

5.4.2 Illustrative Example to Demonstrate the Applicability of the Model

The applicability of the proposed framework with respect to safety treatment is demonstrated by an illustrative example as follows.

The inputs of the second objective models are derived based on the Cumulative Safety Index (CSI) developed in this study. A road network consisting 15 roads is considered in the example. For the objective function of safety improvement, users need CSI of the road network in the initial state and the CSI of the road network after adapting respective safety treatment schemes as addressed in Table 5.13.

Initial CSI of the roads in the network is calculated based on the safety issues prevailing there. CSI was calculated according to the methodology described in "Development of the Safety Index". Attributes considered for the calculation of CSI for each road were discussed in ANNEX 03.

Table 5.14 illustrated the CSI of each issue type prevailing on the considered roads of the network along with the respective EPDO values for each road.

Table 5.14. Initial CSI of the roads in the network

Road	CSI of Issue types as addressed in Validation of Cumulative Safety Index						CSI_k	EPDO
	CSI_a	CSI_b	CSI_c	CSI_d	CSI_e	CSI_j		
C001		28		66		36	130	31
C002		18	42	66	48	18	192	58
C003	24	32	36	24	27		143	44
C004	18	18	18	36		18	108	28
C005		18		54	96		168	61
C006	18	12	18	18	24		90	29
C007	16	24		18			58	15
C008	72			54			126	32
C009		36	27	90			153	33
C010		27	108	63	48		246	73
C011		18	45	48			111	27
C012		12	18	34	36	36	136	44
C013			27	81	36		144	40
C014	114			24			138	40
C015	42			144	96	27	309	94

For each road mentioned in Table 5.14, the safety treatments described in Table 5.13 are considered. The next step was calculation of the CSI after adapting each safety treatment strategy. Adapting of safety treatments have a direct influence on the attributes affecting each safety issue type. Therefore, when adapting treatments, the ratings given for the risk parameters (exposure, probability and severity) are subjected to change. CSI_k for each road is then determined by the new CSI_i values after adapting treatment types.

Table 5.15, Table 5.16, and Table 5.17 illustrates the new CSI values of each road after adapting safety treatment types S=1, S=2, and S=3 respectively along with their new EPDO values.

Table 5.15. CSI values of roads in the network after adapting safety treatment type 1

Road	CSI of Issue types as addressed in Validation of Cumulative Safety Index						CSI_k	EPDO
	CSI_a	CSI_b	CSI_c	CSI_d	CSI_e	CSI_j		
C001		12		24		36	72	19
C002		6	42	42	16	18	124	35
C003	8	8	12	16	12		56	17
C004	6	6	18	12		18	60	17
C005		6		18	32		56	20
C006	8	4	12	12	4		40	11
C007	4	8		6			18	4
C008	12			18			30	7
C009		9	27	54			90	20
C010		9	81	36	12		138	39
C011		6	30	24			60	15
C012		8	12	20	12	36	88	27
C013			27	69	12		108	26
C014	30			8			38	11
C015	18			84	32	27	161	45

Table 5.16. CSI values of roads in the network after adapting safety treatment type 2

Road	CSI of Issue types as addressed in Validation of Cumulative Safety Index						CSI_k	EPDO
	CSI_a	CSI_b	CSI_c	CSI_d	CSI_e	CSI_j		
C001		30		63			93	19
C002		18	34	42	48		142	45
C003	16	32	27	24	18		117	35
C004	12	18	18	36			84	20
C005		18		54	48		120	38
C006	8	12	18	18	12		68	20
C007	8	24		18			50	12
C008	24			54			78	17
C009		36	27	72			135	30
C010		27	108	63	18		216	59
C011		18	9	42			69	15
C012	16		30	18	18		82	26
C013			27	81	18		126	31
C014	60			24			84	23
C015	30			126	48		204	55

Table 5.17. CSI values of roads in the network after adapting safety treatment type 3

Road	CSI of Issue types as addressed in Validation of Cumulative Safety Index						CSI_k	EPDO
	CSI_a	CSI_b	CSI_c	CSI_d	CSI_e	CSI_j		
C001		12		17			29	6
C002		22	18	36	16		92	25
C003	8	8	12	12	12		52	16
C004	6	6	18	12			42	11
C005		6		18	24		48	16
C006	4	4	12	12	4		36	10
C007	4		8	6			18	5
C008	12			18			30	7
C009		9	27	42			78	18
C010		9	81	36	6		132	36
C011		12	6	18			36	8
C012	8		12	16	6		42	12
C013			27	63	6		96	22
C014	20			12			32	8
C015	13			72	18		103	25

Table 5.18 provides a summary on the initial and after CSI values and EPDO values after adopting each safety treatment strategy.

Table 5.18. CSI and EPDO values after adopting treatment schemes

Road	Initial CSI	Initial EPDO	After adopting S=1		After adopting S=2		After adopting S=3	
			CSI	EPDO	CSI	EPDO	CSI	EPDO
C001	130	31	72	19	93	19	29	6
C002	192	58	124	35	142	45	92	25
C003	143	44	56	17	117	35	52	16
C004	108	28	60	17	84	20	42	11
C005	168	61	56	20	120	38	48	16
C006	90	29	40	11	68	20	36	10
C007	58	15	18	4	50	12	18	5
C008	126	32	30	7	78	17	30	7
C009	153	33	90	20	135	30	78	18
C010	246	73	138	39	216	59	132	36
C011	111	27	60	15	69	15	36	8
C012	136	44	88	27	82	26	42	12
C013	144	40	108	26	126	31	96	22
C014	138	40	38	11	84	23	32	8
C015	309	94	161	45	204	55	103	25

Table 5.19. Summary of safety improvements after adopting each strategy

Road	Reduction of CSI and EPDO after adopting S=1		Reduction of CSI and EPDO after adopting S=2		Reduction of CSI and EPDO after adopting S=3	
	ΔCSI	ΔEPDO	ΔCSI	ΔEPDO	ΔCSI	ΔEPDO
C001	58	12	37	12	101	25
C002	68	23	50	12	100	33
C003	87	27	26	10	91	28
C004	48	11	24	8	66	17
C005	112	41	48	23	120	45
C006	50	18	22	9	54	19
C007	40	10	8	3	40	10
C008	96	25	48	15	96	25
C009	63	14	18	3	75	16
C010	108	35	30	15	114	38
C011	51	12	42	12	75	18
C012	48	17	54	18	94	32
C013	36	14	18	9	48	18

C014	100	29	54	17	106	32
C015	148	49	105	39	206	68

Table 5.19 illustrates the improvements achieved after adopting each safety strategy. Improvements are presented in terms of both CSI and EPDO.

This analysis provides safety improvements in terms of both CSI and EPDO. The reduction of CSI, i.e., safety improvement, can be used in equation 5-4 to be incorporated in the multi-objective optimization model.

The major objective of carrying out safety treatments on selected roads is to improve the safety performance of that road. By calculating the safety improvement based on CSI for each treatment type, the user gets the opportunity to analyse the safety improvement of the road after adopting selected treatment types since CSI addresses the safety level of the road(s). To obtain this improvement, users have to consider all types of safety issue. But if the user wants to check the relative reduction of crashes, the new CSI values after adopting treatment types guides the user towards calculating the reduction of EPDO. Therefore, the agencies of authorities have the opportunity to compare the EPDO reduction along with the cost to undergo each safety issue type. Although obtaining an absolute crash reduction indication is not possible at the moment, obtaining at least the relative reduction of crashes is an importance consideration of highway planning. If the concern is only to improve the safety performance of the road(s), this type of an analysis can be carried out with the aim of developing a benefit-cost ratio for adoption of each safety treatment type. Benefit can be calculated in terms of EPDO.

5.5 A Framework for Selecting Safety Treatments for Rural Roads

One of the main objectives of the road authorities / agencies is to ensure that road users have a safe, comfortable and efficient travel experience. In order to ensure a safe journey, it is their responsibility to implement comprehensive road safety strategies as they will help reduce the incidence of road crashes under consideration. In developing such strategies, there should be a proper guideline or safety management system to guide agencies / authorities to optimize the safe operation of the roads they govern, within budget constraints. Therefore, the approach should indicate confirmation of the estimated safety performance improvement and the crash reduction after following the selected safety treatment measures. Suppose a separate budget can be allocated to improve road safety performance of a given road. In such a case, a linear programming model would act favor to optimize safety performance of the road concerning availability of the resources.

The previous subsection (5.1) presented an application from the developed framework that optimizes both safety condition and pavement condition according to the given budget in a network level. This subsection presents an application of the proposed network, but it is designed for a project-level approach. Here, only safety performance improvements are considered. Safety treatment strategies that can be implemented for a given project are determined using a linear-programming model in this approach.

Let us consider a rural low-volume road “R”. R is in a critical condition in terms of safety risk for its road users. Therefore, a proper guideline should be developed as it eases the implementation of safety treatment strategies based on the budget allocated for a given year. R consists of different types of prevailing safety issues on the road which must be treated in order to improve the safety performance of the road “R”. As in the previous application, one key factor which act against the treatment of all prevailing safety issues is the budgetary condition of the governing authorities. Specially in developing countries like Sri Lanka, the budget allocation for these types of road is very low. Therefore, the authorities have to pay more attention on their expenditure on safety treatment, while assuring a safe road for the users. When there a considerable impact from the budgetary conditions, it is not possible to treat all the prevailing issues of the selected road. The authorities have to identify the most crucial safety issues and treat them according to their prioritization. This scenario implies that, the budgetary conditions play a crucial role when it comes to developing road maintenance schemes. Without having a proper framework to guide the decision-makers on this scenario, it is not possible to achieve the expected safety improvements.

The application presents in this chapter is developed considering several working principles to address the restrictions mentioned above.

- The safety performance of the selected road should be evaluated using a quantitative approach.
- The selected road should consist of prevailing safety issues that require treatments in order to improve the safety performance of the road.

- Each treatment has a defined cost to implement.
- The treatment should have a contribution on improving the safety performance of selected road.
- The total cost to treat all the prevailing safety issues should be higher than the available budget in the given period.

Therefore, the objective function should optimize the safety performance of the selected road adhering to the availability of the budget. As it has been mentioned in 3.2.1, safety issues prevailing on the road are identified by carrying out a road safety audit with a multi-disciplinary team. Identification of safety issues is carried out adhering to the standards provided in [20]. The number of treatment schemes that can be adopted to the road, is not considered as a constraint in this application. Table 5.20 summarizes the important aspects considered under the application.

Table 5.20. Considerations of the Application

Objective	Improving the safety performance of the selected road (Linear programming)
Required data and indicators	Safety Performance indicator Safety Performance model Prevailing safety issues Available budget
Constraints	Minimum safety performance level Allocated budget for the road
Results	Safety treatment plan Estimated cost Safety performance improvement

Formulation of a linear programming model can be described as follows.

1. Understanding the problem.

   The main purpose of a linear programming model is to find a way to achieve the most, or least, or some quantity of the consideration. In this application, the consideration is safety issues to be treated. The quantity to achieve is the primary objective of the model.

   The answer depends on how much of some decision variables chosen. Constraints of the model will limit the quantity to be achieved.

2. Describing the objective

   This step reflects what we try to optimize. In this application, the requirement is to optimize the safety performance of the selected road.
3. Identifying the decision variables

   These are the variables that decide the desired outputs. They have a representation of the ultimate solution. In order to solve any problems, the decision variables have to be identified initially.
4. Formulation of the objective function

   This is the objective of making decisions. The variables that have been chosen are used to formulate the problem as an algebraic expression.
5. Defining the constraints

   These are the restrictions or limitations act on the decision variables. The value of the decision variables is usually limited by the constraints. In most of the cases, budgetary conditions act as constraints.

   Ex: - The available budget will have an affect towards the number of safety issues to be treated in order to optimize the safety performance of the road.
6. Defining non-negativity constraints

   Decision variables should always contain non-negative values (≥0)

A sample linear programming problem can be formulated as follows.

Maximize	4A	+	3B
Subjected to:	A	<	70
	B	<	60
	2A – B	<	100
	U	>	0
	H	>	0

5.5.1 The framework of the proposed system

The objective function proposed in this application is designed as it minimizes the CSI of the road after implementing the available safety treatment strategies applied for the road. The linear model in this study provides an indication to the relevant authorities about the safety issues that need to be prioritized to improve the safety performance of the road, based on the available budgetary conditions.

The allocation of the budget can be implemented in two ways.

- Single-period budget allocation
- Multi-period budget allocation

When implementing according to a multi-period budget allocation, the variables required to adopt a multi-period analysis are also subjected to high level of uncertainties: inflation, discount rate, traffic growth rate, crash growth rate, etc. Therefore, a single-period budget allocation is considered in this study. The solutions provided by this model can be used to implement a number of safety treatments for a given project. Based on the budget availability, any road can adopt to more than one safety treatment strategies. The proposed mathematical model maximizes the objective function that corresponds to the overall project condition.

5.5.1.1 Scope of the Model

The safety performance improvement of the road is measured by the reduction of CSI proposed in section 4.2 in this study. The safety improvement adjacent to a road is governed by the available treatment types for the road, crash reduction capability of each treatment strategy based on the existing ground condition. Based on the available treatment strategies, and their adaptability to the existing conditions of the prevailing safety issues determine the quantified amount of the safety performance improvement. This model does not guide us to select the treatment type for each location, but it guides us to select the safety issues that need to be treated/ prioritized. One of the advantages in this approach is, safety issues and their level of improvements are determined based on the data collected during field inspections/ road safety audits. Limitations prevailing in developing countries about lack to reliable data can be overcome by this approach. An auditor can focus on the attributes impact on each safety issue type as described in section 4.2 and determine the prevailing safety condition and safety performance improvements in terms of CSI.

Indexes

$X_i \in \{1,2 \dots \dots . I\} = index\ for\ the\ safety\ issue\ types$

Model Parameters

$Imp\ (X_i): Improvement\ accounted\ when\ the\ issue\ type\ X_i\ is\ treated\ in\ a\ given\ road$

$CSI_i = Initial\ CSI\ of\ the\ road$

$CSI_z = Minimum\ CSI\ allowed\ for\ a\ given\ road$

$B = Available\ budget$

$C_i = Cost\ to\ treat\ the\ selected\ safety\ issue\ X_i$

Decision Variable

$$U_i = \begin{cases} 1, & if\ the\ safety\ issue\ type\ X_i is\ selected\ to\ be\ treated\ in\ the\ selected\ road \\ 0, Otherwise & \end{cases}$$

Objective Function

$$\text{Minimize } (\mathbf{CSI_i} - \textstyle\sum_{\mathbf{i=1}}^{\mathbf{I}} \mathbf{Imp}(\mathbf{X_i})\ \mathbf{x}\ \mathbf{U_i}) \qquad 5.6$$

Subjected to

$$\textstyle\sum_{\mathbf{i=1}}^{\mathbf{10}} \mathbf{C_i}\, \mathbf{U_i}\ \leq \mathbf{B} \qquad 5.7$$

$$CSI_z > 50$$

IMP (X_i), CSI_i, CSI_z, B, $C_i > 0$

Overall safety condition of the selected road is expressed by the objective function.

U_i is in the binary for, which directs the decision makers towards to select or not to select a particular issue type to be treated.

X_i represents the safety performance improvement adjacent to each safety issue after treating is undergone.

5.5.2 Illustrative Example to Demonstrate the Approach

This section provides an illustrative example to provide a better understanding about the application developed in this section.

Two individual projects are considered in this example that are having initial CSIs of 320 and 241. The projects are considered for the treatment implementation based on the assumption that treatments are carried out for the same period when the budget is allocated to. The model selects the most important safety issues to be treated based on the treatments applicable for each issue and cost of respective treatments. The safety performance improvement capability of each treatment will vary on the existing conditions of the safety issues i.e., up to what extent the issues can be treated. Cost estimations of the proposed treatment schemes were selected according to findings of [69], Highway Schedule of Rates [70], and based on the knowledge of local construction practices. The base values of the costs used for the analysis are illustrated in ANNEX 0.

Table 5.21 summarizes the issue types considered along with possible treatment strategies.

Table 5.22, Table 5.23, Table 5.24, and Table 5.25 summarize the treatment schemes proposed by the model. Details of the initial CSI of the prevailing issue types, the improvement when applying treatment for each issue, the cost of treatment for each issue and the decision provided by the model, and respective safety performance improvements are presented there.

Table 5.21. Road safety issues and possible treatments

Issue Type	Safety Issue	Possible Safety Treatments
1	Lack of signage, road markings at intersections	Sight distance improvement Lane marking Installing warning signs Providing pedestrian facilities Removing roadside objects
2	Poor visibility at Access Roads	Sight distance improvement Lane marking Installing warning signs Removing roadside objects
3	Limited Roadside Space Availability	Clearing roadside vegetation Removing roadside objects
4	Road alignment, Sight distance Issues, and Lack of Warning signs at Curves	Sight distance improvement Installing warning signs Removing roadside objects Geometrical improvements Improving side friction Superelevation improvement

5	Inadequate Pedestrian Facilities near Schools, Town Areas	Sight distance improvement Installing warning signs Removing roadside objects Providing pedestrian facilities
6	Issues at Railroad Crossings	Sight distance improvement Providing rail crossing hardware and warning system
7	Roadside Vertical Drops – Unprotected Steep Roadside Slope	Installing guardrails Geometrical improvements Installing warning signs Measures to increase the distance between the road edge and slope Increasing lane/ shoulder width (if applicable)
8	Unprotected Bridges and Culverts	Installing warning signs Increasing lane/ shoulder width (if applicable) Installing guardrails
9	Open Drains	Providing drain covers

Table 5.22. Initial Conditions of Road 1

Road 1						
Initial CSI 320	Total Cost (LKR'1000) 2447.2					
Issue Type	1	2	3	4	5	9
Initial CSI of issue	60	133	34	30	47	16
Imp (Xi)	18	53	10	12	14	5
Cost (LKR '1000)	988	285	190	114	760	205.2

Table 5.23. Treatment schemes for Road 1

Budget (LKR '1000)	Issues to be treated	Final CSI
0	None	320
950	2,3,4,9	240
1425	2,3,4,5	231
1900	1,2,3,4,9	222
2375	1,2,3,4,5	213

Table 5.24. Initial Conditions of Road 2

Road 2						
Initial CSI 241	Total Cost (LKR '000) 2076.7					
Issue Type	1	2	3	4	5	9
Initial CSI of issue	54	81	12	54	32	8
Imp (Xi)	5.2	0.9	0.55	1.2	2	1.08
Cost (LKR '1000)	988	285	95	114	760	205.2

Table 5.25. Treatment schemes for Road 2

Budget (LKR '1000)	Issues to be treated	Final CSI
0	None	241
950	2,3,4,5	165
1425	2,3,4,5,9	157
1900	1,2,3,4,5	149

Figure 5.14 demonstrates the reduction of CSI according to different budget levels on both roads.

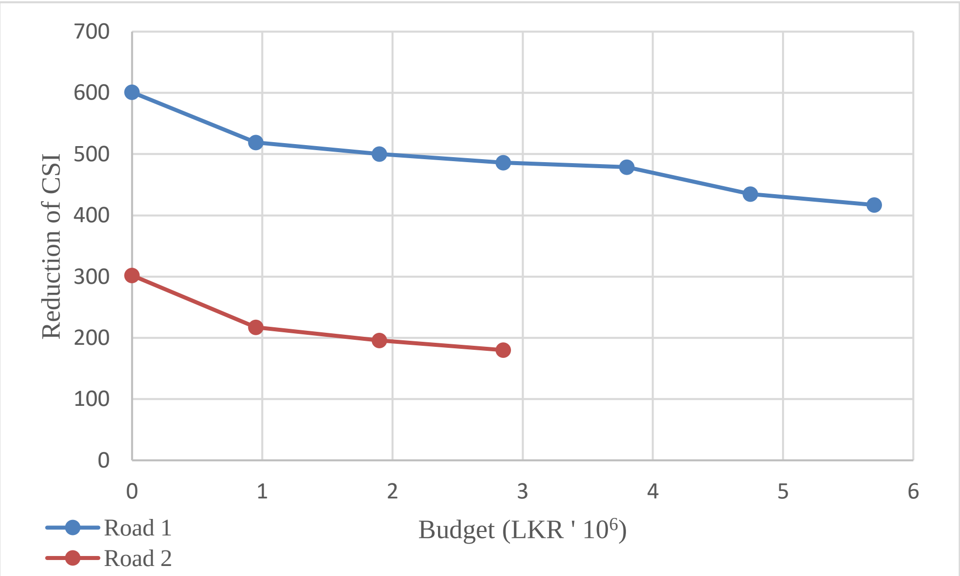


Figure 5.14. Reduction of CSI according to different budget levels

This approach is beneficial when carrying out sensitivity analyses for the future endeavors. Sensitivity analysis is very important because the potential for budget allocations can be exposed to uncertainties. The cost used in the model is sometimes an estimated value. Safety performance improvements can sometimes be approximated and there is an uncertainty related to probable changes in the allocated budgets as well.

This model is initially developed with a single-period budget allocation consideration. This model can further be calibrated concerning the uncertainties that may have arisen when considering multi-period budget allocations such as inflation, discount rates, traffic growth rates, and crash growth rates.

Also, this model addresses road conditions, social and environmental parameters related to rural low-volume roads in developing countries. Therefore, the model can be further calibrated as it addresses the above parameters in developed countries and / or urban environments in order to use under such conditions.

5.6 Future Avenues Coupled with the Proposed Methodology

5.6.1 Self-Explaining Roads

In self-explaining roads, road user's expectations and understanding of safe and appropriate behaviour is implicit. That is designing a road environment that promotes safe and appropriate road user behaviour due to its inherent design. This is difficult to achieve when projects are delivered on a project-by-project basis, so adoption of a network-wide approach facilitates achievement of this principle.

Difference between a project-by-project plan and a network-wide safety plan is shown below in Table 5.26

Table 5.26. A comparison between project-by-project evaluation and network-wide evaluation

Project-by-project basis	Network-wide
Best outcome for project budgets	Best outcome for the network
Standard redecided on projects	Standards sets once for function
Inconsistence/unsuitable for user	Consistent for user (self-explain)
PM/ designer role influence over time	Sustainable

5.6.2 Safe System

The Safe System approach is regarded as the best international road safety practise. A safe system provides an outcome whereby death and serious injury are virtually eliminated amongst users of the road system. Reducing the potential conflicts between road users and aiming to provide a forgiving roadside for errant vehicles are the main principles of a safe system.

The safe system treatment hierarchy provides a framework for the implementation for the key risk types, e.g., run-off-road, head-on. By adopting a safe system approach, road authorities get the provision to carry out consistent developments based on geometric standards and the safe system hierarchy.

5.6.3 Road Function and Movement and Place Framework

Roads and streets can perform multiple functions – facilitating the movement of people, while also functioning as a place (i.e., a destination in itself) and/or providing access to properties and land uses adjacent to the road. How a road should be managed can be determined by properly defining the function of the road.

The movement and place framework demonstrates the priorities of movement by road users across the network. The framework enables more effective management of infrastructure and operational issues to prioritise the road user’s journey needs, reduce potential user conflicts and facilitate safe and timely journeys with minimum disruption.

When considering the type of road for evaluation, the movement and place framework provides a useful way to consider the road cross-section and how the different road user requirements can be balanced in determining how any cross-section component or treatment may address network objectives.

6 CONCLUSION

This study proposes a simplified and less data-intensive methodology to evaluate safety performance of low-volume road in developing countries. One of the major limitations that the developing countries currently experience is the lack of accurate crash and traffic data. The methodology proposes in this study overcomes those limitations. Based on the non-subjective methodology proposed in this study, any auditor can carry out a road safety audit on the desired road or the network and evaluate the safety performance. Ten general safety issue types were identified from the safety audits. From the identified safety issue types, Issues at horizontal and vertical curves have affected the greatest number of fatal crashes. Lack of signage, road markings at intersections have affected the greatest number of grievous and non-grievous crashes, as well as in total covering all types of crashes.

One of the major steps of this study was developing the Cumulative Safety Index (CSI). CSI is used to evaluate the safety performance of a road or risk of a particular safety issue. CSI is calculated through the findings of safety audits. The study further explored on different attributes that affect the identified safety issues. The proposed criteria to calculate the CSI in this study is totally based on the attributes impacting individual safety issues. The impact of attributes is evaluated using three risk parameters i.e., exposure, probability, and severity. This study proposed a ranking system to evaluate the impact of attributes based on the iRAP fact sheets, local knowledge, and best available literature. When comparing the CSI of identified issue types, it was identified that although safety issues at intersections have affected the most numbers of crashes, its CSI is not the highest. The main reason for this is although CSI could address the prevailing safety risk, it does not address the magnitude of the crashes. Therefore, use of CSI as a quantified parameter to evaluate the safety performance is validated based on the Equivalent Property Damage Only (EPDO) factor. A stepwise linear regression was carried out to identify the correlation between CSI and EPDO. The analysis identified six significant safety issue types to determine EPDO using CSI. The R-squared value for the correlation between CSI and EPDO was obtained as 0.96 while the adjusted R^2 was obtained to be 0.95. Once the model was obtained, Root Mean Square Error (RMSE) was calculated to measure the fit of the estimated EPDO value to the data set. The correlation between the estimated and actual EPDO value was obtained to be 0.96 while the RMSE was obtained as 5.04.

Based on the developed framework for safety performance evaluations, two applications were proposed. The first application was to incorporate road network safety performance at network-level pavement management systems in rural roads. CSI represents the safety risk of the considered road network. EPDO factor represents the magnitude of the road crashes. The CSI values are incorporated in the optimization model, which also considers the pavement condition characterized by roughness. A multi-objective optimization approach was adopted to combine both aspects, i.e., maximizing pavement condition and minimizing safety risk within the given budget constraints. Results show that a reasonable level of road pavement condition improvements can be obtained at a given budget level while ensuring relevant safety improvement schemes are implemented. Although single-objective optimization results in more individual improvements than multi-objective optimization, multi-objective optimization provides more beneficial and realistic outcomes under available budgets. One of the major shortcomings at present is the limited analytical tools available to highway agencies at the rural level to determine budget allocations for projects related to pavement maintenance and safety. This application helps road agencies to assess budget requirements to meet key performance goals for pavement conditions and safety performance. Moreover, it provides a very important planning level tool for considering the safety aspects of network level pavement management in rural road networks. Other enhancements may include the addition of other risk factors, such as surface condition, and the improvement of grading criteria with analytical models to allow risk levels to be assessed more consistently. As part of the road asset management plan, the model can be easily expanded to set crash rate reduction targets and can be an important analytical component for safety-related fund approvals.

The other application is a linear programming model to identify the safety issues that have the highest potential to improve the safety performance of a given road subjected to the availability of funding. Authorities and road agencies can allocate the available funding more effectively as it helps to prioritize the safety issues that require treatments. The objective function is designed as it improves the safety performance of a selected project limited to the allocated budget. In this application as well, the road safety performance is evaluated by the Cumulative Safety Index (CSI), which is calculated based on the risk parameters of existing safety issues on the selected road.

This model guides the decision maker about choosing / not choosing a type of safety issues to be considered for treatment based on the existing budget and reducing safety risk. It is achieved through binary decision variable included in the objective function and before and after CSI values of the road. Another advantage of this application is, this focuses on the safety issues more precisely rather than in a multi-objective approach. Therefore, this application can be adopted when the concern is to improve only the safety performance of a road.

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PUBLICATIONS

Title	Published in	Category	Rank Indicator
A Framework for Selecting Safety Treatments for Rural Roads	International Conference on Road and Airfield Pavement Technology (Proceedings are published in Lecture Notes in Civil Engineering) (2022)	Indexed Conference (Scopus)	
Incorporating road safety into rural road network pavement management	International Journal of Pavement Engineering (2021)	International Journal (Scopus Indexed)	Q1
A Framework to Incorporate Safety Performance for Low Volume Roads in Pavement Management Systems	Moratuwa Engineering Research Conference (2020)	Indexed Conference (Scopus)	
Incorporating Road Safety in Rural Road Network Level Pavement Management	Transport Research Board 100th Annual Meeting (2021)	International Conference	
Evaluation of causal factors related to accidents in low volume roads	International Conference on Road and Airfield Pavement Technology (2019)	International Conference	
Evaluating the Risk Factors in Fatal Accidents involving Motorcycle – Case Study on Motorcycle Accidents in Sri Lanka	Engineer - Journal of the Institution of Engineers, Sri Lanka (2019)	Supplementary Journal Publication (ESCI Indexed)	

ANNEX 01

Road Types in Sri Lanka			
Type	Class	Description	Administration
Expressways	E	Connecting major cities	Ministry of Highways and RDA
National Roads	A	Connecting major cities	Ministry of Highways and RDA
	B	Roads connecting major urban areas	
Provincial Roads	C	Major feeder roads	Ministry of provincial councils and PRDA
	D	Minor feeder roads	

ANNEX 02

Attribute	ANRAM consideration	Consideration in our method
Motorcycle flow	Considered	Not considered
Bike flow	Considered	Not considered
Number of lanes	1 2 3 4 or more 2 and 1 2 and 3	2 4
Operating speed of vehicles	30km/h – 150km/h in 5km/h intervals	30km/h – 60km/h in 10km/h intervals
Lane width	> 0 to < 2.75 ≥ 2.75 to < 3.25 ≥ 3.25	Consider the total paved length
Paved shoulder	None 0 to ≤ 1.0 1.0 to < 2.4 ≥ 2.4	
Shoulder rumble strips	Not present Present	Not considered
Curvature	Straight or gently curving (> 900 m radius) Moderate curvature (500 m to 900 m radius) Sharp curve(200 m and 500 m radius) Very sharp curve (<200m radius)	>900m 500m-900m 200m-500m 0m-200m

Quality of curve	Adequate Poor Not applicable	Not considered
Delineation	Adequate Poor	Considering improper delineation only
Grade	0 – < 4% 4 – < 5% 5 – < 7.5% 7.5 – < 10% > 10%	0% to < 7.5% 7.5% to < 10% >= 10%
Road surface condition	Good Medium Poor	Good Medium Poor
Land use	Undeveloped areas Farming and agricultural Residential Commercial Not Recorded Educational Industrial and manufacturing	Religious Residential Recreational Educational Commercial
Parking side friction	Low Medium High	Not considered
Pedestrian crossing facilities	Considered	Considered
Pedestrian crossing quality	Considered	Not considered
Bicycle facility	Considered	Not considered
Facilities for motorised two wheelers	Considered	Not considered
Access points	Commercial access Residential access None	Not considered
Distance to roadside severities	0 to <1.0m 1.0 to <5.0 5.0 to <10.0 >10.0	0<1m 1m<5m 5m<7M 7m<10m >=10m
Roadside severities - Objects	Safety barrier – metal Safety barrier – concrete Safety barrier – metal(motorcycle friendly) Safety barrier – wire rope Aggressive vertical face Upwards slope – (rollover gradient) Upwards slope – (no rollover gradient) Deep drainage ditch Downwards slope Cliff Tree > 10 cm	Safety barrier – metal Safety barrier – concrete Safety barrier – motorcycle friendly Safety barrier – wire rope Aggressive vertical face Upward slope (15^0-75^0) Upward steep slope (>75^0) Deep drainage ditch Downward slope Cliff (Unprotected) Tree (>=10cm diameter)

	Non-frangible sign/ post./pole ≥ 10 cm Non-frangible structure/bridge or building Frangible structure or building Unprotected barrier end Large boulders ≥ 20 cm high None	Non-frangible sign/post/pole (>=10cm diameter) Rigid Structures Frangible Structures Unprotected barrier end Large boulders (>=20cm tall)
Intersection type	Considered	Considered
Intersection quality	Considered	Not considered
Intersecting road volume	Considered	Considered AADT of the surveying road only
Median type	Considered	Not considered
Roadworks	Considered	Not considered
Skid resistance/grip	Sealed – adequate Sealed – medium Sealed – poor Unsealed – adequate Unsealed – poor	Sealed - adequate Sealed - medium Sealed – poor Unsealed - adequate Unsealed - poor
Street lighting	Considered	Not considered
Centreline rumble strips	Considered	Not considered
Service road	Considered	Not considered
Speed management/ traffic calming	Considered	Not considered
Differential speed limits	Considered	Not considered
Sight distance	Adequate Poor	Adequate Poor
Meets car spec	Considered	Not considered
Pedestrian fencing	Pedestrian fencing full 100m length Pedestrian fencing at pedestrian crossing No pedestrian fencing	Not considered
Pedestrian crossing facilities- side road	Grade separated facility Signalized with refuge Signalized without refuge Unsignalized marked crossing with refuge Unsignalized marked crossing without a refuge Refuge only No facility	Grade separated facility Marked crossing with a refuge Marked crossing without a refuge Refuge only No facility
Sidewalk provision	Not considered	Physical barrier Non-physical separation >3m Non-physical separation >1m Adjacent to traffic Paved Shoulder >1m

		Total shoulder >1 m Informal Path None and 0 < shoulder < = 1m
Intersection channelization	Considered	Not considered
Arrangement around 100m	Not considered	Presence of educational facilities Presence of bus stops Presence of alcohol sales establishments
Types of vehicles operated	Not considered	Considered
Pedestrian maneuver	Not considered	Crossing at crosswalks Walking against traffic Walking on Road If crossings are not provided Walking within traffic Darting into traffic
Road geometry	Not considered	Considered as straight or curve
Required speed reduction	Not considered	Considered
Depth to water bodies (if present)	Not considered	<5m 5m-10m 10-15m 15m-20m >20m
Nature of water flow (if present)	Not considered	Stream River
Depth of the drainage (if present)	Not considered	<1m >1m
Characteristics of the pavement edge	Not considered	Edge cracking present Edge drop-off present

ANNEX 03

Road: C 001

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Open Drains	Length of the ditch opening - (2)					Distance from outer shoulder edge to the ditch/drainage - (5)	Road Geometry - (2)	Lane and shoulder width - (2)			Depth of the drainage - (2)
	Roadside vertical drop	Segment Length (Length of road where user is exposed to the slope approximately) - (3)					Obstructions to the sight distance - (1)		Distance from outer shoulder edge to the side slope Approximately) - (5)	Road geometry - (2)	Lane and shoulder width - (2)	Unavailability of guardrails/ barriers - (3)

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	Segment Length - (1)					Sight Distance - (3)		Unavailability of warning signs - (3)	Lane and shoulder width - (2)		Presence of buildings and other fixed objects (Downward slope) - (3)
	Open drain	Length of the ditch opening - (2)					Distance from outer shoulder edge to the ditch/drainage - (5)	Road Geometry - (2)	Lane and shoulder width - (2)			Depth of the drainage - (2)
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves											

	Poor visibility at Access Roads						Not having stop ahead pavement markings - (3)	Sight Distance - (3)	Improper signage - (3)	Lane width -(3)		Presence of frangible or rigid structures - (2)
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	Segment Length - (2)					Sight Distance - (3)	Provided side friction - (1)	Unavailability of warning signs - (3)	Getting collided with a fixed object if the distance to the object is - (4)	Lane and shoulder width - (2)	Presence of building and other fixed objects (Tree) - (3)
	Poor visibility at Access Roads						Not having stop ahead pavement markings - (3)	Sight Distance - (1)	Improper signage - (3)	Lane width -(2)		Presence of frangible or rigid structures - (2)

Road: C 002

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Limited Roadside Space	AADT - (4)	Segment Length - (3)				Sight Distance - 1	Road geometry - 2	Lane and shoulder width - 4			Drainage ditch - 3
	Poor pedestrian facilities in town areas	AADT - 4	Lane width - 3				Inadequate notifications to drivers - 3	Sight Distance - 1	Pedestrian crossing facilities - 4	Sidewalk provision - 4		Pedestrian Manoeuvre - 4
	Limited Roadside Space	AADT - 3	Segment Length - 3				Sight Distance - 1	Road geometry - 2	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 3

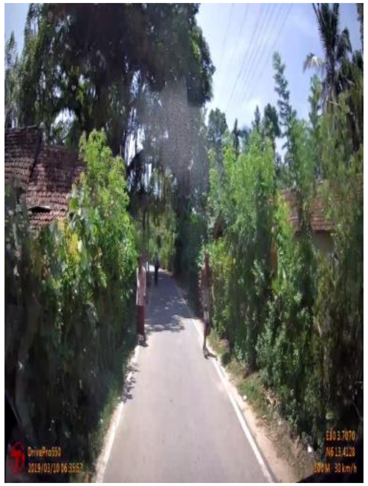
	Open Drains	AADT - 3	Length of the drain/ditch opening - 2				Distance from outer shoulder edge to the ditch/drainage - 4	Road geometry - 2	Lane and shoulder width - 3			Depth of the drainage (Approximately) - 2
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment length (Length of the curve approximately) - 1				Lane and shoulder width - 3	Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 3		Presence of buildings and other fixed objects - 4
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment length (Length of the curve approximately) - 1				Lane and shoulder width - 2	Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 3		Presence of buildings and other fixed objects - 4

	Poor visibility at Access Roads	AADT - 3					Not having stop ahead pavement markings - 3	Sight distance - 3	Lane width - 2			Presence of buildings and other fixed objects - 2
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment length (Length of the curve approximately) - 1				Lane and shoulder width - 2	Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 3		Presence of buildings and other fixed objects - 3

Road: C 003

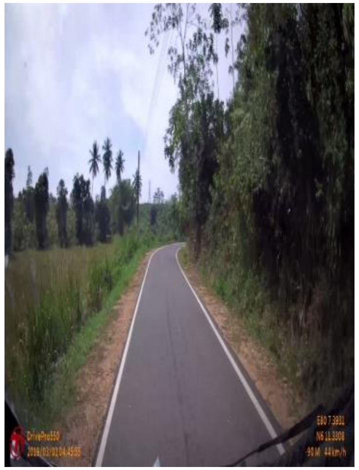
Location	Issue Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Lack of signage, road markings at intersections	AADT - 2					Not having stop ahead pavement markings - 3	Sight Distance - 1	Improper signage - 3	Intersection configuration - 2	Lane width - 1	Pedestrian Maneuver - 3
	Poor visibility at Access Roads	AADT - 2					Not having stop ahead pavement markings - 3	Sight Distance - 1	Improper signage - 3	Lane width - 1		Presence of buildings and other fixed objects - 2
	Poor Pedestrian Facilities near Schools, Town Areas	AADT - 2	Lane width where the pedestrians are exposed - 4				Inadequate notifications to drivers - 3	Sight distance - 1	Pedestrian crossing facilities - 4	Sidewalk provision - 4		Pedestrian Maneuver - 3

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 2	Segment length - 2				Sight distance - 1	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 4		Presence of buildings and other fixed objects - 4
	Poor Visibility at access roads	AADT - 2	Lane width where the pedestrians are exposed - 4				Not having stop ahead pavement markings - 3	Sight distance - 1	Improper signage - 3			Presence of buildings and other fixed objects - 4

	Limited roadside space availability	AADT - 2	Total length where there is a limited roadside space availability approximately - 3				Sight Distance - 3	Road geometry - 2	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 3
	Lack of signage, road markings at intersections	AADT - 2					Not having stop ahead pavement markings - 3	Sight Distance - 1	Improper signage - 3	Intersection configuration - 2	Lane width - 1	Pedestrian Maneuver - 3

Road: C 004

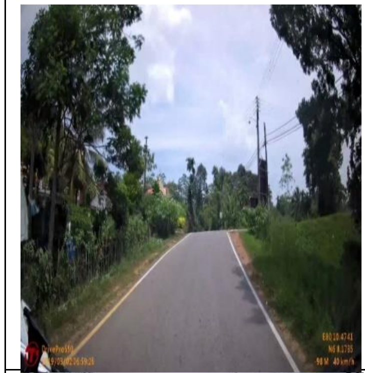
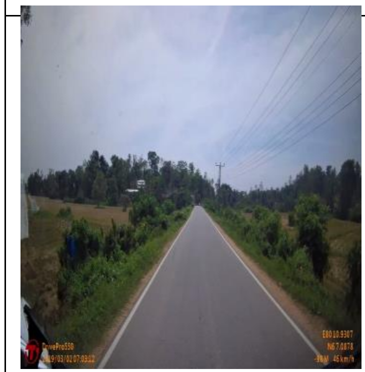
Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Limited Roadside Space Availability	AADT - 3	Total length where there is a limited roadside space availability approximately - 3					Sight Distance - 1	Road geometry - 2	Lane and shoulder width - 3		Presence of buildings and other fixed objects - 3
	Open Drains	AADT - 3	Length of the drain/ditch opening - 2				Distance from outer shoulder edge to the ditch/drainage - 5	Road geometry - 2	Lane and shoulder width - 3			Depth of the drainage (Approximately) - 2
	Lack of signage, road markings at intersections	AADT - 3					Not having stop ahead pavement markings - 3	Sight distance - 3	Intersection configuration - 2	Lane width - 1		Pedestrian Maneuver - 3

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length (Length of the cure approximately) - 2				Unavailability of warning signs - 3	Sight distance - 3	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 2
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length (Length of the cure approximately) - 2				Unavailability of warning signs - 3	Sight distance - 3	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 2
	Roadside vertical drops	AADT - 3	Segment Length (Length of the cure approximately) - 2				Sight distance - 3	Unavailability of warning signs - 3	Distance from outer shoulder edge to the side slope Approximately) - 4	Road geometry - 3	Lane and shoulder width - 3	Unavailability of guardrails/ barriers for a downward slope - 3

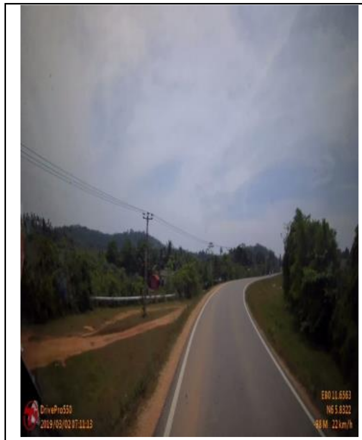
	Poor visibility at Access Roads	AADT - 3					Not having stop ahead pavement markings - 3	Unavailability of warning signs - 3	Improper signage - 3	Lane width - 1		Presence of buildings and other fixed objects - 2

Road: C 005

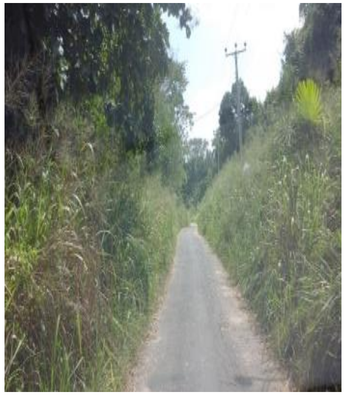
Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Poor Pedestrian Facilities near Schools, Town Areas	AADT - 4	Lane width where the pedestrian is exposed - 4				Inadequate notifications to drivers - 3	Sight Distance - 1	Pedestrian crossing facilities - 4	Sidewalk Provision - 3		Pedestrian Manoeuvre - 4

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length (Length of the cure approximately) - 2				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3		Presence of buildings and other fixed objects - 3
	Poor Pedestrian Facilities near Schools, Town Areas	AADT - 4	Lane width where the pedestrian is exposed - 4				Inadequate notifications to drivers - 3	Sight Distance - 1	Pedestrian crossing facilities - 4	Sidewalk Provision - 3		Pedestrian Manoeuvre - 4
	Road-Side Vertical Drops	AADT - 3	Length of road where user is exposed to the slope approximately - 2				Sight distance - 1	Unavailability of warning signs - 3	Distance from outer shoulder edge to the side slope Approximately - 4	Road geometry - 2	Lane and shoulder width - 3	Unavailability of guardrails/ barriers for a downward slope - 3

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length (Length of the cure approximately) - 3				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3		Presence of buildings and other fixed objects - 3
	Road-Side Vertical Drops	AADT - 3	Length of road where user is exposed to the slope approximately - 3				Sight distance - 1	Unavailability of warning signs - 3	Distance from outer shoulder edge to the side slope Approximately - 4	Road geometry - 2	Lane and shoulder width - 3	Unavailability of guardrails/ barriers for a downward slope - 3
	Road-Side Vertical Drops	AADT - 3	Length of road where user is exposed to the slope approximately - 3				Sight distance - 1	Unavailability of warning signs - 3	Distance from outer shoulder edge to the side slope Approximately - 4	Road geometry - 2	Lane and shoulder width - 3	Unavailability of guardrails/ barriers for a downward slope - 3

	Road-Side Vertical Drops	AADT - 3	Length of road where user is exposed to the slope approximately - 3				Sight distance - 1	Unavailability of warning signs - 3	Distance from outer shoulder edge to the side slope Approximately - 4	Road geometry - 3	Lane and shoulder width - 3	Unavailability of guardrails/ barriers for a downward slope - 3
	Poor visibility at Access Roads	AADT - 3					Not having stop ahead pavement markings - 3	Sight distance - 3	Improper signage - 3	Lane width - 1		Presence of buildings and other fixed objects - 2

Road: C 006

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Poor Visibility at access Roads	AADT - 2					Not having stop ahead pavement markings - 3	Sight distance - 3	Improper signage - 3	Lane width - 1		Presence of buildings and other fixed objects - 2
	Limited roadside space availability	AADT - 2	Total length where there is a limited roadside space availability approximately - 2				Not having proper lane markings - 2	Sight Distance - 3	Road geometry - 2	Lane and shoulder width - 4		Presence of buildings and other fixed objects - 3

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 2	Length of the cure approximately - 1				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 2	Lane and shoulder width - 4		Presence of buildings and other fixed objects - 3
	Poor Pedestrian Facilities near Schools, Town Areas	AADT - 2	Lane width where the pedestrian is exposed - 2				Inadequate notifications to drivers - 3	Sight Distance - 3	Pedestrian crossing facilities - 4	Sidewalk Provision - 4		Pedestrian Manoeuvre - 3
	Unprotected Bridges and Culverts	AADT - 2	Length of the culvert/bridge - 1				Improper signage - 3	Lane width - 3				Nature of the water flow - 2
	Lack of signage, road markings at intersections	AADT - 2					Not having stop ahead pavement markings - 3	Sight Distance - 3	Improper signage - 3	Intersection configuration - 2	Lane width - 3	Pedestrian Maneuver - 3

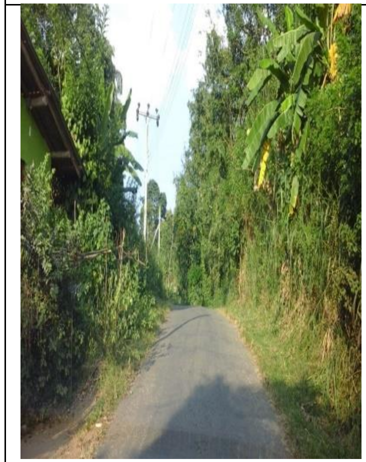
Road: C007

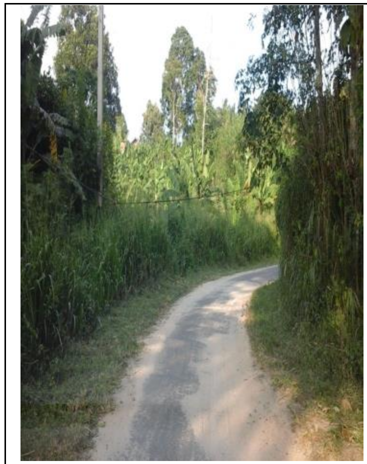
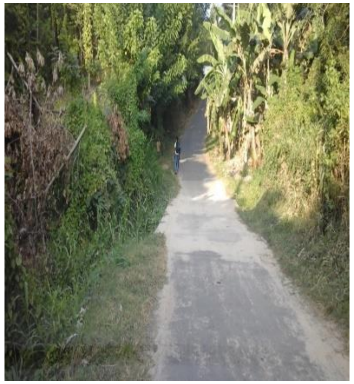
Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Lack of signage, road markings at intersections	AADT - 2					Not having stop ahead pavement markings - 3	Sight distance - 3	Improper signage - 3	Intersection configuration - 2	Lane width - 1	Pedestrian Maneuver - 4
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 2	Segment Length - 1				Sight distance - 3	Unavailability of warning signs - 3	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 3

	Poor visibility at Access Roads	AADT - 2					Not having stop ahead pavement markings - 3	Sight distance - 3	Improper signage - 3	Lane width - 2		Presence of buildings and other fixed objects - 2
	Unprotected Bridges and Culverts	AADT - 2	Length of the culvert/bridge - 2				Improper signage - 3	Lane width - 1				Depth to the water body - 1

	Poor visibility at Access Roads	AADT - 2					Not having stop ahead pavement markings - 3	Sight distance - 3	Improper signage - 3	Lane width - 2		Presence of buildings and other fixed objects - 2
	Unprotected Bridges and Culverts	AADT - 2	Length of the culvert/bridge - 1				Improper signage - 3	Lane width - 1				Depth to the water body - 1

Road: C 008

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Lack of signage, road markings at intersections	AADT - 3					Not having stop ahead pavement markings - 3	Sight distance - 3	Improper signage - 3	Intersection configuration - 2	Lane width - 2	Pedestrian Maneuver - 4
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Length of the cure approximately - 2				Sight distance - 3	Improper signage - 3	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 3

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Length of the cure approximately - 2				Sight distance - 3	Improper signage - 3	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 3
	Unprotected Bridges and Culverts	AADT - 3	Length of the culvert/bridge - 1				Improper signage - 3	Lane width - 2				Depth to the water body - 2

	Lack of signage, road markings at intersections	AADT - 3					Not having stop ahead pavement markings - 3	Sight distance - 3	Improper signage - 3	Intersection configuration - 2	Lane width - 2	Pedestrian Maneuver - 4

Road: C 009

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Limited Road Side Space Availability	AADT - 3	Segment Length - 2				Sight Distance - 3	Road geometry - 3	Lane and shoulder width - 4			Presence of buildings and other fixed objects - 3
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 4		Presence of buildings and other fixed objects - 3

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 3				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3		Presence of buildings and other fixed objects - 3
	Road Side Vertical Drops – Unprotected Steep Road Side Slope	AADT - 3	Segment Length - 3				Sight Distance - 3	Unavailability of warning signs - 3	Distance from outer shoulder edge to the side slope Approximately - 4	Road geometry - 3	Lane and shoulder width - 3	Unavailability of guardrails / barriers for a, downward slope -3

	Poor visibility at Access Roads	AADT - 3					Not having stop ahead pavement markings - 3	Sight Distance - 3	Improper signage - 3	Lane width - 2		Presence of buildings and other fixed objects - 4
	Road Side Vertical Drops	AADT - 3	Segment Length - 3				Sight Distance - 3	Unavailability of warning signs - 3	Distance from outer shoulder edge to the side slope Approximately - 4	Road geometry - 3	Lane and shoulder width - 3	Unavailability of guardrails / barriers for a, cliff -4
	Road Side Vertical Drops	AADT - 3	Segment Length - 2				Sight Distance - 3	Unavailability of warning signs - 3	Distance from outer shoulder edge to the side slope Approximately - 4	Road geometry - 3	Lane and shoulder width - 3	Unavailability of guardrails / barriers for a, cliff -4

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3		Presence of buildings and other fixed objects - 3

Road: C 010

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Poor visibility at Access Roads	AADT - 3					Not having stop ahead pavement markings - 3	Sight Distance - 3	Improper signage - 3	Lane width - 2		Types of vehicles operated mostly - 3

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 4		Presence of buildings and other fixed objects - 3
	Limited Roadside space availability	AADT - 3	Segment Length - 2				Sight Distance - 3	Road geometry - 3	Lane and shoulder width - 4			Presence of buildings and other fixed objects - 3
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3		Presence of buildings and other fixed objects - 3

	Limited Roadside space availability	AADT - 3	Segment Length - 2				Sight Distance - 3	Road geometry - 3	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 3
	Limited Roadside space availability	AADT - 3	Segment Length - 3				Sight Distance - 3	Road geometry - 2	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 3
	Poor pedestrian facilities near school areas	AADT - 3	Lane width where the pedestrian is exposed - 3				Inadequate notifications to drivers - 3	Sight Distance - 3	Pedestrian crossing facilities - 4	Sidewalk Provision - 4		Pedestrian Manoeuvre - 4
	Limited Roadside space availability	AADT - 3	Segment Length - 2				Sight Distance - 3	Road geometry - 3	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 3

Road: C 011

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Limited Road Side Space Availability	AADT - 2	Segment Length - 3				Sight Distance - 1	Road geometry - 3	Lane and shoulder width - 4			Presence of buildings and other fixed objects - 5
	Road Side Vertical Drops – Unprotected Steep Road Side Slope	AADT - 2	Segment Length - 3				Sight Distance - 1	Unavailability of warning signs - 3	Distance from outer shoulder edge to the side slope Approximately - 4	Road geometry - 3	Lane and shoulder width - 4	Unavailability of guardrails/ barriers for a, cliff -4
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 2	Segment Length - 2				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 4		Presence of buildings and other fixed objects - 3
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 2	Segment Length - 2				Sight Distance - 3	Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 4		Presence of buildings and other fixed objects - 3

	Poor Visibility at access roads	AADT - 2					Not having stop ahead pavement markings - 3	Sight Distance - 3	Improper signage - 3	Lane width - 2		Types of vehicles operated mostly - 3

Road: C 012

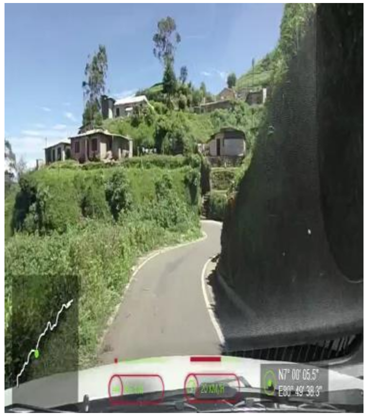
Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Poor Pedestrian Facilities near Schools, Town Areas	AADT - 4	Lane width where the pedestrian is exposed - 2				Inadequate notifications to drivers - 3	Sight distance - 1	Pedestrian crossing facilities - 4	Sidewalk provision - 4		Pedestrian Manoeuvre - 4
	Excessive Pavement Edge Drop Offs	AADT - 4	Length of the distressed road section - 2				Road geometry - 2	Characteristics of the pavement edge - 3	Lane and shoulder width - 2			Presence of buildings and other fixed objects - 4

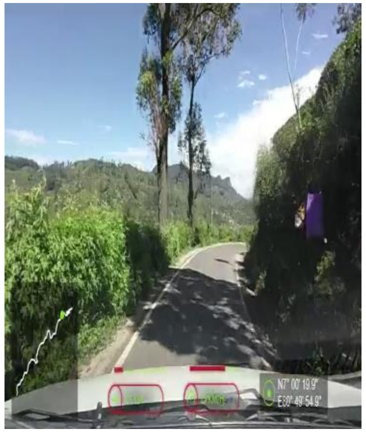
	Open Drains	AADT - 2	Length of the drain/ditch opening - 2				Unavailability of warning signs - 3	Distance from outer shoulder edge to the ditch/drainage - 5	Road geometry - 2	Lane and shoulder width - 3		Types of vehicles operated mostly - 3
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 2	Segment Length - 2				Unavailability of warning signs - 3	Getting collided with a fixed object if the distance to the object is - 4	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 3
	An intersection is in the vicinity of the vertical curve	AADT - 2					Not having stop ahead pavement markings - 3	Obstructions to the sight distance - 3	Improper signage - 3	Intersection configuration - 2	Arrangement around 100m - 1	Presence of buildings and other fixed objects - 4
	Open Drains	AADT - 2	Length of the drain/ditch opening - 2				Unavailability of warning signs - 3	Distance from outer shoulder edge to the ditch/drainage - 5	Road geometry - 2	Lane and shoulder width - 3		Types of vehicles operated mostly - 3

	Limited roadside space availability	AADT - 2	Segment Length - 2				Not having proper lane markings - 2	Obstructions to the sight distance due to growth of vegetation - 3	Road geometry - 3	Lane and shoulder width - 4		Types of vehicles operated mostly - 3
	Poor visibility at access roads	AADT - 2					Not having stop ahead pavement markings - 3	Obstructions to the sight distance - 3	Improper signage - 3	Lane width - 2		Presence of buildings and other fixed objects - 2

Road: C 013

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Poor pedestrian facilities at town area	AADT - 4	Lane width where the pedestrian is exposed - 2				Inadequate notifications to drivers - 3	Sight distance - 1	Pedestrian crossing facilities - 4	Sidewalk provision - 4		Pedestrian Manoeuvre - 4
	Limited roadside space availability	AADT - 3	Segment Length - 2					Sight Distance - 3	Road geometry - 3	Lane and shoulder width - 4		Types of vehicles operated mostly - 3

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Unavailability of warning signs - 3	Getting collided with a fixed object if the distance to the object is - 4	Lane and shoulder width - 3	Sight distance -3		Presence of buildings and other fixed objects - 3
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Unavailability of warning signs - 3	Getting collided with a fixed object if the distance to the object is - 4	Lane and shoulder width - 3	Sight distance -3		Presence of buildings and other fixed objects - 3

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Unavailability of warning signs - 3	Getting collided with a fixed object if the distance to the object is - 4	Lane and shoulder width - 3	Sight distance -3		Presence of buildings and other fixed objects - 3

Road: C 014

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 2	Segment Length - 2				Unavailability of warning signs - 3		Lane and shoulder width - 3	Sight distance -3		Types of vehicles operated mostly - 2

	Excessive Pavement Edge Drop Offs	AADT - 2	Length of the distressed road section - 2				Road geometry - 3	Characteristics of the pavement edge - 3	Lane and shoulder width - 3			Types of vehicles operated mostly - 2
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 2	Segment Length - 2				Unavailability of warning signs - 3		Lane and shoulder width - 3	Sight distance -3		Presence of buildings and other fixed objects - 2
	Excessive Pavement Edge Drop Offs	AADT - 2	Length of the distressed road section - 2				Road geometry - 2	Characteristics of the pavement edge - 3	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 2
	Excessive Pavement Edge Drop Offs	AADT - 2	Length of the distressed road section - 2				Road geometry - 2	Characteristics of the pavement edge - 3	Lane and shoulder width - 3			Presence of buildings and other fixed objects - 2
	Excessive Pavement Edge Drop Offs	AADT - 2	Length of the distressed road section - 2				Road geometry - 2	Characteristics of the pavement edge - 3	Lane and shoulder width - 1			Presence of buildings and other fixed objects - 2

	Lack of signage, road markings at intersections	AADT - 4					Not having stop ahead pavemen t marking s - 3	Obstruct ions to the sight distance - 3	Imprope r signage - 3	Intersect ion configur ation - 2	Lane width - 2	Presence of building s and other fixed objects - 4
	Lack of signage, road markings at intersections	AADT - 2					Not having stop ahead pavemen t marking s - 3	Obstruct ions to the sight distance - 3	Imprope r signage - 3	Intersect ion configur ation - 2	Lane width - 2	Types of vehicles operated mostly - 3
	Lack of signage, road markings at intersections	AADT - 4					Not having stop ahead pavemen t marking s - 3	Obstruct ions to the sight distance - 3	Imprope r signage - 3	Intersect ion configur ation - 2	Lane width - 2	Presence of building s and other fixed objects - 4

Road: C 015

Location	Issues Prevailing	Exposure					Probability					Severity
		Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 1
	Open Drains	AADT - 3	Length of the drain/ditch opening - 2				Unavailability of warning signs - 3	Distance from outer shoulder edge to the ditch/drainage - 5	Road geometry - 2	Lane and shoulder width - 3		Types of vehicles operated mostly - 3
	Lack of signage, road markings at intersections	AADT - 3					Not having stop ahead pavement markings - 3	Obstructions to the sight distance - 3	Improper signage - 3	Intersection configuration - 2	Lane width - 1	Presence of buildings and other fixed objects - 4

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3	Sight distance -3		Types of vehicles operated mostly - 2
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3	Sight distance -3		Types of vehicles operated mostly - 3

	Lack of signage, road markings at intersections	AADT - 3					Not having stop ahead pavement markings - 3	Obstructions to the sight distance - 3	Improper signage - 3	Intersection configuration - 2	Lane width - 1	Types of vehicles operated mostly - 3
	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3	Lane and shoulder width - 3	Sight distance -3	Presence of buildings and other fixed objects - 4

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3	Lane and shoulder width - 3	Sight distance -3	Presence of buildings and other fixed objects - 3
	Road Side Vertical Drops	AADT - 3	Segment Length - 2				Unavailability of warning signs to warn drivers - 3	Sight distance - 3	Distance from outer shoulder edge to the side slope - 4	Road geometry - 3	Lane and shoulder width - 3	Unavailability of guardrails for a cliff -5
	Road Side Vertical Drops – Unprotected Steep Road Side Slope	AADT - 3	Segment Length - 2				Unavailability of warning signs to warn drivers - 3	Sight distance - 3	Distance from outer shoulder edge to the side slope - 4	Road geometry - 3	Lane and shoulder width - 3	Unavailability of guardrails for a cliff -5

	Road alignment, Sight distance Issues and Lack of Warning signs at Curves	AADT - 3	Segment Length - 2				Unavailability of warning signs - 3	Getting collided with a fixed object - 4	Lane and shoulder width - 3	Lane and shoulder width - 3	Sight distance -3	Presence of buildings and other fixed objects - 4
	Poor pedestrian facilities near the school	AADT - 4	Lane width where the pedestrian is exposed - 4				Inadequate notifications to drivers - 3	Sight distance - 1	Pedestrian crossing facilities - 4	Sidewalk provision - 4		Pedestrian Manoeuvre - 4

	Poor pedestrian facilities near the school	AADT - 4	Lane width where the pedestrian is exposed - 3				Inadequate notifications to drivers - 3	Sight distance - 1	Pedestrian crossing facilities - 4	Sidewalk provision - 4		Pedestrian Manoeuvre - 4

ANNEX 04

Item	Unit	Price (LKR)
Edge Line	m	1140
Centerline	m	1140
Guardrail	m	19000
Pedestrian warning sign	sign	13300
Curve warning sign	sign	12350
Signs at intersections	sign	12350
Chevron signs	sign	6100
Railway crossing warning sign	sign	9500
Roadside clearing and sight distance improvements	100m	25000
Pedestrian crossing marking	item	142500
Sidewalk construction	sqm	9500
Cover slabs	sqm	3500
Pavement edge correction	sqm	7000