Evaluation of Safety Performance in Provincial Road Network

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***Abstract*—Provincial roads in Sri Lanka considered as class C and D which serves connection between urban and rural to ensure the social and economic necessities. Even though it is a developing country, the majority of these roads are in poor condition, and safety concerns are minimal. The lack of accurate accident data and the lack of a road condition monitoring program are frequently mentioned as factors. This study proposes a methodology to determine safety index to evaluate safety performance in provincial roads in Sri Lanka. Cumulative safety index is computed with the fundamental elements such as exposure, probability and consequences. Computed Cumulative Safety Index is compared with the available crash data. All severity levels are translated to a single scale termed Equivalent Property Damage Only (EPDO) to validate the results. Once the actual EPDO is calculated, multiple regression analysis tool is used to determine the relationship between actual EPDO and computed CSI composed of identified safety issues in the road segments. Actual EPDO and Estimated EPDO were compared using Root Mean Square Error (RMSE)**

Keywords— Provincial Road, Safety Index, Equivalent property Damage Only, Root Mean Square Error

I. INTRODUCTION

Roads are the presiding mode of transport in Sri Lanka where 90% of passengers and 98 % of freights are accomplished by road. Sri Lanka include 115,900 km of road network which is classified into national, provincial, and local roads according to functionality and management responsibility. The Provincial roads consisting of 15,500km in Sri Lanka which are administrated by provincial council and provincial road development authorities[1]. Provincial roads connect residential and business regions to the rest of the country's highway system. They are especially important in rural and urban regions for ensuring community access to social and economic necessities. Nearly 16% road network accounts as provincial road in total road network system[1].

The provincial road network in Northern Province are managed by Northern Provincial Road Development Department (NPRDD) where around 90% of roads are in poor condition without proper maintenance. Northern province provincial roads comprises 855 km of gravel roads and 1,105 km of metaled and tarred roads, with about 60 bridges and 4,000 culverts [1].

Road accidents are serious public issue, steadily increase with time in Sri Lanka and significant number of deaths are recorded in last two decades. Based on the study from 2010 to 2013, number of accident per year is over 40,887and fatalities per day is around six [2]. Northern provinces are improved by economically after the civil war which leads the increase of road users and increase in rate of motorization which results the traffic accident increase drastically.

This study presents an evaluating method for safety performance in provincial road. Safety performance is evaluated with the safety index, tabulated based on function of exposure, severity and probability. Objective of the safety index is to compute a results with the quantifiable manner to rank the high risk location based on the safety issue types[3]. Despite diverse of safety issues in provincial road network, geometric safety issues are only focused for this study.

II. RESEARCH BACKROUND

A. Road Accident Caused by Road Infrastructure Safety Issues

With the rapid motorization that has occurred in Sri Lanka in recent years, it is expected that traffic on these roads would increase significantly in the future. Vehicles such as motorcycles and three-wheelers have increased remarkable percentages by accident severity which were computed from the police record form called 297B. Multi vehicle crashes were occurred more in low volume roads. From the analysis, it was concluded, motorcycles were one of the most commonly involved vehicles

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in low-volume traffic accidents. In Sri Lanka, motorcycle usage has risen dramatically in recent years. The second greatest percentage of casualties were three-wheelers. Pedestrians were the third most common element type involved in low-volume traffic incidents. In Sri Lanka, the accident investigation method does not always precisely identify any relevant highway attribute that may have led to the accident. Roadway-related elements were recognized as cause factors in less than 1% of all incidents that occurred in 2017 [4]. Word health organization information, from 2001 to 2013, the number of road accidents worldwide increased. According to the WHO, road accidents kill over 1.2 million people each year, making them the leading cause of death among those aged 15 to 29 [5]. Risk of road side accidents are measured with the road infrastructure features of highway and roadside design elements. Based on the categorization of affecting factors, roadway factors 3% in the accident risk. Despite the improper engineering variable directly cause accident, features of road environment misleads a road user, resulting in human errors[6].

B. *Identification of safety issues*

Team approach performs a road safety audit, which was a methodical technique to identifying the safety issues exist on low volume road (LVR). The team travels on roadways where it is necessary to identify safety hazards. Issues that arise on LVRs had been classified into 10 broad kinds in a research undertaken by authors. Those are, improper signage and road marking, limited roadside space, alignments such as horizontal and vertical curves, poor pedestrian facilities in high pedestrian activity area, rail crossing issues, vertical drops, unprotected culverts and bridges and open drains[7]. Safety issues incorporate with the road accidents under major categories of safety issues which are summarized. Geometry design, pavement condition, safety hardware and road side features are the major categories of safety issues [8,9,10].

C. *Safety Evaluation and validation method*

Safety performance of roads were evaluated in different ways in several highway agencies [8,10,11,7]. Function of exposure, probability and consequences were used to develop Road Safety Risk Index (RSRI). Exposure is the measure of road users to specific safety issues where the exposure was evaluated according to the traffic volume in safety issue location. When investigating a specific corridor, exposure were calculated relative to the corridor using traffic volume statistics both rural and urban environment. Probability was calculated for the measure of the chance of collision due to the safety issue. A guideline was developed to evaluate probability where four point score was provided for each road features from zero to three. Consequence was calculated in a quantifiable measure of severity level. Vehicle speed, potential for speed differential, mix of vehicle sizes, and roadside hazards were influenced on consequence. Thresholds vehicle speed limit was considered in the formulation of consequences where four point score was provided for each road features from zero to three. Accident data were used to illustrate the validity of the estimated road safety risk index. The Potential for Improvement (PFI) indicator is defined as the difference between the current collision frequency and the predicted collision frequency at a certain location. . A viable collision prediction model was used to obtain the predicted collision frequency, which is then refined using the Empirical Bayes (EB) approach**.** The approach used to construct the collision prediction model was called Generalized Linear Modeling (GLIM). The agreement level between the RSRI and the PFI was determined using the Spearman rank correlation coefficient. Both the RSRI and the potential for improvement (PFI) were used to rank the sites, with the Spearman correlation confirming agreement at a 99 percent significance level [3].

Safety performance in Low Volume Roads in Sri Lanka were evaluated with Cumulative Safety Index (CSI) and pavement condition evaluated using International Roughness Index (IRI). In the performance of Cumulative Safety Index, each detected safety issues was graded on a 1–5 scale on three safety risk parameters: exposure, probability, and severity. The CSI values were then used to assess the association between the accident number on a certain road section and the CSI value. The computed CSI values produced for the road segments were compared with crash data available for the same road segments to validate CSI. Various severity levels which included fatal, grievous non grievous of crashes were combined into a single scale of Equivalent Property Damage (EPDO) alone[11].

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III. METHODOLOGY

A. Introduction to the Study area

Provincial road network in Jaffna district was selected for this study where the road network is administrated by provincial road development department. Density around the provincial road drastically increased due to economic development after the civil war. Some provincial roads are under construction even through, most of the roads are still in poor condition without maintenance. All are single carriage way limited to maximum of 6m width. The provincial roads that were covered in this study is connected to national road, local roads around agriculture area and high density area such as schools universities. Geographic conditions and terrain of the roads are remains same within the study area.

B. Data Collection and Method

Define Safety issues - 1km road segment was selected for the identification of prevailing road safety issues in each road network. Five prioritized safety issue types were considered based on the risk towards roads users especially in Jaffna district under geometric safety issue in each road network. Safety audit was carried out systematically to find issue type in each road segments cause safety hazards.

Traffic related data- maximum traffic volume data such as non-motorized and motorized with different composition of vehicle counts in the selected road and in each safety issue location were obtained from the traffic counts and survey.

Vehicle speed related data- maximum speed limit of the selected road and speed limit in each safety issue location were acquire from safety audit

Accident data- number of accident based on collision type such as fatal grievous non grievous were obtain from the police record form called 297B.

C. Development of Safety Index

The process begins with the identification of safety issues in the road segment. Geometry design was considered as the major safety issue category attributable to provincial road network in Jaffna district. Under the geometry design five issue types were selected for this study which are most vulnerable for the road users.

Safety index is the quantifiable method to evaluate safety performance of a road segment with the fundamental elements subsumed exposure, probability and consequences defined as follows[3].

Safety Index = Function of (exposure, probability and consequences)

Exposure is the number of users susceptible to the particular location of issue type. Since the bicycle users are high in Jaffna, exposure of motorist and non-motorist (bicycle and pedestrian) were considered at the same time to provide scaling system. Exposure of each location was tabulated relative to maximum volume of traffic at the corridor as shown in (1) and (2). Exposure score of motorist and non-motorist were ranging from zero to three.

$$E_m = (V_{i(m)}/V_m) \times 3 \quad (1)$$

$$En = (V_{i(n)}/V_n) \times 3 \quad (2)$$

Where;

E_m= Exposure of motorists

$V_{i(m)}$=Volume of motorist at the location of a specific road feature i

V_m = Maximum volume of motorist on the corridor

E_n = Exposure of non-motorists

$V_{i(n)}$ =Volume of a non-motorist at the location of a specific road feature i

V_n=Maximum volume of non-motorist on the corridor

Table I explained the exposure of the location with the scale ranging from 1 to 5[7].

TABLE I. SCALE OF THE EXPOSURE AT THE SPECIFIC ROAD FEATURE

Exposure of motorist	Exposure of Non motorist		
	0-1	*1-2*	*2-3*
0-1	1	2	2
1-2	3	3	4
2-3	4	5	5

Probability is the measure of a vehicle being involved in an accident in the particular location of issue. The probability component of risk was obtained by using the guidelines developed for each safety issue and by making an assessment of each road feature using the point scale. This provides a probability score for each road feature ranging from 0 to 5. Score assigned in the International Road Assessment Program (iRAP) sheets in attributes impacting the safety issues, attributes in the

Infrastructure Risk Rating (IRR) Manual, research evidences and pre-crash factors were considered to develop probability score criteria for each safety issues[12]

TABLE II. SCALE OF PROBABILITY OF OCCURRECE

Probability of occurrence	Score
Rare	1
Unlike	2
Moderate	3
Likely	4
High	5

Consequences is the measure of severity level result from the crashes in the particular location of issue. The degree of severity is influenced by several factors such as vehicle speed, vehicle size, and road side hazards. Rather than consider individual factors separately, relative consequences calculated as mentioned in the (3)[3]. This provides the severity score ranging from zero to a maximum of 5.0, with a high score representing high exposure.

Where;

$$Ci = PS_i/PS_{max} \quad (3)$$

C_i= Consequences in location of safety issue

PS_i=Posted speed at the location of safety issue

PS_{max}= Maximum posted speed in the corridor

TABLE III. SCALE OF PROBABILITY OF OCCURRECE

Score	Severity	Score
0-1	Insignificant	1
1-2	Minor	2
2-3	Moderate	3
3-4	Major	4
4-5	catastrophic	5

Safety Index in each safety issue (SIi) was computed with (4)

$$SIi = Ei \times Pi \times Ci \quad (4)$$

SIi= Safety index of issue i

Ei = Exposure of issue i

Pi = Probability of issue i

Ci = Consequences of issue i

Cumulative safety index is the combination of each safety issues occur in corridor 'k' which was computed to evaluate the safety performance of a particular road segment and ranked based on their performance. From this ranking system roads with immediate safety treatments can be identified. 30 roads were selected randomly, subsequently safety index for identified safety issues were calculated for 1km segments of each roads. Cumulative Safety Index for the roads were computed using Equation(4)[7].

$$CSI_C = \sum_{i=1,I}\sum_{t=0,T}(SI_{it})_c \quad (5)$$

Where;

CSI_C= Cumulative Safety Index for corridor 'c'

(SI_{it})=Safety Index for t^{th} occurrence of i^{th} safety issue

I= number of safety Issue types

T= Number of occurrences of each safety issue types.

D. Validation pf Cumulative Safety Index

Validation of cumulative safety index was accomplished by comparing it to the available crash data from the same road. Every single accident is recorded by the Department of Police in Sri Lanka utilizing an accident recording system which is a form called 297B. The information divided into three major categories: accident details, element details, and casualty details. For the validation, the recorded data were gathered from the accident database. Date, severity, accident environment, road name and number, coordinates of the place, collision type, kind of location, and traffic regulation in the region are all listed under accident information. The element types involved, as well as the pre-crash factors, were derived from the element details. Despite the fact safety risk is depend on the crashes take place in the road segment, it is obvious that the safety risk is not entirely proportional to the total number of crashes occur in the respective road. Since the severity level of each crashes are classified as fatal, grievous, and non-grievous and property damage only, it is need to be represented in a single standard scale according to the weightage of severity[11]. Equivalent property damage only (EPDO) factor which was allocate higher factor to fatalities and

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decrease along with grievous, non-grievous and property damage only. In Sri Lanka, crash economic cost analysis was used to develop an equation to Equivalent Accident Numbers (EAN) with respect to severity level of property damage only by L. L. Ratnayake, C. Jayasinghe in 2001 [13]. Equation (3) shows the weightage s of severity level relative to EPDO[7].

Where;

EPDO (A) = 14.6F+8G+1.14N+D (6)

EPDO (A) = Actual EPDO of the road

F= Number of fatal crashes

G= Number of grievous crashes

N= Number of Non- Grievous crashes

D= Number of property damage only

Once the actual EPDO is computed with the available accident data, the multiple regression analysis tool is used to determine the relationship between actual EPDO and computed CSI composed of identified safety issues in the road segments. Result obtained from the analysis shows that R-Squared was 0.96.with the significance level of all factors was less than 0.05 under the confidence interval of 95%.

Equation for the estimated EPDO was obtained from the results of regression analysis is shown in (7)

EPDO (E) =4.2+0.03X1+0.01X2+0.035X3 +0.009X4+(-0.0002)X5 (7)

EPDO (E) = Estimated EPDO for the road

X1= Cumulative safety index for issues on sight distance

X2 = Cumulative safety index for issues on road side space

X3= Cumulative safety index for issues on Access

X4= Cumulative safety index for issues on pedestrian facilities

X5= Cumulative safety index for issues on bicycle facilities.

Root mean square Error (RMSE) is an excellent measure to compare predicted and observed static values. Estimated EPDO was calculated using (7) subsequently, the Actual EPDO and estimated EPDO were compared using RMSE and regression model was developed (Fig. 1). RMSE and R-square was found to be 1.3 and 0.87 respectively.

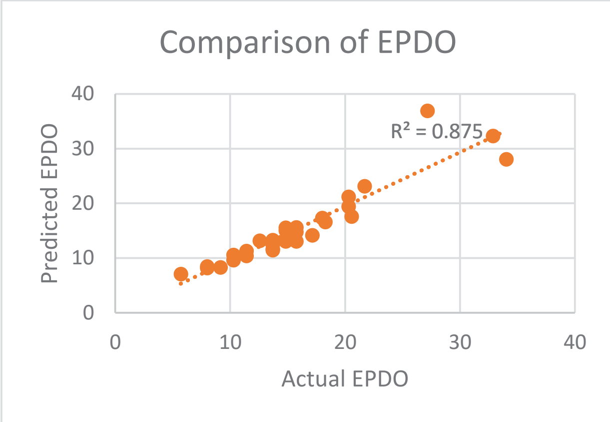

Fig. 1. Comparison of Predicted and Estimated EPDO values

E. Possible countermeasures for the safety issues

Determine a set of relevant safety improvement remedies that will successfully reduce or remove these issues. Possible safety improvement counter measures which are appropriate to the study area are represent in the Table IV.

TABLE IV. SCALE OF PROBABILITY OF OCCURRECE

Safety issue type	Possible countermeasure
Sight distance	Provide warning sign Reduce the speed, remove/modify the obstruction
Road side space	Widen the road, improve shoulder
Access	Install left turn and right turn restriction sign board, reduce speed limit in the major road. Provide alternative route for local roads
Pedestrian facilities	Install/improve pedestrian facilities, reduce the speed limit
Bicycle facilities	Provide separate lane or share path, reduce the speed limit

CSI after the implementation of safety counter measures was calculated.

The gap between the current-case safety index (before the implementation of counter measures) and the base-case safety index (after the implementation of countermeasures) is considered the Potential for Safety Index (PSI)[10]. Roads were ranked based on their performance and furthermore, roads with immediate safety treatments were identified.

IV. CONCLUSION

Geometric safety issue in the study area was identified. Safety performance was evaluated based on Cumulative safety Index (CSI). Safety index of each safety issue types was calculated with the fundamental elements such as exposure probabilities and consequences. Exposure was measured with the volume of motorists and non-motorists. Probability was measured with the guideline developed for each safety issues identified in the study area. Consequence was measured with the posted speed in the safety issue location. The linear regression study revealed that there is a high correlation between CSI and traffic accidents. The Equivalent Property Damage Only Factor was used to account for road accidents. RMSE was used to compare the fitness between Actual and Estimated EPDO. The implementation of countermeasures for each safety issue resulted in a considerable reduction in the Cumulative Safety Issue.

Improvement may include, the addition of other safety issues such as pavement condition, safety hardware and road features in the study area.

Other improvement may include, the budget constraints after during the implementation safety countermeasures.

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