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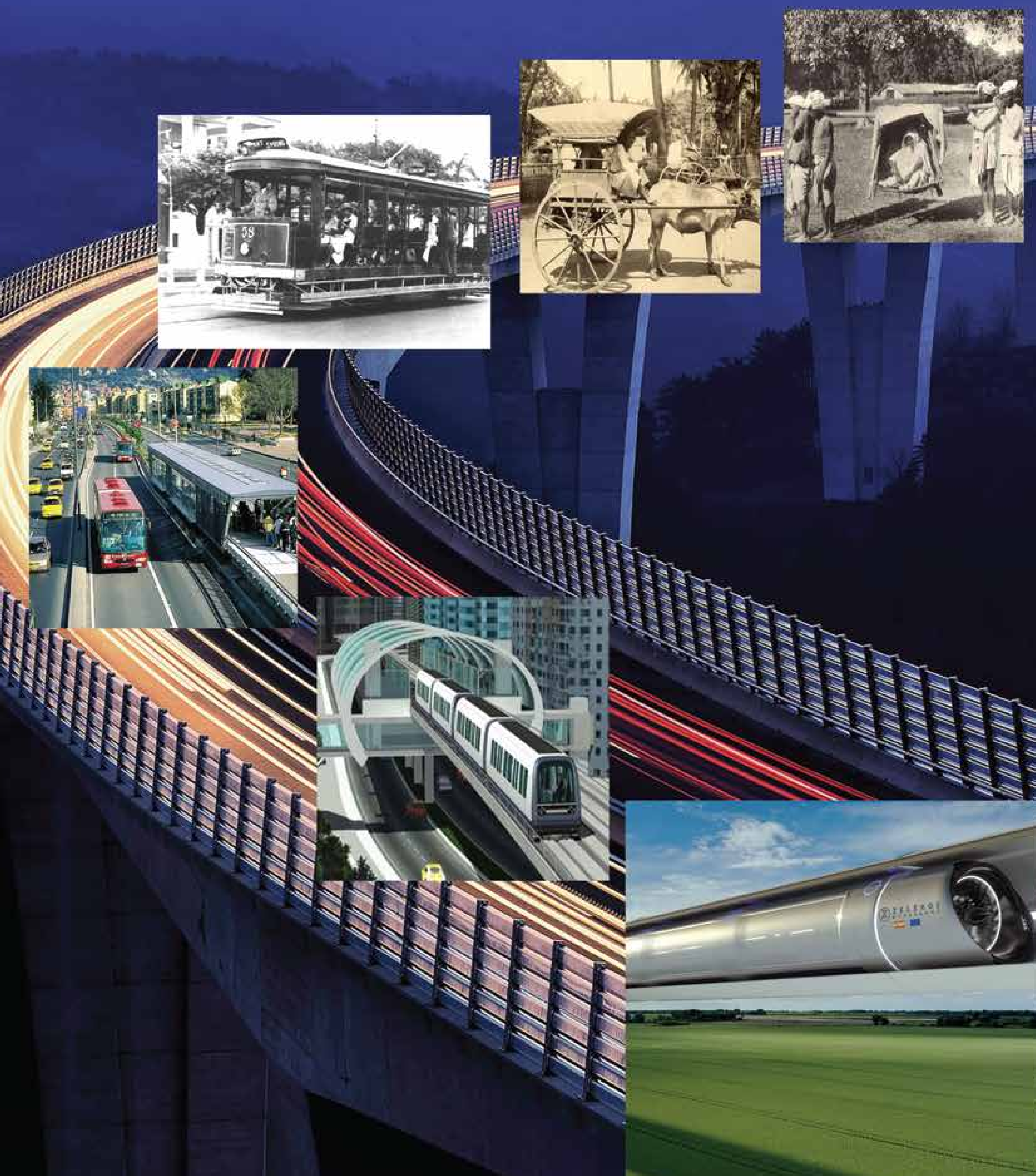

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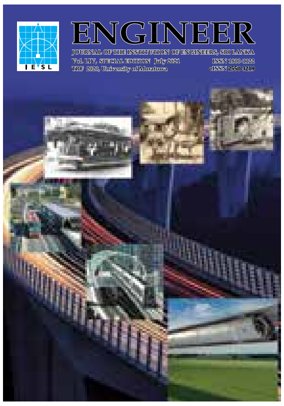

Cover Description

The cover image shows the evolution of transportation. The Institution of Engineers, Sri Lanka acknowledges information given in https://uom.lk/civil/transportation/trf

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Notes:

- **ENGINEER**, established in 1973, is a **Quarterly Journal**, published in the months of January, April, July & October of the year.
- All published articles have been **refereed** in anonymity by at least two subject specialists.
- **Section I** contains articles based on **Engineering Research** while **Section II** contains articles of **Professional Interest**.
- **ENGINEER**, is indexed and abstracted in Emerging Sources Citation Index (ESCI) by Thomson Reuters and Clarivate Analytics services.

FROM THE EDITOR…

Transportation has been one of the key factors for economic, social and cultural development of a country. Sri Lanka has had a long history of having efficient transportation facilities connecting all geographical regions in the country. Ancient remains, such as the stone bridge over Malwathu Oya in Anuradhapura, Bogoda bridge in Badulla are living examples for the ancient legacy of an efficient transportation system. The British started to construct a vast network of road and rail transport in Sri Lanka from early decades of 19th century to the Independence, making it one of the best countries in terms of transportation density. At present, it is needed to conduct high quality research studies in the area of transportation engineering to withstand challenges due to increasing urban population of the country.

University of Moratuwa, being a fore frontier in engineering education and research, started in providing necessary inputs to the country since 1980's in the area of transportation engineering. Transport Research Forum (TRF) is an annual conference organised by the Transportation Engineering Division of the Department of Civil Engineering, University of Moratuwa. The prime objective of this conference is to create a platform for researchers in the transportation engineering field to build up their research career and to share their research findings with other colleagues and the industry. Practitioners, researchers and academics including a number of international experts in the areas of Highway Engineering, Transportation Engineering and Planning are the participants for this annual event. Further, representatives from the industry and the related government institutions are also invited every year.

Department of Civil Engineering, University of Moratuwa conducted the first ever Sri Lanka Transportation Forum in 1983 and since late 90's the Transportation Engineering Division of the university has organised many Transport Research Conferences at local and international levels. Later, the TRF was established and two conferences were held initially and since 2010 TRF was held consecutively every year. Therefore, TRF 2020 is the 13th Transportation Research Forum conducted by the Transportation Engineering Division. Many of the research findings presented in TRFs have been put in to practice and the one of the main objectives of TRF is to come up with solutions to address transport related issues in the country and disseminate knowledge to the industry. Honouring contributions of TRF, the Institution of Engineers, Sri Lanka publishes selected peer-reviewed full papers of the proceedings of TRF 2020 in this special issue of "ENGINEER" journal.

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Axle Load Distribution Characterization for Mechanistic Pavement Design

S.A.S.L. Sumanasekara and W.K. Mampearachchi

Abstract: In Sri Lanka, Overseas Road Note 31 and AASHTO method are the most frequently used pavement design methods. However, in these methods the consideration given for utilization of readily available in-situ materials and incorporating characteristics of substandard materials into the designs, is not significant. On contrary, the AASHTO Mechanistic-Empirical (M-E) method of pavement design allows the designer to utilize in-situ materials and allows to optimize the pavement design to suit the conditions at site. However, due to the amount of data input required in M-E design, the preference of local practitioners in using the M-E method is not satisfactory. This study was carried out with the objective of identifying trends in axle load group type distributions of different regions in Sri Lanka. It has been found that there are similar patterns in distribution of axle group types throughout the island. Also, it was found that there are certain geographical regions with similarities in pavement loading conditions. An attempt for zoning traffic load distributions for selected geographic areas is presented in this study. This will aid in determining the traffic data input for M-E design, with a degree of accuracy level 2 as defined in M-E design method.

Keywords: Axle load distribution, Traffic load zoning, Mechanistic-Empirical pavement design

1. Introduction

As per the World Bank records of year 2018, Sri Lanka had the highest road density among the South Asian countries with 173.9 km of roads per 100 square kilometres of land. Sri Lankan government reserves a considerable amount of finance every year for developing and maintaining the existing road infrastructure, which is a well-recognized national priority. In the currently used methods for local pavement designs, utilization of the readily available in-situ materials is not widely seen. Also, consideration given to incorporate substandard materials is not prominent. Therefore, in most of the occasions, the economics of the construction processes have been adversely affected. The AASHTO M-E method of pavement design combines the physical causes such as stresses, strains, and deflections within a pavement structure and the empirical mathematical models. The pavement responses under M-E method are computed using detailed traffic loading, material properties, and environmental data, and are used to predict the incremental damage over time. The design of pavements under M-E method is an iterative process using analysis results based on trial designs postulated by the designer. Pavement design using M-E approach has been well developed since the release of Mechanistic-empirical Pavement Design Guide (MEPDG) in 2002 [1]. The basic advantage of combined M-E method over a purely Empirical method is the ability to accurately characterize in situ material. Hence, it provides practical designs for the given conditions. M-E method can be used in designing new pavements and also in designing overlays for existing pavements. It has been proven through previous studies that M-E approach in designing pavements provides more reliable performance predictions with more realistic and optimized designs than the empirical methods [2, 3].

2. Literature Review

2.1. Mechanistic-Empirical Pavement Design

A mechanistic approach refers to physical causes to explain phenomena such as stresses, strains, and deflections within a pavement structure. The physical causes in a pavement are the load and material properties of the structure. Traffic loading is a heterogeneous mix of vehicles, axle types, and axle loads, with distributions that vary with time throughout the day and over the pavement design life. Pavement materials respond to these loads in complex ways influenced by stress state and magnitude, temperature, moisture, time, loading rate, and other factors [4]. Mathematical models had been used to describe the relationship between these phenomena and their physical causes.

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Along with the mechanistic approach, empirical elements are used when defining what value of the calculated stresses, strains and deflections result in pavement failure. The relationship between physical phenomena and pavement failure is described empirically by derived equations that compute the number of loading cycles to failure.

2.2 Importance of Traffic Loads on Pavement Design

The pavement design reliability is defined as "the probability that the pavement's traffic load capacity exceeds the cumulative traffic loading on the pavement during a selected design life" [5].

Traffic axle loads and volumes are very crucial parameters in the design of pavements. In a study done to assess the impact of reliability of inputs on the M-E design has shown that the axle weight variability has an overwhelming effect on the variability of either fatigue or rutting performance predictions. The study has used Monte Carlo simulation and the investigation has been done on a typical three-layer pavement cross section consisting of Asphalt Concrete (AC) over granular base on top of subgrade soil. Traffic load distributions, obtained from Weigh-in-Motion (WIM) sites had been utilized for the study and it had been found that when the loads applied are constant, the variability of predicted fatigue performance depends on the thickness and the stiffness of the AC layer. Further, the study states base thickness and the subgrade modulus have a minor effect on the output variability. This is acceptable as the fatigue transfer function for M-E design is based on tensile strain at the base of the AC layer. Therefore, in M-E design, the AC parameters take precedence over the parameters of base and subgrade. They have also found that though the pavement structural parameters contribute to output variability, the traffic weight is the single most important input parameter [6].

The M-E pavement design requires to assume axle load spectrum data. It allows three levels of hierarchical approaches to assign traffic inputs for the design procedure [1].

Level 1: Highest accuracy in data with site-specific axle load and traffic volume data collected at or near the project

Level 2: Intermediate accuracy in data, with average knowledge of traffic characteristics with regional axle load data and site-specific volume data

Level 3: Least accuracy. Use knowledge of state-wide default vehicle weight and volume data.

Gathering level 1 traffic data is straightforward and requires a lot of resources. In general, traffic volume is easier to obtain than load spectrum considering the time and resource consumption, in gathering data. On many existing routes, the designers are more likely to have only historical traffic counts and vehicle classifications. For a new route, historical traffic data may not exist at all. Under these circumstances, it is necessary to estimate load spectra based on indirect information. If available, the WIM data in proximity, could be used with some level of confidence for the M-E design process.

Therefore, there is a requirement to identify the traffic load distribution patterns in order to derive representative axle load spectra that can be used with some level of confidence in the M-E design process.

3. Objectives

The objectives of this study are to determine the trends in axle load distributions of different axle group son pavements and to identify similarities in axle load distributions in different axle load survey locations, to be used in mechanistic pavement designs.

4. Methodology

4.1 Data Collection

The data include the axle load surveys and manually classified vehicle counts for different roads collected from Road Development Authority and from expressway projects.

4.2 Method of Analysis

In order to identify the traffic trends in a region, the Axle type distributions were analysed in the data samples gathered. For this, the axle counts measured at axle load survey stations were classified to their axle group type as follows.

- Single axle/ single tires (SAST)
- Single axle/ dual tires (SADT)
- Tandem axle/ dual tires (TADT)
- Tri axle/ dual tires (TRDT)

The above axle group types were defined as per the Austroad guidelines [7]. The axle counts were then converted to percentages to identify trends in the axle group type distributions.

Clustering techniques have been utilized to identify groups with similarities in pavement loading conditions. Cluster analysis helps in constructing groups (or clusters) while ensuring the property that, within a group, the observations are as similar as possible, and the observations belonging to different groups are different as possible [8].

Among the two main clustering techniques, i.e. K-means clustering and Hierarchical clustering, Hierarchical clustering technique was used for this research as the number of clusters were unknown and it is aimed at determining optimal number of clusters (K-Means can be used only when the number of clusters is predefined).

Clustering algorithms use the distance in order to separate observations into different groups. Here, Euclidian Distance, e was used. Euclidian Distance is defined as the distance between attributes for each pair of objects. If two attributes $I(x^1,y^1)$ and $j(x^2,y^2)$ are plotted in a Cartesian coordinate plane, the Euclidian distance e_{ij} would be linear distance between two attributes defined on the plot by their coordinates.

$$e_{ij} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad \dots (1)$$

A value of e_{ij} closer to 0 suggests that there is a similarity between the pair of objects/ attributes.

A clustering tree is to be constructed so that pairs of objects will be sequentially grouped together (This is called Ward's Minimum Variance method). The steps in hierarchical clustering are listed as follows.

Step 1:

Start by including every point into its own cluster. The axle load spectra for all the axle load survey locations were treated as clusters. The axle loads were set into axle load bins with a range of 5 kN. Axle count in the load bins were converted to percentages so that all the values compared will be standardized as required by hierarchical clustering.

Step 2:

Then the two points that are closest to each other based on the distances from the distance matrix were merged together and an average is obtained. The consequence would be that there is one less cluster.

Step 3:

Then the distances between the new (i.e. the averaged cluster) and old clusters were recalculated and saved in a new distance matrix which will be used in the next step.

Step 4:

Steps 1 and 2 were repeated until all clusters were merged into a reduced number of clusters, each containing all suitable, related points. Consideration was given to form a number of clusters which were similar and could be utilized to define a region with a similar axle load distribution.

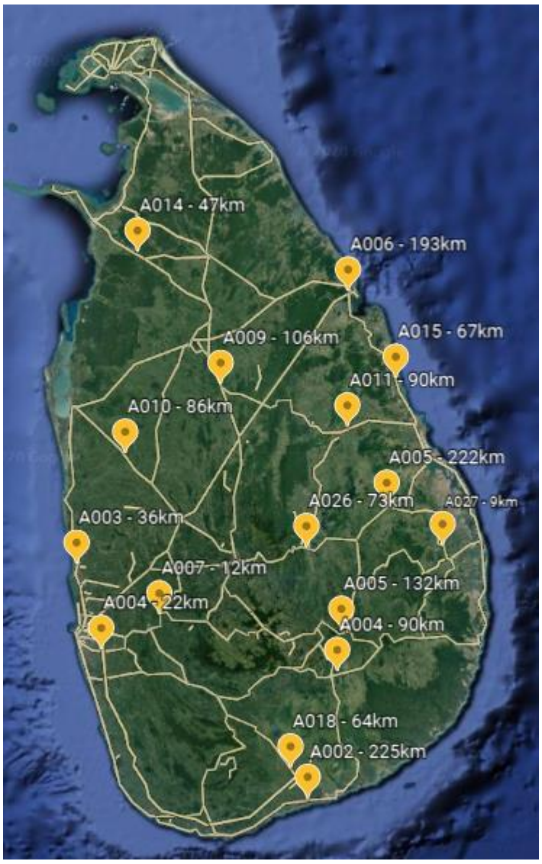

Figure 1- Axle Load Survey Locations

For this cluster analysis, the 'IBM SPSS Statistics 25' software [9] was used.

5. Analysis

5.1 Axle Load Survey Locations

The axle load survey data from the 16 axle load survey locations shown in Figure 1 were collected from Road Development Authority and highway projects.

5.2 Analysis of Trends in Axle Loads on Pavements

5.2.1 Distribution of Axle Counts

A summary of the axle counts under each axle group types at the surveyed locations is presented in Table 1. The axle counts under each axle group type were converted into percentages to make the data more rational in analysing. Accordingly, Table 2 presents the percentages of axle counts under each axle load group.

From Table 2, it can be seen that about 57% of the axles were single axles with single tire. About 38% were single axles with dual tires. The tandem axles with dual tires count to about 5% and the tri axles with dual tires were 0.1%. It can be seen that the contribution of tri axle dual tires is negligible and TRDT was not considered in further analysis of this research.

Table 1 - Axle Counts under Each Axle Group Types

Axle load survey location	No. of Axles in Axle group types				Total no. of axles
	SAST	SADT	TADT	TRDT	
A002-225km	538	301	61	0	900
A003-36km	1102	768	216	1	2087
A004 -22km	928	550	57	2	1537
A004 -90km	727	547	84	2	1360
A005-132km	333	181	3	0	517
A005-222km	297	183	18	2	500
A006-193km	429	263	111	1	804
A007-12km	790	533	28	0	1351
A009-106km	282	227	27	0	536
A010-84km	355	219	18	0	592
A011-90km	476	354	44	2	876
A014-47km	253	208	12	0	473
A015-67km	229	97	12	0	338
A018-64km	349	258	34	3	644
A026-73km	185	164	5	0	354
A027-9km	279	154	28	0	461

Table 2 - Percentages of Axle Counts under Each Axle Load Group

Axle load survey location	% of Axles in Axle group types			
	SAST	SADT	TADT	TRDT
A002-225km	59.78	33.44	6.78	0.00
A003-36km	52.80	36.80	10.35	0.05
A004 -22km	60.38	35.78	3.71	0.13
A004 -90km	53.46	40.22	6.18	0.15
A005-132km	64.41	35.01	0.58	0.00
A005-222km	59.40	36.60	3.60	0.40
A006-193km	53.36	32.71	13.81	0.12
A007-12km	58.48	39.45	2.07	0.00
A009-106km	52.61	42.35	5.04	0.00
A010-84km	59.97	36.99	3.04	0.00
A011-90km	54.34	40.41	5.02	0.23
A014-47km	53.49	43.97	2.54	0.00
A015-67km	67.75	28.70	3.55	0.00
A018-64km	54.19	40.06	5.28	0.47
A026-73km	52.26	46.33	1.41	0.00
A027-9km	60.52	33.41	6.07	0.00
Average	57.32	37.64	4.94	0.10
Standard deviation	4.69	4.57	3.35	0.15

5.2.2 Distribution of Axle Loads

The graphs of average relative frequency versus the axle load show the shapes and distributions of axle loads. Following presents a discussion on the SAST, SADT, and TADT axle load distributions.

Single Axle/Single Tire

The relative frequencies of single axle count versus the axle loads in the 16 locations are shown in Figure 2. There are four distinct peaks that can be identified in the graphs. The First two of the peaks occur in between the axle load range 10-18 kN. The third peak occurs around 38 kN and the fourth peak occurs around 62 kN. These peaks can be considered to represent the loaded and unloaded conditions of the vehicles. The peak in 10-18 kN range represents the unloaded situations and the 38 kN and 62 kN represent the loaded situations. It is also seen that the frequency of the first two peaks is higher than the frequency of occurrence of the second two peaks. The maximum axle load for single axle-single tire is approximately 90 kN.

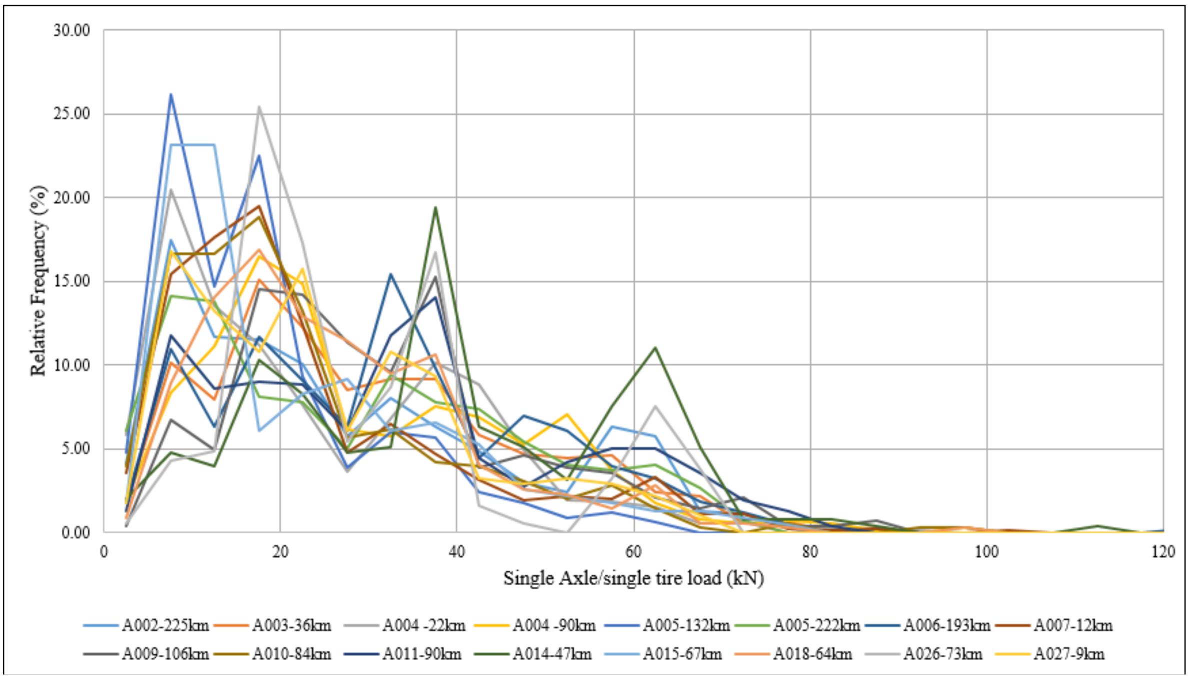

Figure 2 - Relative Frequency vs Single Axle/Single Tire Load

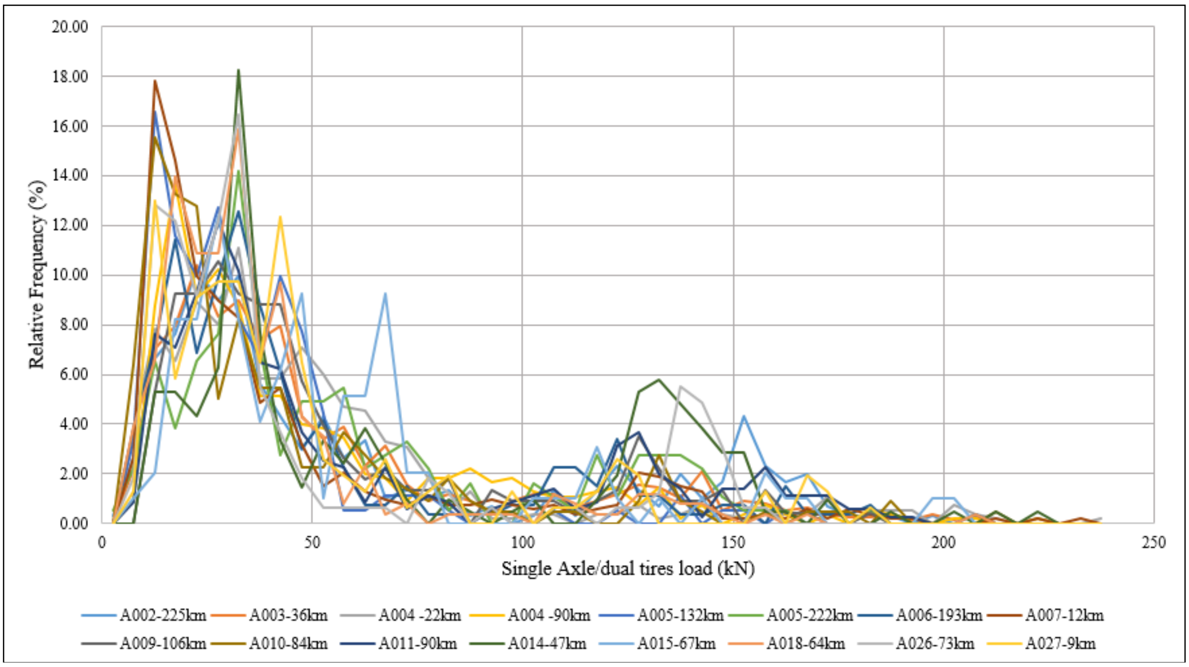

Figure 3 - Relative frequency vs Single Axle/Dual Tires Load

Single Axle/Dual Tires

The graphs of relative frequency of single axle/dual tires counts versus the axle load are shown in the Figure 3. The Maximum axle load for single axle/dual tire is approximately 200kN. Three peaks can be identified in these graphs. The first two peaks occur in the load range of 15-25 kN and the third peak occurs around 135 kN. These peaks can be considered to represent the mean axle loads of a loaded (third peak) and unloaded (first and second peaks) vehicle with single axles having dual tires. It is also seen that the occurrence of the third peak is less frequent than the first and second peaks.

Tandem Axle/Dual Tires

The graphs showing the relative frequency of tandem axle/dual tire counts versus the axle load are in Figure 4. From these graphs it can be identified that there is a clear peak arising around 60 kN load. However, unlike in the previous plots, it is difficult to identify any other distinct peak in these graphs.

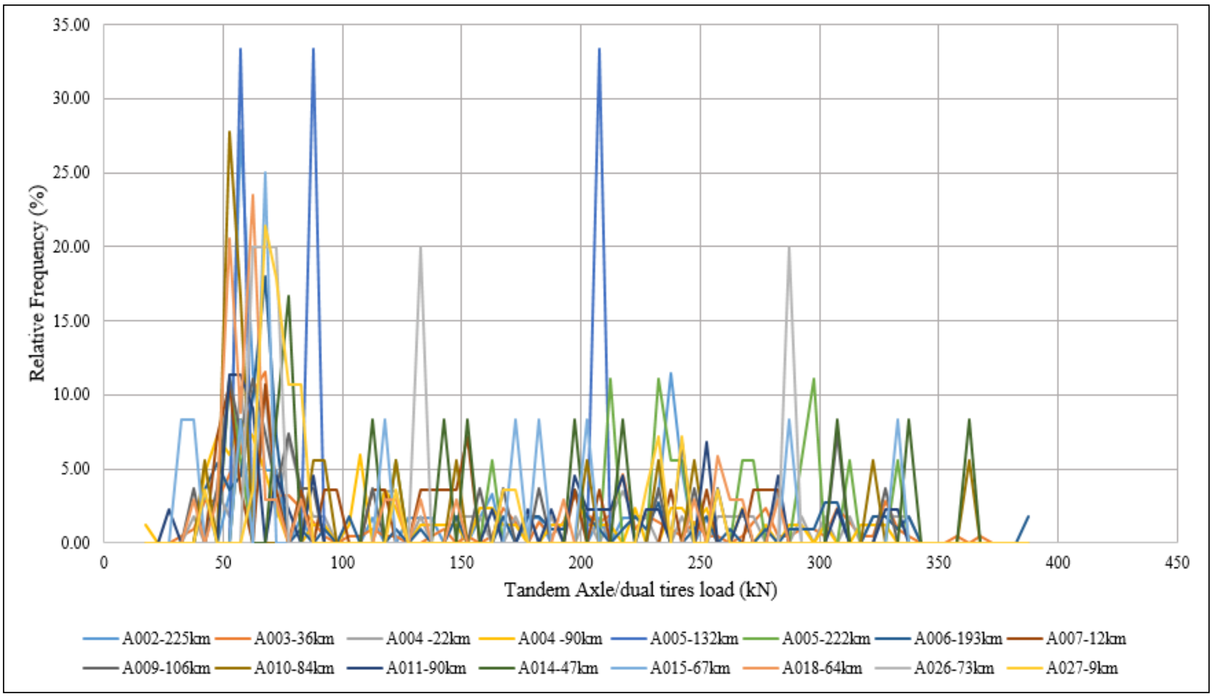

Figure 4 - Relative Frequency vs Tandem Axle/Dual Tires Load

5.3 Classification of Pavement Loading Patterns in Regions

For the 16 axle load surveys, a cluster analysis was carried out using IBM SPSS Statistics 25 software. The objects for cluster analysis were the 16 axle load survey locations and the attributes were the values in the load bins. Following presents the discussion on the cluster analysis.

Single Axle/Single Tire

The Euclidean matrix for the distributions of SAST loads is in the following Table 3.

Table 3 - Squared Euclidean Distance Matrix for SAST Load Distributions

Case	Squared Euclidean Distance														
	1:A002-225km	2:A003-36km	3:A004 -22km	4:A004 -90km	5:A005-132km	6:A005-222km	7:A006-193km	8:A007-12km	9:A009-106km	10:A010-84km	11:A011-90km	12:A014-47km	13:A015-67km	14:A018-64km	15:A026-73km
1:A002-225km															
2:A003-36km	0.013														
3:A004 -22km	0.010	0.025													
4:A004 -90km	0.020	0.005	0.030												
5:A005-132km	0.028	0.047	0.024	0.049											
6:A005-222km	0.007	0.016	0.009	0.021	0.045										
7:A006-193km	0.019	0.008	0.029	0.020	0.061	0.016									
8:A007-12km	0.014	0.021	0.021	0.017	0.016	0.023	0.038								
9:A009-106km	0.034	0.008	0.047	0.017	0.077	0.036	0.016	0.045							
10:A010-84km	0.013	0.020	0.019	0.016	0.014	0.022	0.037	0.001	0.044						
11:A011-90km	0.015	0.011	0.024	0.023	0.061	0.013	0.008	0.037	0.015	0.038					
12:A014-47km	0.047	0.031	0.060	0.042	0.113	0.044	0.035	0.075	0.026	0.079	0.021				
13:A015-67km	0.026	0.053	0.020	0.056	0.040	0.025	0.061	0.032	0.081	0.030	0.048	0.106			
14:A018-64km	0.021	0.008	0.032	0.011	0.046	0.024	0.021	0.016	0.013	0.017	0.020	0.047	0.046		
15:A026-73km	0.063	0.033	0.084	0.038	0.086	0.077	0.051	0.054	0.025	0.059	0.048	0.042	0.134	0.032	
16:A027-9km	0.009	0.013	0.016	0.017	0.033	0.014	0.018	0.016	0.026	0.014	0.015	0.056	0.026	0.015	0.056

In the above Euclidean matrix, the values that are closest to 0.0 are 0.001, 0.005, and 0.007 (values ≤ 0.005 are considered). Therefore, it can be said that the SAST load distributions of two sets A010-84 km/A007-12 km and A004-90 km/A003-36 km show similarities. This can be clearly seen from the axle load distribution curves in Figures 5 and 6.

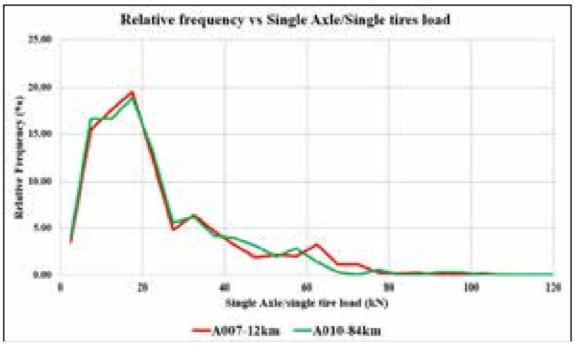

Figure 5 - SAST Axle Load Distribution at Locations A010-84 km and A007-12 km

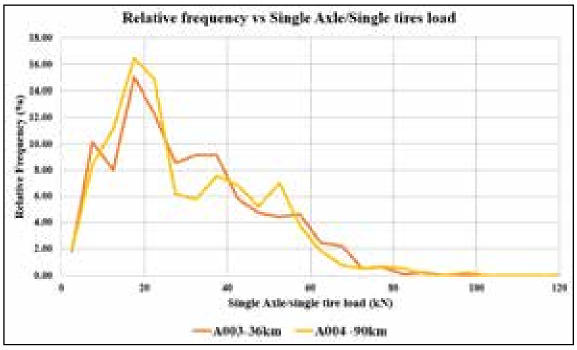

Figure 6 - SAST Axle Load Distribution at Locations A004-90 km and A003-36 km

Single Axle/Dual Tires

Table 4 presents the Euclidean matrix for the distributions of SADT loads. It is seen that the sets A003-36 km/A002-225 km, A011-90 km-A002-225 m, A004-22 km/A003-36 km, A009-106 km/A003-36 km, A011-90 km/A003-36 km and A011-90 km/A009-106 km show similarities in load distributions. These observations can be clearly seen from the axle load distributions shown in Figures 7 and 8.

Table 4 - Squared Euclidean Distance Matrix for SADT Load Distributions

Case	Squared Euclidean Distance														
	1:A002-225km	2:A003-36km	3:A004 -22km	4:A004 -90km	5:A005-132km	6:A005-222km	7:A006-193km	8:A007-12km	9:A009-106km	10:A010-84km	11:A011-90km	12:A014-47km	13:A015-67km	14:A018-64km	15:A026-73km
1:A002-225km															
2:A003-36km	0.005														
3:A004 -22km	0.008	0.005													
4:A004 -90km	0.01	0.007	0.012												
5:A005-132km	0.024	0.018	0.02	0.015											
6:A005-222km	0.011	0.011	0.008	0.02	0.036										
7:A006-193km	0.009	0.008	0.012	0.007	0.019	0.014									
8:A007-12km	0.023	0.019	0.025	0.011	0.009	0.035	0.02								
9:A009-106km	0.009	0.003	0.01	0.008	0.019	0.015	0.008	0.024							
10:A010-84km	0.02	0.016	0.02	0.014	0.016	0.033	0.021	0.006	0.026						
11:A011-90km	0.005	0.005	0.011	0.009	0.019	0.012	0.008	0.02	0.005	0.024					
12:A014-47km	0.021	0.024	0.026	0.033	0.056	0.011	0.023	0.048	0.025	0.048	0.022				
13:A015-67km	0.022	0.016	0.016	0.021	0.04	0.024	0.027	0.046	0.017	0.046	0.019	0.044			
14:A018-64km	0.016	0.012	0.017	0.012	0.019	0.025	0.008	0.023	0.012	0.023	0.014	0.031	0.031		
15:A026-73km	0.02	0.023	0.028	0.018	0.023	0.025	0.017	0.016	0.025	0.024	0.018	0.026	0.046	0.016	
16:A027-9km	0.017	0.009	0.014	0.017	0.01	0.024	0.017	0.019	0.012	0.022	0.01	0.039	0.029	0.02	0.028

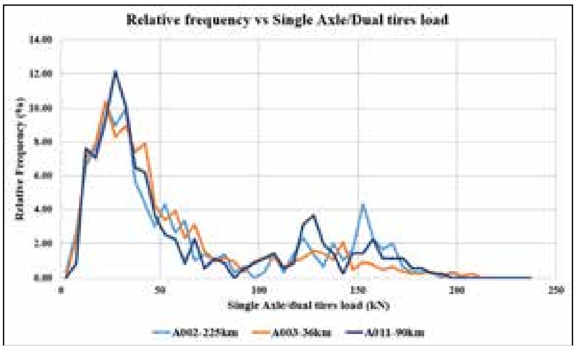

Figure 7 - SADT Axle Load Distributions at Locations A003-36 km, A002-225 km & A011-90 km

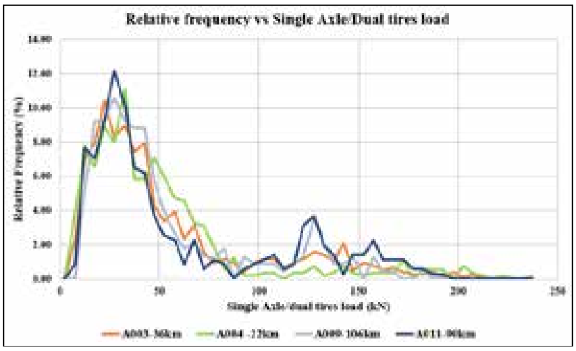

Figure 8 - SADT Axle Load Distributions at Locations A003-36 km, A004-22 km, A009-106 km & A011-90 km

Summary

From the distributions of axle counts, it was found that in all axle load survey locations, on average 57% of the axles were single axles with single tires, 38% were single axles with dual tires, 4.9% were tandem axles with dual tires and only 0.1% constitutes tri axles with dual tires. This composition can be used to determine the traffic data input to M-E design when the manual classified counts are available.

It was seen from the cluster analysis that there are certain representative locations which has the same axle load distributions. Accordingly, the SAST axle load distributions in A010 and A007 roads were similar. Also, SAST axle load distributions in A004 and A003 roads were similar. The SADT axle load distributions in A003, A002 and A011 were having similar distribution patterns and also A003, A004, A009 and A011 were having similar axle load distributions. Through these observations it can be predicted that there could be regions in the island where there are similar axle load distributions.

However, as per the observations in this study, the similar axle load distributions were seen not in the locations in proximity. Therefore, further axle load survey data collection in the nearby areas is required and further analysed by clustering, in order to determine whether the axle load distributions of locations in a particular region show similarities. Using the methodology followed in this study, traffic loading zones could be identified if the axle load distributions in a particular region show similarities.

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Evaluation of Aircraft Excursion Risk at Bandaranaike International Airport

S.D.B. Galagedera, H.R. Pasindu and V. Adikarivattage

Abstract: Flight safety is one of the key priorities in the air transport industry. Considering historical aircraft accidents, majority of the aircraft accident occurred at airports. Among the airport related aircraft accidents, a higher percentage of accidents have taken place during the landing operations. Runway excursions such as overruns and veer-offs are the typical runway related aircraft accidents that frequently occur during aircraft landings. Thus, this paper focuses on aircraft excursion risk at the Bandaranaike International Airport (BIA) where the majority of the international flight movements are currently taking place in Sri Lanka.

This paper considers different operational conditions that probably exist at BIA, and accordingly associated excursion risks are estimated. Aircraft airfield design elements such as the runway length, safety areas and the corresponding critical aircraft for the BIA are used for the estimation. Potential overrun and veer-off risks at aircraft landings are mainly focused. The methodology follows a quantitative approach which consists of event probability, location probability and consequent severity estimation steps. Among the potential weather factors, the conditions at which tailwind over 12 knots (6.17 m/s), reduced visibility and rain are the worst contributory factors for the greatest overrun risk. The paper highlights that the airfield design elements can compensate excursion risks that generate due to various spikes of the operational conditions.

Keywords: Excursion, Overrun, Veer-off, Airfield

1. Introduction

1.1 Aircraft Accidents

Worldwide aircraft accidents are considered, total aircraft accident rate in 2019 was 1.13 per million flights [1]. The majority of the aircraft accidents take place at airports or airport vicinity areas [2]. A higher proportion of aircraft accidents have occurred during landing and take off phases. Aircraft excursions are the leading accident type during landings and take offs. Thus, airport runways incur associated aircraft excursion risk.

Runway excursion is defined as an inappropriate exit of an aircraft from the runway. That is, an aircraft is unable to stop before it reaches the end of the runway or exceeds the lateral limits. Such stopping locations longitudinally away from the runway ends, are defined as overruns, and laterally away from the runway edges are defined as veer-offs.

Runway excursions are divided into five main categories such as landing overruns (LDOR), landing undershoots (LDUS), landing veer-offs (LDVO), take-off overruns (TOOR) and take-off veer-offs (TOVO) [2]. Among the historical worldwide runway excursions, the landing overruns are identified as the most frequent type of excursion event [3]. Further, landing veer-offs are also comparatively 4 times higher than the veer-offs during take-off operations [4]. Aircraft accident statistics indicate that about 80 percent of the veered-off aircraft have stopped within 52.5 m from the runway edge [4].

It is observed a consistent annual air passenger growth about 6% is observed during the previous decade and it is forecasted about 40 billion annual air passenger travels in 2040 [5]. Increasing passenger volumes are considered, airport runways need to facilitate for increasing number of aircraft movements and new larger aircrafts as well. Accordingly, airport runways become more congested and associated excursion risk will also be worse.

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Considering the associated aircraft risk at existing airport runways, it is important to assess associated risks in order to minimize them. Using the same approach, risk-based designs for future runways are also worthwhile with regard to air transport safety.

Bandaranaike International Airport (BIA) is the main international airport still serving for 99% of the international flight movements in Sri Lanka. It is approximately 72000 annual flight movements [6]. As per the Civil Aviation Authority of Sri Lanka [7], there were no major excursion events recorded in BIA other than a tail strike at a hard landing in 2013. However, considering the future operations at BIA, this paper focuses on the potential excursion risk of landing at Bandaranaike International airport.

2. Literature

2.1 What is Risk?

Risk is defined as an impact of a hazard to a person, asset or an operation. It is a function of the likelihood of an event and the corresponding consequences of the same event (Equation 1). Accordingly, a higher the likelihood of an event, or higher the severity (consequences), the associated risk will be higher. For excursion risk estimation, likelihood of an event is further divided into event frequency estimation and the respective location probability estimation (Equation 2).

Risk (*R*) = Likelihood of event (*P*) x Severity (*D*) ...(1)

$P = P1 \times P2$ …(2)

where,

P1 = Likelihood for occurrence of an event

P2 = Probability that an aircraft passes a certain distance from the runway due to an event

2.2 Probability Model (*P1*)

There is a large number of studies conducted on aircraft excursion risk analysis and they have followed a quantitative approach. With the initial one dimensional probability models of Eddowes (2001) and Kirkland (2001), Wong et al. [8] developed a probability model including aircraft and weather related multiple risk factors. their multivariate probability model was modified by Hall et al. [2] including few more risk factors under the Airport Cooperative Research Program (ACRP) for Analysis of Aircraft Overruns and Undershoots for Runway Safety Areas. In 2011, Ayres et al. developed a similar model for veer-off probability analysis [9]. This included a risk factor called runway criticality factor. This was the first time a runway design element (runway length) was taken into account for runway excursion event probability modelling. Trucco et al. (2013) developed a risk map for airport safety areas [10]. In this approach, the expected kinetic energy of the overrun aircraft at any given point was used as the event severity. Considering the latest accident data and aircraft types, Ayres et al. [9] further modified veer-off probability model for landings in 2014 under the ACRP study "Development of a Runway veer-off location distribution risk assessment and reporting template" [4]. Similarly, Shirazi et al. [11] modified landing overrun probability model in the tool development for "Runway Protection Zones (PPZ) Risk Assessment". In the study conducted by Moretti et al. (2017), wind distribution was related with the veer-off probability estimation [12].

Shirazi's landing overrun probability model is used in this analysis as shown in Equation 3. Further, the probability model developed by Ayres et al. (2014) is used for landing veer-off probability estimation.

$$P(landing\ overrun) = \frac{1}{1+e^{-Z}} \quad \ldots(3)$$

where,
Z = regression coefficients X independent variables
For landing overrun probability model,
Z= –11.96 – 3.32 (Hub) + 1.71 (Foreign O/D) – 1.18 (Aircraft class A) + 2.25 (Piston) – 1.22 (Prop) + 1.6 (Fog) + 1.50 (Icing) + 1.61 (Night) + 0.76 (Rain) + 1.57 (Snow) – 1.23 (Electric Storm) – 0.86 (Temperature greater than 25 C) + 0.94 (Tailwind between 5 and 12 kts) + 3.22 (Tailwind greater than 12 kts) + 1.60 (Visibility less than 2 SM) + 0.98 (Visibility between 2 and 4 SM) – 1.11 (Crosswind between 2 and 5 kts) – 0.47 (Crosswind between 5 and 12 kts) + 5.82 (Log Criticality fct)

Input variables for the overrun model are defined in Table 1.

Table 1 – Input Variables – Overrun Model

Variable	Definition
Hub	An airport where connecting flight operations take place
Foreign Origin-Destination	An airport where international flight operations take place
Aircraft class A	Maximum take-off weight 12.5lbs or less
Piston	Piston engine aircraft

Propeller	Propeller engine aircraft
Fog	Presence of fog
Icing	Presence of ice on the runway
Night	Land at night time
Rain	Presence of rain
Snow	Presence of snow on the runway
Electric storm	Presence of electric storms
Temperature greater than 25^{o}C	Ambient temperature above 25^{o} C
Tailwind between 5 kts and 12 kts	Presence of tailwind between 5 knots and 12 knots
Tailwind greater than 12 kts	Presence of tailwind greater than 12 knots
Visibility less than 2 SM	When visibility less than 2 Salute miles
Visibility between 2-4 SM	When visibility between 2 and 4 Salute miles
Crosswind between 2-5 kts	Presence of crosswind between 2 and 5 knots
Crosswind between 5-12 kts	Presence of crosswind between 5 and 12 knots
Log criticality factor	Defined in Equation 4

For landing veer-off probability,
Z = –13.088 + 1.682 (User Class G) – 0.770 (Aircraft Class A/B) – 0.252 (Aircraft Class D/E/F) + 2.143 (Visibility less than 2SM) + 0.653 (Crosswind between 5-12kt) – 0.091 (Crosswind between 2-5kt) + 2.192(Crosswind greater than >12kt) + 0.066 (Tailwind between 5-12kt) + 0.98 (Tailwind greater than12kt) + 0.558 (Temperature less than 5C) – 0.453 (Temperature between 5-15C) + 0.29 (Temperature greater than 25C) + 2.67 (Icing conditions) – 0.126 (Rain) + 0.548 (Snow) – 0.103 (Frozen Precipitation) –0.036 (Guts) + 1.74 (Fog) – 2.517 (Turboprop) – 0.334 (Foreign OD) + 4.318 (Log Criticality fct) – 1.36 (Night condition)

Input variables for the veer-off model are defined in Table 1.

Table 2 – Input variables – Veer-off model

Variable	Definition
User Class G	General aviation flight maximum take-off weight less than 6k lb
Aircraft Class A/B	Aircraft maximum take-off weight 255,000 lb or above
Aircraft Class D/E/F	Maximum take-off weight Class D - 41k – 255k lb, Class E - 12.5k – 41k lb, Class F - 12.5k lb or less
Visibility less than 2 SM	When visibility less than 2 Salute miles
Crosswind 5-12 kts	Presence of crosswind between 5 knots - 12 knots
Crosswind 2-5 kts	Presence of crosswind between 2 - 12 knots
Crosswind more than 12 kts	Presence of crosswind greater than 12 knots
Tailwind between 5-12 kts	Presence of tailwind between 5 - 12 knots
Tailwind greater than 12 kts	Presence of tailwinds greater than 12 knots
Temp less than 5 C	Ambient temperature below 25^{o} C
Temp between 5-15 C	Ambient temperature between 5-15^{o} C
Temp greater than 25 C	Ambient temperature greater than 25^{o} C
Icing conditions	Presence of ice on the runway
Rain	Presence of rains
Snow	Presence of snow on the runway
Frozen Precipitation	Presence of frozen
Gusts	Presence of gust
Fog	Presence of fog
Turboprop	Propeller engine aircraft
Foreign OD	An airport where international flight operations take place
Electric storm	Presence of electric storms
Hub	An airport where connecting flight operations take place
Night	Land at night time
Log criticality factor	Defined in Equation 4

The risk models are considered, aircraft design and operational, weather related independent variables are used as input parameters. The runway criticality factor, which is an airport runway related input parameter determined by the aircraft type, is the only input parameter account runway dimensions in the excursion probability estimation (Equation 4).

Criticality factor = L_R / La …(4)

where,
L_R – Runway length required
La – Runway length available

This required length depends on factors such as airport elevation, ambient temperature, headwind, tailwind and runway surface condition (wet, snow, ice).

2.3 Location Model (*P2*)

Aircraft final wreckage locations are important findings with regard to associated consequences. Using historical accident data [2, 9], distinct ACRP studies for different event types (landing overruns and veer-offs). These models find the respective probability values that the aircraft passes certain distance from the runway end/edge in case of an overrun/a veer-off respectively (Figure 1).

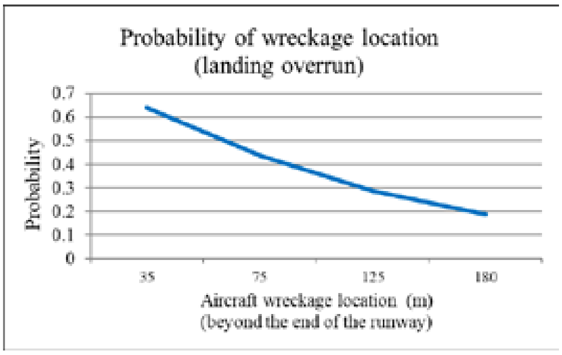

Figure 1 – Aircraft Wreckage Location Probability Curve

By multiplying event probability with the corresponding location probability, it can estimate the probability that an aircraft stops at a certain distance (a defined distance) from the runway (either longitudinally or laterally) in case of an excursion event.

Considering several location models, this paper uses the models developed by Shirazi et al. [11] for landing overrun location probability estimation (Equation 5) and model developed by Ayres et al. [4] for landing veer-off location probability estimation (Equation 6).

The probability that the overrun aircraft exceeding a given distance x from the runway end is estimated by

$$P(location > x) = e^{-0.00321x^{0.9849}} \quad \ldots(5)$$

where, x is the chosen longitudinal distance from the runway end.
The probability that the veer-off aircraft exceeding a given distance y from the runway centerline is estimated,

$$P(location > y) = e^{-0.02568y^{0.804}} \quad \ldots(6)$$

where, y is a chosen lateral distance from runway the centerline.

2.4 Consequences

Accident severity is assessed in terms of the accident consequences. Aircraft wreckage location is also a key determinant factor on respective consequences. All wreckage locations away from the runway end/edge may possess higher kinetic energy. Such higher kinetic energy lends to severe consequences in case of any collision with an obstacle in the adjacent airfield. Based on the damages to human health and aircraft condition, International Civil Aviation Association (ICAO) classifies accident consequences [13]. Moretti et al. (2017) introduced a severity index based on the consequences not only on human health and aircraft but also on the soil bearing capacity of the adjacent safety areas [12].

Considering potential consequences on the aircraft mechanical components at different airfield areas adjacent to runways, this paper defined location based severity levels as in Table 3 and Table 4.

Table 3 – Landing Overrun Severity Classification

Longitudinal distance	Consequence	Severity
X1 m	Major	0.25
X1 - *X2* m	Hazardous	0.50
X2 – *X3* m	Catastrophic	1.00

Table 4 – Landing Veer-off Severity Classification

Transverse distance	Consequence	Severity
Y1 m	Major	0.25
Y1 - *Y2* m	Hazardous	0.50
Y2 – *Y3* m	Catastrophic	1.00

The excursion risk analysis methodology developed under ACRP studies is adapted for estimating runway excursion risk at the BIA.

3. Methodology

3.1 Excursion Risk Estimation

The paper analyses various operating conditions that can be experienced at the BIA. The finding to be reasonable for the type of aircraft operating on the BIA. Accordingly, the critical aircraft for the BIA runway facility is used for this analysis.

I. Using Equation (4), runway criticality factor is estimated. For the critical aircraft, Airport Planning manual is used to find the required landing length (L_R) at the relevant ambient temperature and runway elevation. Runway length is used as the available runway length (La).

II. Considering weather data and aircraft operational conditions, input data is inserted into Equation (3).

III. Using Equation (3), event probability (overrun/veer-off probability) is estimated.

IV. As aircraft excursion events may result in distinct consequences, type of event is defined based on the consequences. Accordingly, aircraft risk on the focused event type is estimated.

V. Considering aircraft locations that lead to major events, respective longitudinal distance from the runway end for overrun events, and respective lateral distance from the runway edge are identified. Aircraft wreckage locations beyond the runway safety area are categorized as major events. Hence longitudinal distance X= 240 m and lateral distance Y= 75 m are considered for location probability estimations with regard to major events [14].

VI. Using Equations (5) & (6), respective location probabilities leading to major events are estimated in case of overruns and veer-offs.

VII. The results from step III (event probability) and VI (location probability) are substituted into the Equation (2) for estimating the likelihood of the focused event type (e.g. major event).

VIII. As major events are concerned, the corresponding severity value is inserted into Equation (1). Accordingly, landing overrun risk for major events and landing veer-off risk on major events are estimated.

3.2 Case Study

As this paper considers Bandaranaike International Airport (BIA), the corresponding operational and design data are required to be used as model inputs. BIA runway (04/22) length (3350 m) and runway safety area dimensions mentioned in Tables 3, 4 are important airfield design factors. Further, BIA can be considered as a hub airport as connecting flight operations take place with various worldwide destinations. As B747-400 is the critical aircraft for BIA, this paper use B747-400 for the analysis [15].

In addition to airport and aircraft related data, weather data plays a vital role in the probability estimation. Using 10-year weather data [16], extreme weather conditions were chosen with regard to tailwind, visibility, runway surface condition and rain. Average ambient temperature 30^oC is used for the entire analysis. For BIA, none of the rain, tailwind and crosswind conditions at 30^oC ambient temperature in day time is considered as the base condition. Such a base condition is defined to compare risk at various weather conditions using a common platform. Table 5 defines a set of operational scenarios using potential weather conditions at the BIA. Aircraft overrun and veer-off risk at these scenarios are compared by using the methodology practiced in this paper.

Table 5 – Weather Condition Based Scenario

Scenario	Weather Condition
A	Day Time, 30^o C
B	Tailwind 6 knots, 30^o C
C	Tailwind 12 knots, 30^o C
D	Rain, 30^o C
E	Visibility < 4 SM, 30^o C
F	Visibility < 4 SM, rain, 30^o C
G	Visibility < 4 SM, 6 knots tailwind, rain, 30^o C
H	Visibility < 4 SM, 12 knots tailwind, rain, 30^o C

4. Results

Considering the above defined extreme operational conditions such as the scenarios B to H, landing overrun risk on major events (aircraft stops within the runway safety area) at BIA for the critical aircraft B747-400 is estimated. Accordingly, Table 6 shows the respective overrun risks and the worst risk could be observed in condition H (presence of 12 knot (6.17 m/s) tailwind, visibility below 4 SM (6437 meters)). This is about 670 times increase of overrun risk compared to the base condition scenario A.

Table 6 – Landing overrun risk

Scenario	Landing overrun risk
A	4.96E-07
B	1.31E-06
C	1.36E-05
D	2.47E-06
E	2.44E-06
F	1.22E-05
G	3.29E-05
H	3.37E-04

Similarly, the estimated veer-off risk of B747-400 when it lands on the runway (04/22) when the presence of crosswind above 12 knots (6.17 m/s) is 1.5 x 10^{-6}. This is 60 times higher compared to the non-crosswind condition at BIA. Thus, crosswind is a leading risk factor for landing veer-offs. The corresponding impact of the factors such as visibility, rain and tailwind causes to increase successive landing overrun risk at BIA. The analysis highlights that the tailwinds above 12 knots (6.17 m/s) when rain at reduced visibility levels are the worst weather conditions for BIA landing operations. The worst overrun risk at the scenario H is used for further analysis. Considering runway design elements and their improvements, increasing risk could be managed. According to the Equation (4), runway length improvement causes to decrease the overrun risk in terms of runway criticality factors. As shown in Figure 2, 30 percent runway length drops overrun risk by 50 percent. Similarly, as shown in Figure 3, increasing runway safety area will drop overrun risk. This happens by altering possible severe consequences into minor consequences and thus severity values becoming smaller.

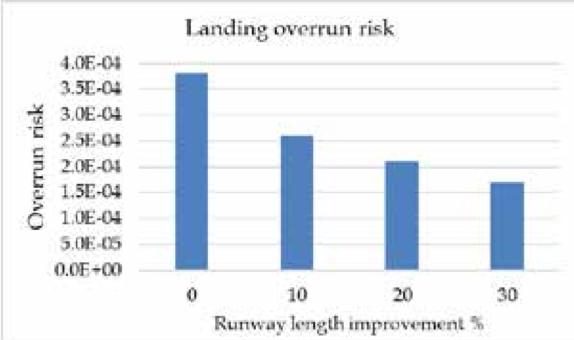

Figure 2 – Landing Overrun Risk with Runway Length Improvement

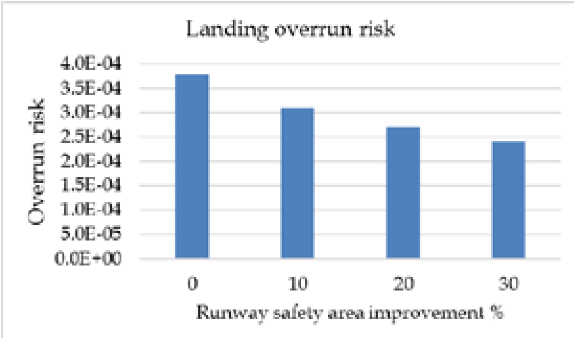

Figure 3 – Landing Overrun Risk with Runway Safety Area Improvement

As Figures 2 and 3 depict, airport airside design elements can manage excursion risks by reducing the event probabilities or minimizing potential event consequences.

5. Conclusion

The paper focused on aircraft excursion risk at the Bandaranaike International airport. Considering usual weather pattern at BIA and the probable extreme weather conditions at BIA, aircraft risk on overruns and veer-offs were estimated. Using previous accident data, several probability models and location models have been developed by various aviation professionals and they are being used by the aviation industry for assessing existing facilities and design level applications. The paper used an existing probability model and a location model while developing a severity index. Considering the results, it could be found that the impact of the visibility, rain and tailwind to be high on landing overrun risk. Presence of tailwinds above 12 knots (6.17 m/s), rain and reduced visibility levels is the worst weather condition out of the defined weather scenarios. Similarly, crosswinds above 12 knots (6.17 m/s) is a critical weather condition on landing veer-offs. Among the runway design element alternations, runway length improvement can significantly reduce landing overrun risk. According to the findings, at the given condition, 30 percent runway length improvement reduces over risk by 50 percent. Further, runway safety area improvement minimizes accident consequences, and finally reduce excursion risks.

This mathematical approach on landing overrun and veer-off risk at BIA found that the aircraft operational and weather factors create excursion risk on landing aircraft. Airfield design elements such as runway length, width and safety areas play a vital role for maintaining excursion risks within the acceptable risk levels. Thus, airfield design elements need to be upgraded in terms of potential operational and weather conditions. These operational conditions include new larger aircraft or new fleet types other than the critical aircraft etc. as well. Airfield design elements should have necessary tolerance to bear associated spikes of the aircraft risk due to various unavoidable operational conditions.

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Analysis on Transport Mode Choices of School Children in Colombo District, Sri Lanka

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Abstract: Traffic congestion on roads in peak hours has negatively impacted on a country's economy as well as the well-being of its citizens. In Sri Lanka, a major portion of the traffic during morning and afternoon peak hours is due to school traffic. It has been identified that the daily travel distances of school children are exceeding the limitations imposed by the Ministry of Education on home to school distance. As a result, students choose different transport modes to reach their schools based on many factors, which has resulted in more vehicles on roads during peak hours. The study focuses on identifying the daily travel distances and the respective transport mode choice of the students in Colombo district. In addition, the factors that affect the school children to avoid public transport modes were also analysed. The study has been divided into three phases as factor identification, mode choice and demand distribution. A quantitative approach has been used in developing the methodology and the data collection was conducted through a questionnaire survey in 28 selected schools in the study area, with a total sample size of 2,875. Stratified sampling technique was used to collect data from the different types of schools defined by the Ministry of Education. The study recommends a procedure to develop an improved public transport system for school trips considering network connectivity and system planning to attract more students into public transport services. Results of this study can be used to identify the most influencing factors for selecting a particular transport mode for school trips by the students and to identify optimum routes for school buses in order to improve the public transportation services with respect to the identified issues.

Keywords: Travel mode choice, School trips, Public transportation

1. Introduction

Colombo District consists of 402 functioning government schools, with a total student population of 374,995 [1]. Apart from the government schools, there are some private and international schools located in the district which consist of 68,828 students. The government schools have been categorized into three categories based on the availability of class rooms and resources as shown in **Table 1**.

Table 1 - School Categories [1]

Category	Description
Category A	schools which have classes in all streams up to advanced level
Category B	schools which have classes up to advanced level commerce and/or art streams, but no science stream
Category C	schools which have classes only up to grade 11 or below

Distance to school is one of the major factors considered when it comes to the enrolment of students for any government school in the country. But due to the uneven distribution of resources, a demand for certain schools exists in the country. If the popularity of the schools is measured based on the student population or grade 5 scholarship examination cut-off marks, majority of the popular schools are located in Colombo district. High attraction of school trips for these popular schools located in Colombo district has resulted in longer travel distances using several transport modes for school trips which has affected the traffic congestion on roads in peak hours.

Sisu-sariya is the only dedicated public transport service available for school children governed by the Sri Lanka Transport Board.

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There are 778 Sisu-sariya buses in operation over the country and only 23 buses are operating in Colombo district. Insufficient supply of public transport services to cater to the school trip demand in Colombo district has resulted in more usage of private transport modes among school children. Daily travel patterns of school children and the transport modes used for school trips should be thoroughly studied in order to construct a sustainable solution for the traffic congestion due to school trips in Colombo district. Therefore, the study focuses on identifying the transport mode choice of school children in the study area with respect to their school type and location along with identification of factors affecting their selection of transport modes. There are 402 functioning government schools, 30 government approved private schools and few international schools located in Colombo district [1]. Major portion of the school trips is attracted to the government schools located in the study area. Some private schools operate their own transport system for their students. Therefore, as an initiation, this study focuses on analysing the mode choice behaviour of students in government schools located in Colombo district.

2. Literature Review

A trip is defined as moving from one place to another with the use of different transport modes. A trip generated from a household or a boarding place (hostel) and terminating in a school premises is called a school trip. Travel demand for school trips depend on several factors such as distance to school, popularity of the school, availability of resources, choice of school etc. The school choice varies on proximity, school type, authority of the school, extra-curricular activities, inner city student migration etc. [2]. Proximity or in other words nearness is a major factor that governs the school choice [2]. But the school type and the authority of the school may reduce the effect of proximity to the school choice.

Sri Lankan education system is generally state-funded and provide education is free of charge through government schools. Apart from that, there are few government approved private schools and international schools established under the approval of the Board of Investment (BOI) – Sri Lanka, providing education based on local syllabus prepared by the Ministry of Education as well as the British syllabus. There are 10,169 government schools (4,149,661 students) and 118 private schools (279,283 students) available in the country by 2019 as per the Annual report of Central Bank, Sri Lanka [1]. School education in the country consists of 13 years of schooling (Grade 1–13) broken down into four categories based on the age of a student as shown in **Table 2**.

Table 2 - General Education System of Sri Lanka by the Age of a Student [1]

Category	Age (Grade)	Remarks
Primary school	5-10 (1-5)	Compulsory
Junior secondary school	11-14 (6-9)	Compulsory
Senior secondary school	15-16 (10-11)	Not compulsory (For G.C.E. O/L)
Collegiate	17-19 (12-13)	Not compulsory (For G.C.E. A/L)

The current legislation system has made the school education compulsory for all children under the age of 14 years in the country. However, education participation percentage of Sri Lanka has been identified as 94.4% for children aged between 5-9, 92.2% for children aged between 10-14 and reduced to 52.6% for children aged between 15-19 [3]. Poverty is one of the major reasons for leaving schools after the age of 14 years [4], along with other reasons such as not interested in education, engaged with family support economic activities etc. [5].
Mode choice or modal split is the third step of traditional four step model, where the trips distributed among origins and destinations in the study area are split into various transport modes [6]. Factors affecting the transport mode choice can be categorized into four broad categories as trip characteristics, household characteristics, zonal characteristics and network characteristics [6]. Transport mode used for school trips depends on several attributes such as age of the student, type of the resident area (rural/urban/semi-urban), gender of the student, household's monthly income, household's vehicle ownership, student's perspective towards active transportation and parental care giving [8]. Apart from that, utility of a particular transport mode is affected by the cost of using that particular transport mode and the weather of the area as well [2]. It has been found that 1% increase in vehicle travel time, resulted in 21% increase in the walking

probability for trips with shorter travel distances [12]. Supporting that, few other studies have also identified distance or travel time as one of the critical determinant factors of mode choice, specifically for school trips [13]. Individual preference or taste heterogeneity of the school children is a major factor that has not been considered in most of the studies conducted related to travel behaviour of school children [14]. Most of the time, use of active transport modes for school trips is affected by the parent's preferences as well. When considering the school locations, urban form, land use pattern of the area, connectivity to public transportation and availability of urban infrastructures also affect the choice of travel mode by the school children [11].

To evaluate the public transportation services available for school trips, three criteria can be used as efficiency, effectiveness and equity [12]. However, it has been revealed that the use of private transport modes for school trips have been increased in Colombo district compared to the rest of the country while the public transport mode share and the active transport mode share reduced [5].

Escorting children is the other common practice that can be seen in most of the school trips, which makes the children invisible as a transport consumer, since they are taken as a part of another trip [8]. Travel habits at a younger age are found to continue in future whereas children who do not use public transport modes in their younger age are less likely to be public transport users in their adult age [10]. Safety of the children while travelling to school is another major concern of parents which has impacted the travel mode choice of school children [11].

3. Methodology

Colombo district was selected as the study area which consists of 13 Divisional Secretariat Divisions as shown in Figure 1. However, the study concerns school trips attracted to government schools located in the study area which covers about 85% of the total school trips attracted to the study area.

Figure 1 - Study Area

After a critical review of literature, a questionnaire survey was conducted in selected 28 schools in the study area with a total sample size of 2,875 students. Stratified sampling technique was used to collect data as total schools available in Colombo district were divided into subgroups (strata) based on the location, then randomly selected schools from each strata were used to perform the questionnaire survey. Furthermore, participants for the survey in the selected schools were also selected on a random basis. The sample includes five boys schools with a total sample size of 594 students, six girls schools with a total sample size of 681 students and 17 mixed schools with a total sample size of 1,600 students. When considering the school type, there were 12 Category A schools with a total sample size of 1,574 students, eight Category B schools with a total sample size of 758 students and eight Category C schools with a total sample size of 543 students. The sample sizes were selected for each category based on the total number of students studying in each category as a proportion to the total. However, the pandemic situation in the country has affected the later part of the data collection where it was initially planned to collect data from 32 schools but had to limit to 28 schools. The questionnaire was mainly focused on recording the respective transport mode used to travel to schools, origin destination data of school children, distance to school, travel time, travel cost, availability of vehicles at home, accessibility to public transport modes, whether the students were escorted by someone else and some other demographic factors.

Transport modes used by the students in the study area for school trips based on the following sub-categories were analysed separately.

i. Transport mode with respect to the travel distance
ii. Transport mode with respect to the school category
iii. Transport mode with respect to the gender of the student

iv. Transport mode with respect to the student's grade of study
v. Transport mode with respect to whether the student was engaged with any after school activities
vi. Transport mode with respect to the household vehicle availability of the students

If the main transport mode used for school trips differ from public transport modes, reasons to avoid public transport modes were analysed separately in order to identify the improvements to be made to attract more students to public transport services.

A sample O-D matrix was developed using the data collected through the questionnaire survey. The total number of destination zones were equal to 13 Divisional Secretariat Divisions (DSDs) in Colombo District. But all the school trips attracted to Colombo District were not originated from Colombo District. Therefore, total number of origin zones are equal to 15 in order to cater the school trips originated from other two districts of the province. However, there were only eight school trips attracted to the study area from other two bordering districts Kegalle and Ratnapura in the sample, which was 0.2% of the sample, hence neglected in the study. Then a distance matrix was developed using a network analysis carried out with the help of the Arc Map 10.5 software. DSD centres have been identified and the distances were calculated among each DSD centre with respect to the road network. The percentage of trips with respect to their distance from school has been calculated in this step. After that, the number of school age children who live in each DSD of the study area and the number of students that can be accommodated by the government schools located in those DSDs have been analysed separately in order to identify the imbalance of resource distribution in education system which has resulted in the need travelling longer distances to fulfil the educational needs of the children.

Finally, O-D patterns of the school trips in the study area has been analysed and presented as O-D desire lines based on the origin destination data collected through the questionnaire survey in order to identify the potential O-D pairs in which a high demand for school trips exist. Recommendations of the study have been provided at the end of this paper based on the analysis carried out as mentioned above.

4. Results and Discussion

4.1 Daily Travel Distance of School Children in the Study Area

Daily travel distance of school children attracted to the schools located in the study area has been calculated based on the distance between origins and destinations of the sample and presented in a Trip Length Frequency Diagram (TLFD) as shown in **Figure 2**. As per the guidelines of school enrolment process for grade 1, home to school distance should be less than 2 km (mostly in 1 km radius range).

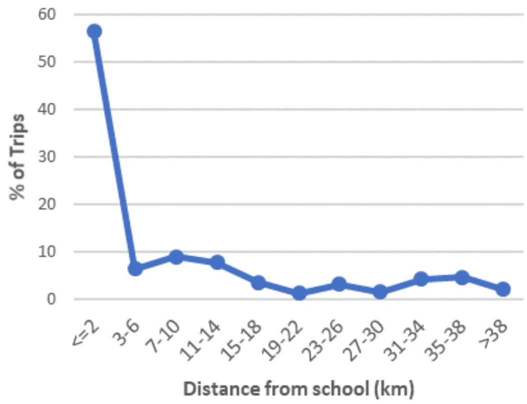

Figure 2 - Trip Length Frequency Diagram for School Trips

In the sample data collected, 44% of trips show longer than 2 km distance from the school and even it has reached up to 50 km of daily travel distance for some school trips. When finding the reasons for these higher trip lengths, it has been identified that imbalance of resource distribution in the study area was one of the major reasons for students to travel from one DSD to another in order to fulfil their educational needs. Therefore, the number of school children live in each DSD of the study area and the number of school children that can be accommodated by the schools located in those DSDs have been compiled by the author as shown in **Figure 3**.

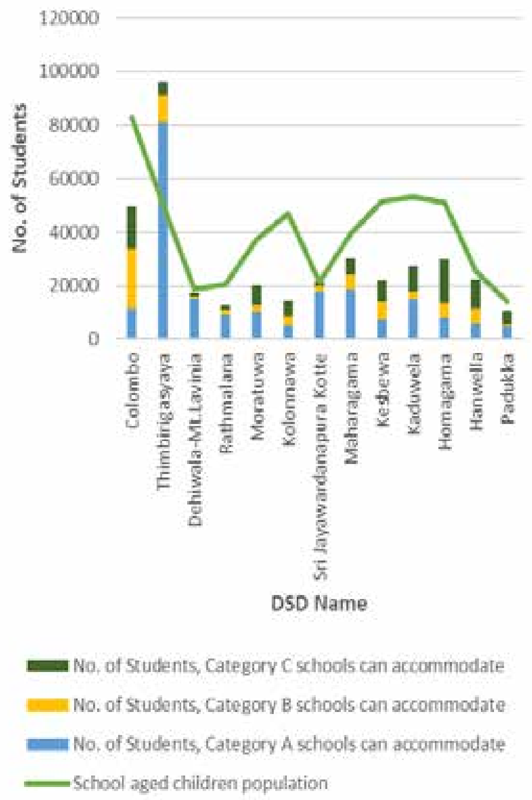

Figure 3 - Student Populations vs. Capacity of Available Government Schools in the Study Area

It can be clearly seen that the number of school aged children live in each DSD except the Thimbirigasyaya and Sri Jayawardenapura Kotte DSDs exceeds the number of students that can be accommodated by the available government schools. This imbalance of resource distribution has resulted in school trips with longer travel distances in the study area.

When considering the daily travel distances of school children in each school categories separately, Category A schools show a lesser percentage of students located near to the school compared to other school types as shown in **Figure 4**.

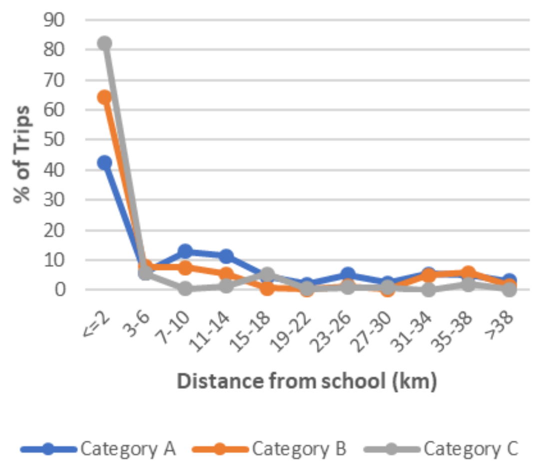

Figure 4 - Trip Length Frequency Diagram for each School Category

Category C schools show 82% of trips originated from less than 2km distance from the schools, but Category A and Category B schools only have 42% and 64% trips respectively originated from less than 2km distance from the school. Therefore, most of the school trips with higher distances are attracted to Category A and Category B schools in the study area as it is allowed to apply for any school after the grade 5 scholarship exam and also after O/L if preferred stream of study is not available in the present school. Further, admission based on different other categories such as old boy/girl, brother/sister category, armed forces and other professional category quota also in effect.

4.2 Transport Modes Used for School Trips

The composition of transport modes used for school trips in the study area is shown in **Figure 5**.

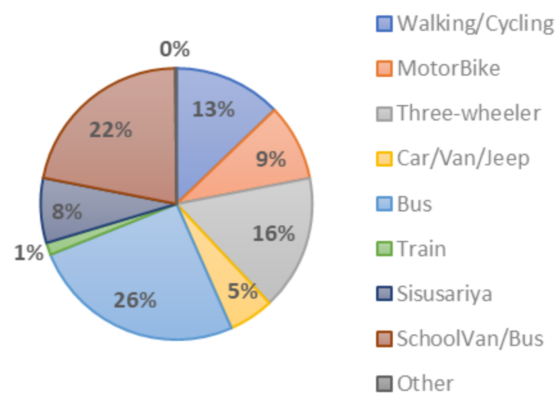

Figure 5 - Composition of Transport Modes used for School Trips

As it is shown in the above figure, buses are the most commonly used transport mode for school trips when considering the whole study area along with school van/bus services and three-wheelers as the second and third transport mode, respectively. However, trains show only 1% share because of the limited railway tracks available in the study area. In order to clearly interpret the transport modes used by the school children, those vehicle categories have been re-categorized into walking/cycling as active transport mode, bus, train and Sisu-sariya bus service as public transport mode, motorbikes, three-wheelers, car/van/jeep and other modes as private transport mode and private school transport services including both school vans and school buses separately as shown in **Table 3**.

Table 3 - Modal Share for each Transport Mode Category

Mode	Modal share
Active Transport Mode	13 %
Public Transport Mode	35 %
Private Transport Mode	30 %
School Van/Bus Services	22 %

Public transport modes have the highest modal share (34%) for school trips in the study area, while active transport modes were the least popular mode category among school children, and the private transport modes have a considerable share (35%) along with the school van/bus services (22%).
In order to have an in depth understanding of the transport mode choices of the school children and the factors affecting their mode choice, it has been analysed with respect to different sub categories as follows.

i. Transport Mode vs. Travel Distance

The transport mode used with respect to the daily travel distance of school children has been analysed separately as shown in **Figure 6**.

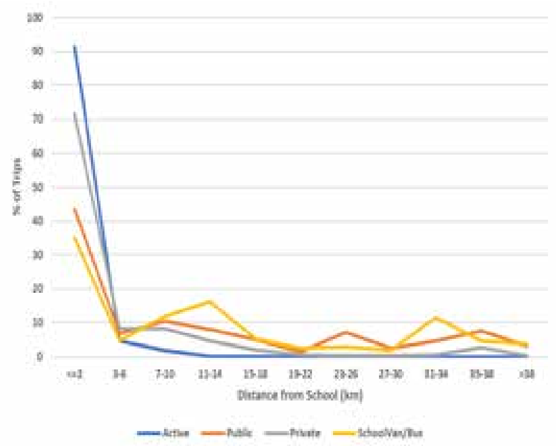

Figure 6 - Percentage of Trips Used by each Transport Mode vs. Distance

91 % of the active transport mode users (walking and cycling) originated within 2km radius from the schools. At the same time, 71% of the private transport mode users were also living within 2km range from the school which has contributed to the higher congestion on roads in the peak hours. When the distance from school increases, public transport modes and school van/bus services become more popular among the school children.

ii. Transport Mode vs. School Category

Students in different school categories show different patterns in transport mode selection for their school trips as shown in **Figure 7**.

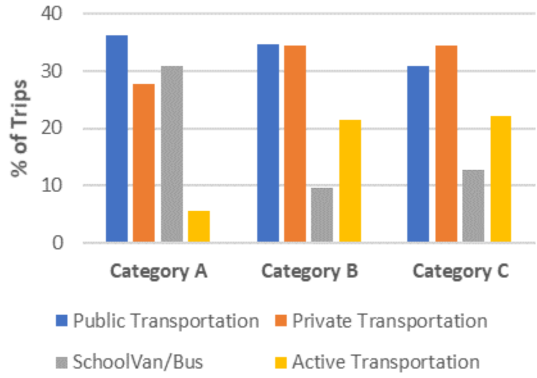

Figure 7 - Transport Mode Selection Based on the School Type

Public and private transport modes are the prime mode of travel among the students of category B & C schools while school van/bus services along with public transport modes are much popular among the school children of category A schools. Active transport modes are comparatively popular among the students of category C schools, because they show more than 80% of trips generated within 2 km distance from the school. Supporting that, it has been found by another study that school children would prefer to walk or cycle not more than 15 minutes time interval for their daily school trips [11]. The active transport users identified in the study also live in near proximity to their schools proving that school children do not prefer to use active transport modes for longer travel distances or trips with longer travel times.

iii. Transport Mode vs. Gender

The transport modes used by the male students and female students have been analysed separately in order to identify the most popular transport modes among each gender category.

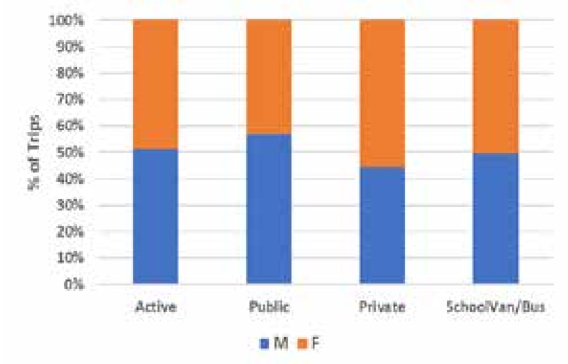

Figure 8 - Transport Mode vs. Gender

Active and public transportation modes are slightly more popular among male students while private transport modes and school van/bus services are more popular among female students in the study area considering the safety while travelling. But in general, gender was not found to be a major influential factor for transport mode choice among school children in the study area based on the above analysis.

iv. Transport Mode vs. Grade of study

The choice of transport mode with respect to the grade of study was analysed separately as shown in **Figure 9**.

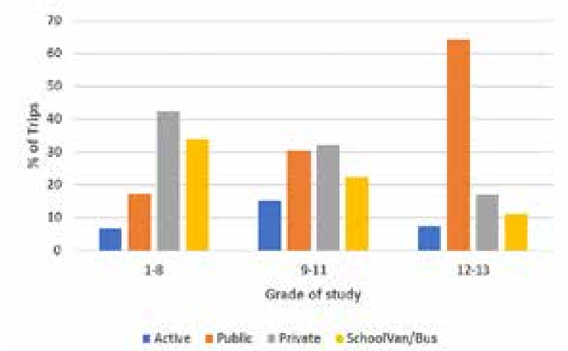

Figure 9 - Transport Mode vs. Grade of Study

As can be seen from the above figure, public transport modes become popular among students when they advance to higher grades of study. 64% of the students who are in advanced level classes (12 and 13) use public transport modes for their daily school trips. Private transport modes are more popular in lower grades where, 42% of the students in below grade 8 and 32% of the students in grade 9-11 uses private transport modes as their main mode of travel to school. This shows that age of the student or the grade of study is an influential factor for use of public transport modes for school trips in the study area.

v. Transport Mode vs. After school Activities

It has been identified that after school activities affect the transport mode choice of school children, because 32% of the students who were engaged with after school activities have selected private transport modes as their main mode of travel while the students who were not engaged with after school activities have only 25% share on private transport modes. All the other modes have comparatively decreased their modal share when students engaged with after school activities as shown in the **Table 4**.

Table 4 - Effect of After School Activities on Transport Mode Selection

Travel Mode	After school Activities - YES	After school Activities - NO
Active	12%	15%
Public	34%	36%
Private	32%	25%
School van/bus	21%	24%
TOTAL	**100%**	**100%**

vi. Transport Mode vs. Vehicle Availability at Home

Vehicle availability vs. transport mode selection has been analysed and the results revealed that 36% of the students who owned private vehicles in their households, uses them for their school trips while only 9% of them use active transport modes to reach their schools which is a 17% decrease compared to the students with no vehicle at home. It can be assumed that the students who have private vehicles at their homes have higher household income levels compared to other students. 24% of the students who have vehicles in their households use school van/bus services for their school trips which is an 8% increase compared to the students who have no vehicles in their households.

4.3 Reasons to Avoid Public Transport Modes

The reasons to avoid public transport modes for school trips were questioned from the students who were not using public transport modes as their main mode of travel. Those reasons were identified in two broad categories, i.e. major reasons and minor reasons. Major reasons were the travel time and waiting time, accessibility and security. Minor reasons were identified as comfort, reliability and non-availability of vehicles as shown in **Figure 10**.

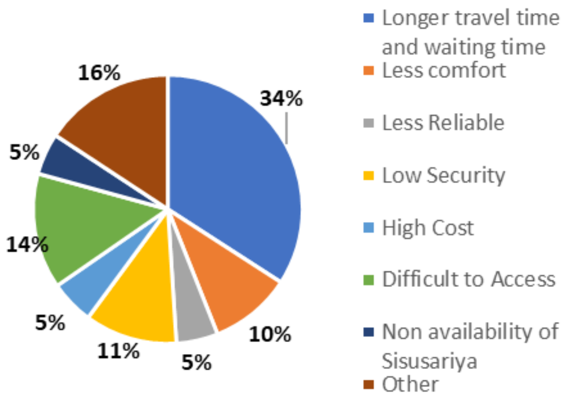

Figure 10 - Reasons to Avoid Public Transport Modes

Travel time and the waiting time incorporated with the public transport services were the main demotivating factors for students to avoid public transport modes in the study area. Accessibility to the public transportation and the security of the passengers were contributing to the choice of public transportation modes as 14% and 11%, respectively. Some of the other reasons mentioned above were the availability of private vehicles in homes, residing near to the school etc. which contributes 16% cumulatively to the choice of public transport services.

4.4 O-D Patterns of the School Trips

O-D patterns of the school trips have been represented by using O-D desire lines generated through analysing the origin and destination data of the sample responses collected through the questionnaire survey. A sample O-D matrix was developed using the collected data and expanded to the actual population using the calculated expansion factors. The sample was first expanded to the total student population of the particular school using the following formula.

$$EXP(1) = \frac{tot_{school}}{tot_{sample}} \qquad ...(1)$$

Where,

$EXP(1) = Expansion\ factor\ for\ sch\ ool\ (n)$
$tot_{sch\ ool} = Total\ no.\ of\ students\ in\ sch\ ool\ (n)$
$tot_{sample} = No.\ of\ trips\ attracted\ to\ sch\ ool\ (n)$ $in\ th\ e\ sample$

Then the expanded number of trips attracted to sample schools located in a particular DSD were added together and expanded into total number of students in schools located in that particular DSD using **Equation 2**.

$$EXP(2) = \frac{TOT_{school}}{exp\_tot_{sample}} \qquad ...(2)$$

Where,
$EXP(2) = Expansion\ factor\ for$ DSD (j)
$TOT_{sch\ ool} = Total\ No.\ of\ students\ in$ government $schools\ located\ in$ DSD j
$exp\_tot_{sample} = Total\ expanded\ sample\ trips$ $attracted\ to\ sch\ ools\ located\ in$ DSD j

The estimation of the O-D trips was destination constrained, because the expansion factors calculated using the number of students in the government schools located in the study area which was equal to the number of school trips attracted to each destination zone of the study area. O-D desire line were developed based on the trip distribution data as shown in **Figure 11**.

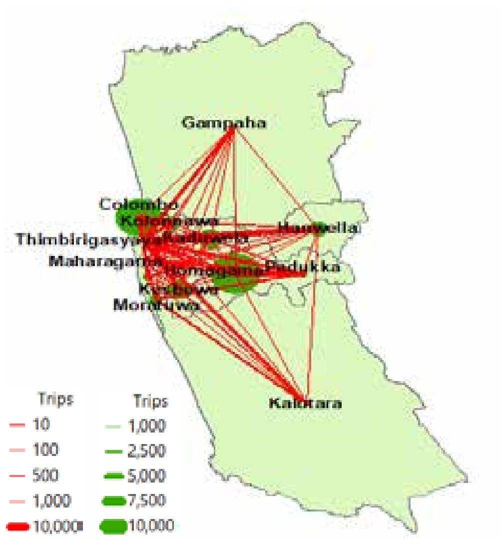

Figure 11 - O-D Desire Lines for School Trips

In Figure 11, the green coloured circles show the intra-zonal trips in the study area while red coloured lines represent the Inter-zonal trips. There are five origin-destination pairs inside the study area that can be identified with more than 5,000 home to school trips distributed per day as Kolonnawa to Colombo, Padukka to Homagama and from Kaduwela, Hanwella, Padukka area to Thimbirigasyaya. Apart from that, Thimbirigasyaya DSD has shown over 5,000 school trips attracted from Kalutara and Gampaha Districts per day, which were identified as External-Internal trips attracted to the study area.
Apart from the major findings of the study, 35% of the students in the sample were escorted by their parents to the schools as a part of another

trip which made them invisible as a transportation service consumer.

5. Conclusion & Recommendations

This paper was targeted on analysing the factors affecting the transport mode choice for home to school trips attracted to Colombo district. There were mainly six factors considered in the study as distance to school, school type, gender of the student, grade of study, engagement with after school activities and household vehicle availability. The variation of transport mode choice with respect to those factors was analysed. Main reasons to avoid public transport modes as the main mode of travel for home to school trips were identified as higher travel time, longer waiting time, poor accessibility and low security. Further, the higher demand that exists for school trips for 5 origin-destination pairs inside the study area were highlighted. This study recommends to address the identified factors which made students away from public transport services for their school trips as well as to supply adequate public transport services to cater the higher demand for school trips identified in particular O-D pairs. Since there are some well-established private and international schools located in the study area, it is expected to extend this study for students in those schools as well, in order to incorporate all the school trips attracted to Colombo district. Further, the study sets the background to develop a mode choice model for school trips followed by a demand model for school trips in the study area.

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Assessing the Walk-Score of Walking Paths in Kandy City Area for Better Walking Experience for the Tourists

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Abstract: Walking has been always considered as a sustainable method of transportation which is more suitable for short distance trips. It is observed that tourists would prefer to walk more than local residents in cities with many tourist attractions located in close proximity. The City of Kandy, in Sri Lanka, can be recognized as one good example for such cities. Even though the tourists are willing to walk longer distances, this study has assessed the walking experience of a pedestrian in the city limits of Kandy, based on a walk score. Several walkability characteristics are taken into account to generate the walk score for segments of roads in the city and Pedestrian Level of Service (PLOS) was also considered. The objective of this study was to recognize the best walking paths between the tourist attractions using these qualities. This study used an evaluation criterion previously developed by Dias in 2012 to obtain the walk-score, and tourism specific features such as availability of shops and ATM machines were considered. The study area was based on the tourist attractions in Kandy. Data were collected through field surveys in 2018 to identify walking facilities provided and to estimate PLOS in the selected street segments. Twenty-six road segments were selected for the study and the Walk-score ranged from 24% to 60% with an average of 45%, which cannot be considered as a satisfactory situation. The results showed lack of pedestrian amenities in many street segments could be discouraging tourists to choose the street segment for their route. When selecting a walking path to reach a tourist destination it is expected that tourists will tend to select the best walking path.

Keywords: Walkability, Walk score, Pedestrian amenities, Tourism, Kandy

1. Introduction

Walking has been always considered as a sustainable method of transportation which is more suitable for short distance trips. There are several, but not many yardsticks available to measure walkability. When the definition is taken, "walkability" is simply how walking is facilitated by infrastructure and urban planning. Further, the concept of "short distance trip" changes with the convenient maximum walking distance of a human being.
As a result, a resident might not walk longer distances as compared to a foreign tourist.

However, it is observed that tourists would prefer to walk more than local residents. Tourism has a significant relationship with walking. Most tourists like to feel the close connection to the environment through walking. This is noticeable specially in cities with many tourist attractions located within proximity and also when the weather is perceived as comfortable. In order to develop walking as a popular travel mode among the tourists, a city should have a variety of walking facilities provided to encourage walking. Most importantly tourists should be able to do walking as an active travel mode without any interruption. Tourists may use walking as a travel mode to reduce traffic congestion they may have to face during their trips.

1.1 Background

Kandy city, the cultural capital of Sri Lanka, is one of the major tourist attraction areas inside the country. City has prominent tourist attractions like temple of tooth, Old Royal Palace compound (headquarters of Malwatta and Asgiriya within its precincts) Annual Esala Perahara, Udawatte preserve and many cultural heritage sites. It was declared a world heritage site by UNESCO in 1988[1].

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Within the Kandy city area, lesser foreign tourists could be observed due to lack of walking facilities and amenities. The sidewalks inside the city area are often overcrowded and it forces the pedestrians to use the road causing traffic congestion. It is important to analyse the adequacy of the walkways to facilitate higher pedestrian volumes without interruption. One basic requirement for pedestrians is sufficiently wide sidewalks. Within the Kandy city limits, walkways are obstructed due to many reasons and some are shown in Figures 1 to 3.

Figure 1 - Unsystematic Garbage Piles

Figure 2 - Constructions Encroaching into the Sidewalks

The first objective of this study was to evaluate the Pedestrian Level of Service (PLOS) of the street segments within the Kandy City. The second objective was to estimate a walkscore for all the main street segments within the Kandy city between the Kandy Railway Station and the Municipal Council junction (entrance to the Udawatte Reserve). Then a strategy is proposed to choose the most preferred route connecting the street segments from a given origin to a destination covering the required tourist destinations.

Figure 3 - Unfavorable Obstructions for Pedestrians

The outcome can be used to superimpose in a digital map of Kandy, so that a tourist can make an informed decision on which road links to use to reach a particular destination from their origin. This could also be used to plan out a walking route to cover all the tourist attractions within the city.

Factors that need to be considered in order to develop a walkscore are, walkway width, pedestrian amenities, recreational activities, etc. Walking is a good solution to prevent unnecessary traffic congestion, but there are better walking routes within the city which are not recognized by the tourists. Thus, tourists are not well informed.

2. Literature Review

Tourists who ever come to visit some place are mostly like to walk through the destination and in-between their journey. As tourism becomes more sustainable, there is interest in encouraging tourists to use an active travel mode when visiting destinations. A study done by Kumarage and Bandara (2018) has proven that tourists are willing to walk to the destinations which are more attractive and it has also mentioned that most of the tourists believe that walking is the best way to experience the city [2]. Hall and Ram (2017) have identified that walkability affects urban as well as rural tourism in many ways [3]. Furthermore, tourists are also interested in walking through built-up environments which is potentially an asset for tourist attraction and services such as transport, accommodation, restaurants. It is also mentioned that tourists are not only interested in walking and they use walking as a travel mode to maximize sightseeing.

In contrast with the interest to walk, an individual's willingness to walk varies greatly depending on age, health, time availability, quality of surroundings, safety, climate, and many other factors. As the convenient maximum walking distance varies for different individuals, an average distance of 400m can be accepted [4].

2.1 Pedestrian Level of Service

Pedestrian Level of Service (PLOS) is defined by the Highway Capacity Manual (HCM) and the version considered in this study is 2000 [5]. Use of PLOS concept to evaluate walking conditions is not new and it was observed in past literature as well. Miranda and Carrasco (2011) in their study have discussed various practical methods to obtain pedestrian data for these studies [6]. They have found that pedestrians walking in the same direction chooses the side of the road that has wider sidewalks to do their walk. Shaban and Muley (2016) studied the impact of weather conditions on pedestrian volume and they have discussed the importance of considering all seasons for pedestrian studies [7]. Sony and Destri (2018) have studied various PLOS methods other than HCM and concluded that the evaluations vary but the recommendations related to effective walking width improvements are much more reliable through HCM [8].

2.2 Evaluating the Walkscore

Sidewalks are defined as the backbone of the pedestrian transportation network. Sidewalks narrow than 1.5 m are not encouraged to be proposed for the score cards and sidewalks more than 1m can score because of the presence of the sidewalks [9]. According to Dias (2012), the effective length of an obstruction is considered as five times its effective width and it further reduces the effective area of the sidewalk [9].

Connectivity factor which can describe as connectivity to the main roads, linkage to other important walking paths which have higher scenic views also very important when considering walking of tourists[10].

Buffers along sidewalks can be provided to increase pedestrian comfort by increasing the lateral separation between pedestrians and fast-moving cars [9]. These buffers can be landscaped and include street trees, green infrastructure, street infrastructure such as light toilet or utility poles, and transit stops. They also provide space for driveway pads while allowing the sidewalk to remain level. Presence of buffers is taken as a measuring element by Dias (2012) in the walkability evaluation criterion. Other than that, modal conflict is safeguarded by elevated sidewalks and that is also considered in the same criterion.
Walkways should be comfortable for all road users including differently abled people. Disability infrastructure listed by Dias (2012) is shown in Table 1.

Pedestrians seek frequent crossing points for their convenience. Most people will walk 150 feet (46 m) to get to locations rewarding their arrival. If pedestrian crossings are not available at frequent distances, pedestrians tend jaywalk and increase the ability for road crashes [9].

Table 1 - Disability Infrastructure – Survey Form Section

	Disability Infrastructure		
i	Correctly placed tactile paving along the sidewalks	YES	NO
ii	Correctly placed tactile paving along the crossings	YES	NO
iii	Gradient/ slope of sidewalks are convenient (less then 1:20)	YES	NO
iv	Cross slopes are convenient (less than 1:50)	YES	NO
v	Dropped curbs/ curb ramps are present at road junctions where there is a change in level	YES	NO
vi	Water does not pool on pathways	YES	NO
vii	No open drains/ tree routes across pathways	YES	NO
viii	Central ramps with flared sides	YES	NO
ix	Ramp surface is wider than 900mm	YES	NO
x	Ramps have non-slip surfacing	YES	NO
xi	Color of ramps and flare sides are in contrast with surrounding	YES	NO
xii	Curb ramps leave at least 900mm of the pathway and do not obstruct through flow	YES	NO
xiii	No overhead obstructions below 2200 mm	YES	NO
xiv	Audible warnings at pedestrian crossings	YES	NO

In many studies it is found that pedestrian friendly community include safety, weather, distance, lifestyle, and best suited layout that is having flat terrain, mild climate, inter-connected network allows to develop pedestrian friendly community[11][12]. In that research, it was also mentioned that importance of building recreational paths and walk paths should be designed knowing that residents are willing to walk 10-15 minutes at a time. Some have identified factors affecting the walkability as continuity, connectivity, absence of barriers, linkage to the transport modes, safety from traffic, physical condition of the path and contextual values such as aesthetic and historic values[13].

A study done for Dhaka city, identified walking parameters as walking path modal conflict (15%), availability of walking paths (25%), availability of crossings (10%), grade crossing safety (10%), motorist behavior (5%), amenities (10%), disability infrastructure (10%), obstructions (10%) and security from crime (5%) and all these parameters have given different weight to determine the walkability ratings (which are given within brackets) [14].

According to a study done to compare neighbourhood walkability to community facilities in Putrajaya emphasized that, facilities such as, grocery/supermarket, parks or recreational facilities (indoor and outdoor), elementary schools, other schools, community centres, banks, bus stops, post offices, and pharmacies and their availability within 400m, increase the tendency of walking [15].

3. Methodology

The study area is Kandy City and 26 street segments in the city as shown in Figure 4 are analysed. High pedestrian volumes can be observed in the morning peak hours where commuters, school children and many other pedestrians are included on a regular day. In the month of July, Esala Perahara (also known as Kandy procession) is starts and held for ten days. Data collection was done in the above-mentioned roads during both in season and off-season time periods.

3.1 Pedestrian Level of Service (PLOS)

PLOS was considered in this study only as a check to determine whether the minimum required pedestrian facilities are available on the selected road segments. Facilitating the foreign or local tourists in walking could become the second need to improve the walking infrastructure in the city.

To evaluate the PLOS for each segment, Highway Capacity Manual (2000) [5] was used.

Figure 4 - Street Segments on a Map

In summary, the steps involved in estimating PLOS are as follows:

Step 1: Measure walkway width (m) - W_t
Step 2: Find the sum of obstructions (m) - W_o
Step 3: Calculate effective width (m) - W_e
Step 4: Measure peak 15-min flow (p/15-min) - V_{15}
Step 5: Calculate pedestrian flow rate (p/min/m) - V_P
Step 6: determine pedestrian level of service

Exhibit 18-6 of HCM (2000) lists the average flow LOS criteria for walkways and sideways.

However, it is important to note that HCM does not provide PLOS evaluation measures for pedestrian activity where pedestrian walk on roadway, bicycle lanes. For these locations PLOS as a concept is considered LOS F as well as for situations where pedestrian platooning occurs. Platoon-adjusted LOS criteria could be found in Exhibit 18-4 [5]. Flow rates less than 16 p/min/m is LOS *A*, 16-23 is LOS *B*, 23-33 is LOS *C*, 33-49 is LOS *D*, 49-75 is LOS *E* and when available pedestrian space is less than 0.75 m^2/p and when the flow rate varies, the LOS is considered as *F*. The platoon adjusted flow rates range from 1.6 to 59 p/min/m.

Field data were collected on walking weekdays from 7.00 am to 10.00 am to identify the morning peak hour and 3.00 pm to 6.00 pm to identify the evening peak hour.

3.2 Determining the Walkscore

Walkscore was evaluated using several aspects. Walkability measurement criterion proposed by Dias [9] was used for these aspects.

- Presence and continuity of side walks
- Effective width of sidewalks
- Modal conflict
  – Presence of buffer

Buffers along sidewalks can be provided to increase pedestrian comfort by increasing the lateral separation between pedestrians and fast-moving cars [9]. These buffers can be on-street parking spaces, landscaped and including street trees, green infrastructure, bicycle lanes, street infrastructure such as lighting or utility poles, or bollards etc.. They also provide space for driveway pads while allowing the sidewalk to remain level.

$$Score = \frac{\text{Total length of sidewalk that satisfy the minimum width of buffer}}{\text{Total length of the street segment}} * 100\% \quad \ldots (1)$$

– Elevation difference between sidewalks and carriageway

Height difference of the sidewalks and the carriageway affects the protection of the pedestrian from motorized or non-motorized traffic flow. Most of the countries, instead of raising the whole sidewalk, only the curb length is raised up to some level to prevent conflict between pedestrians and motor traffic. If such curb is available, it should be taken in account as same as a raised sidewalk[9]. Elevation of the curb depend on the Annual Daily Traffic (ADT) of the conflicting road network and its land use [9].

$$Score = \frac{Total\ length\ of\ sidewalk\ that\ satisfy\ the\ minimum\ height\ of\ sidewalk}{Total\ length\ of\ the\ street\ segment} * 100\% \quad \ldots (2)$$

- Disability infrastructure

Walking should be comfortable for all road users including people with disabilities, parents using baby strollers, etc. Score for this is evaluated according to the disability infrastructure proposed by Dias [9] (See Table 1).

- Availability of crosswalks
- Distance to pedestrian (tourist) amenities
  - Banks
  - ATMs
  - Restaurants
  - Shopping malls
  - Public transportation

A Tourists may have their own preference to these amenities depending on their requirements. Hence, as an output level, when the concept proposed in this paper is available through a digital version – as a mobile application, the users can feed their preference to the application. Then, a factored score will be calculated from Equation 3.

$$Score\ for\ amenities = \frac{\sum_{i=1}^{n} C_i F_i}{n} \quad \ldots (3)$$

Where, C_i is the score related to the distance to each amenity and F_i is the weight factor for each amenity.

A similar method used by Cubukcu et al (2015) in their study [16].

By allowing the users to choose the weight factor according to their preference will improve the suggested paths in a customized manner.

The weight factors used for these sample calculations are shown in Table 4.

- Availability of aesthetic views or recreational areas

Only four road segments among these 26 segments scored to have aesthetic views or recreational areas. Those were: Segments B, D, E, and F. Hence this factor was removed from the final analysis to prevent bias.

3.3 Identifying the Street Segments

Street segments are codes by alphabetical letters such as Greek letters as shown in Figure 4. The list of names of the considered roads is shown in Table 2. Even though walkscore was determined for 26 road segments, PLOS was determined for three extra road segments.

Table 2 - Street Names and Included Segments

Street name	Letter Coding	# of road segments
EL Senanayake Street	A,J,O,U,X	5
Sri DaladaVeediya	B,G	2
YatinuwraVeediya	C,H,M,S,V	5
Colombo Street	D,E	2
DS Senanayake Street	F,L,R,Z	4
Raja Veediya	I,K	2
Kumara Veediya	N	1
SWRD Bandaranayake Mawatha	P	1
KandeVeediya	W,Y	2
Cross Street	Q,T	2
Kappetipola Mawatha	α	1
Sri WickramaRajasinghe Mawatha	β	1
Sangaraja Mawatha	γ	1

4. Results and Discussion

4.1 Pedestrian Level of Service Calculations

Examples of PLOS estimations are given below. Street segment A is considered as EL Senanayake Street. Several important amenities and restaurants are located on this street and this road segment is crowded because of the Kataragama Kovil located on the roadside. PLOS and walk score evaluation sheets for segment A are provided in Table 3, 4 and 5.

Table 3 -PLOS Calculations for Road Segment A

LOCATION		=	A
WALKWAY WIDTH (m)	W_t	=	2.3
SUM OF OBSTRUCTION (m)	W_o	=	0.4
PEAK 15-MIN FLOW RATE	V_{15}	=	912

STEP 1	WIDTH ADJUSTMENTS(SHY DISTANCE) TO WALKWAY (m)	$W_e = W_t - W_o$	=	1.9
STEP 2	PEDESTRIAN FLOW RATE (p/min/m)	$V_p = \frac{V_{15}}{15 * W_E}$	=	32
STEP 3	PLOS			D

Table 4 - Distance to Pedestrian Amenities - Score for Road Segment A

Segment	Factor	Equation	Amenity	Weight Factor	Score for the distance	Final Score
A	Accessibility to amenities	$Score\ for\ amenities = \frac{\sum_{i=1}^{n} C_i F_i}{n}$	Banks	0.75	89.60	56.68
			Restaurants	1.00	100.00	
			Shopping malls	0.75	100.00	
			Bus stops/ train stations	0.50	52.37	
			ATMs	0.25	60.00	

Table 5 - Further Estimation of Scores - Road Segment A

Road Segement	A			
Main Factor	**Equation**	**Considered Factor**	**Data**	**Score %**
Presence and continuity of side walks	$Score = \left(1 - \frac{\sum Discontinuity\ lengths}{Total\ ledngth\ of\ the\ street}\right) *100\%$	Total walkway length (m)	137	100
		Legth of discontinuity (m)	0	
Effective width	$Score = \frac{Effective\ length\ of\ side\ walk\ that\ satisfy\ the\ minimum\ width}{Total\ length\ of\ the\ street\ segment}$	Total walkway width (m)	1.4	0
		Effective length that satisfy the minimum width (m)	0.5	
Present of buffer	$Score = \frac{Total\ length\ of\ side\ walk\ that\ satisfy\ the\ minimum\ width\ of\ buffer}{Total\ length\ of\ the\ street\ segment} *100\%$	Total walkway length (m)	137	0
		Sidewalk length that satisfy the minimum width of buffer (m)	0	
Height different between side walks and carriageway	$Score = \frac{Total\ length\ of\ side\ walk\ that\ satisfy\ the\ minimum\ height\ of\ sidewalk}{Total\ length\ of\ the\ street\ segment} *100\%$	Total walkway length (m)	137	0
		Sidewalk legth that satisfy the minimu height of sidewalk (m)	0	

4.2 Distances to the Nearest Pedestrian Amenities/Services

Figure 5 shows the Color-Coded Map according to the distances to the banks and ATMs. The key to the color code shown in Figure 5 is applicable to Figure 6, 7 and 8 as well. Figure 6 shows the Color-Coded Map according to the distances to the restaurants. Figure 7 shows the Color-Coded Map according to the distances to the shopping malls. Figure 8 shows the Color-Coded Map according to the distances to the bus stops or railway stations.

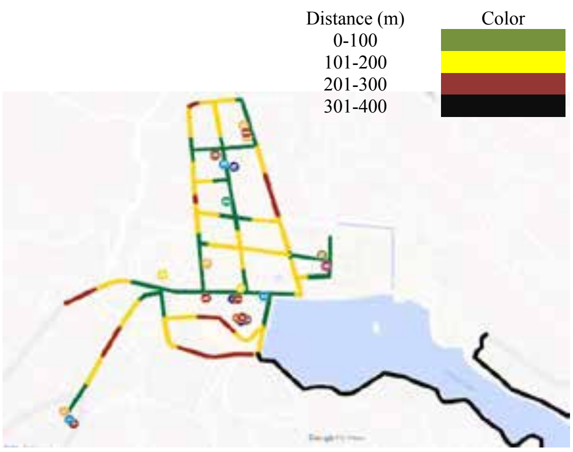

Figure 5 - Color-Coded Map for - Banks and ATMs

Figure 6 - Color-Coded Map for - Restaurants

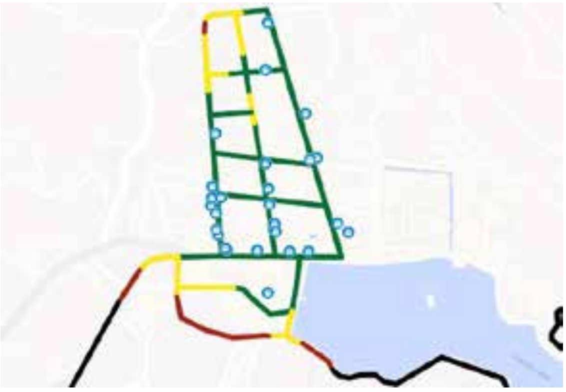

Figure 7 - Color-Coded Map for Shopping Malls

Figure 8 - Color-Coded Map Bus Stops or Railway Stations

4.3 Aesthetics

The total or the average walk-score shown in Table 6 has not incorporated aesthetics factor. Satisfactory levels of aesthetics or the availability of recreational areas were scored by only four street segments, namely *B*, *D*, *E*, and *F*.

Considered recreational areas were parks, roadside benches, availability of trees for shade etc. Although street segment *γ* does not have a higher walk score, it has higher number of recreational areas like parks, tennis courts and activities like boat rides. Amenities like trees, benches at lake side, higher number of hotels and restaurants are also available in this street segment.

4.4 Total Walkscore

When all the above parameters are considered, a total walkscore can be generated assuming equal weight to each parameter. If an opinion survey could be conducted to take the preference for each parameter from the foreign and local tourists, a weightage could be determined. However, that task was not carried out during the study period. Table 6 lists the names of the road segments, in a descending order from the highest walkability to the lowest. With that, it is observed that the highest walkscore obtained by a street segment in the Kandy city is 65%, which is not so satisfactory. Furthermore, when the PLOS is considered, the street segment with the highest walk score "G" has PLOS of F which is the worst condition. It shows that, even though some street segments are facilitated with sufficient amount of walkability measures, due to high pedestrian volumes, the Level of Service for pedestrians is lower. If PLOS A is considered as 100, and PLOS F as zero and respectively, PLOS can be included to estimate the average walkscore, in that manner, street segment "G" gets 57%. However, that decision can be made by each tourists by themselves depending on their priorities or preferences. It is also emphasized that the best route suggested through the highest walk score may or may not be the shortest path between the selected origin and the destination. Hence it has to be understood that it is always the decision of the tourist to decide what they value and select the route accordingly.

4.5 Walk Score for a Selected Walking Path

Here, it is shown how to take an informed decision on choosing the most favourable route from an origin to a destination. The estimated walk scores in Table 6 are uses. A route consists of one or more street segments and as a combination. If the distance factor is put aside, this concept can be discussed more elaboratively, when two alternative routes with similar trip length is considered. An example is from the Kandy Railway Station to the Temple of Tooth Relic (Maligawa).

Figure 9 shows the shortest route Route 1 from the Kandy Railway Station to the Temple of Tooth Relic (Maligawa), but to discuss the walk score, two other alternatives are recognized to fulfil that trip: Route 2 (Figure 10) and Route 3 (Figure 11).

Table 6 - Total Walk-Scores (without amenities)

Street Segment	Score for continuity %	Score for effective walkway width	Modal conflict		Availability of cross walks	Average Walk Score*	PLOS
			Buffer	Height difference between sidewalk and carriageway			
P	100	80	100	100	0	76.0	
G	100	59.4	0	100	100	71.9	F
H	100	80	0	100	50	66.0	E
Q	100	79.5	0	100	50	65.9	C
U	100	66.7	0	61	100	65.5	E
X	100	73.9	0	100	50	64.8	D
Y	100	73.9	0	100	50	64.8	D
F	100	86.4	0	0	100	57.3	D
Z	100	84	0	0	100	56.8	C
B	100	82.1	0	0	100	56.4	F
K	100	80.9	0	90	0	54.2	C
R	100	64.8	0	0	100	53.0	C
W	100	63.7	0	100	0	52.7	E
T	100	0	0	100	50	50.0	D
C	69	75	0	100	0	48.8	E
L	100	42.9	0	0	100	48.6	E
O	100	62.5	0	0	50	42.5	E
E	100	0	0	100	0	40.0	D
M	100	94.4	0	0	0	38.9	E
I	100	0	0	79	0	35.8	C
A	100	0	0	0	50	30.0	D
V	0	80	0	0	50	26.0	E
N	64	0	0	13	50	25.4	C
J	100	0	0	0	0	20.0	F
D	100	0	0	0	0	20.0	D
S	0	80	0	0	0	16.0	E

*This average score is calculated without the score for the distance to amenities.
Note: *Scores for disability infrastructure were zero for all road segments. Hence, it was removed from the table.*

Figure 9 - Shortest Route from the Railway Station to Maligawa (Route 1)

Figure 10 - Route 2 (P-B-A-E-F)

Figure 11 - Route 3 (P-C-D-E-F)

As indicated in Table 7, the shortest path has the highest walk score and a tourist may choose that path. If they were to select between Route 2 and 3, both the Routes 2 and 3 have trip lengths of 971 m, but the walk score for Route 2 is slightly higher than Route 3. Hence, it is clear that a pedestrian (tourist) can make an informed decision using these results.

Table 7 - Walk Score Comparison for Route 1 and 2

Route No.	Street segments included in order	TripLength (m)	Walk Score %
1	P-B-G	738	54.88
2	P-B-A-E-F	971	49.60
3	P-C-D-E-F	971	48.86

5. Conclusions

Twenty-six (26) street segments were selected to evaluate walk score from the Kandy city area. HCM 2000 was used to evaluate Pedestrian Level of Service for the selected street segments. By conducting pedestrian surveys during both morning and evening peak hours, it was identified that the higher pedestrian volume occurs on the road during the morning peak hours. Collected data was taken used to calculate PLOS and to check the adequacy of the walkway segments under two parameters, continuity, and effective walkway width.

Evaluation of walk score of the street segments was done according to a developed method by Dias in 2012 [9] and suitable approaches were also studied from other literature. Walkscore for each street segment basically indicates a qualitative measure of the street segment and it was given a quantitative nature considering several parameters. In this study, all parameters were given equal weight. However, due to limited availability, aesthetics and recreational areas were not incorporated into the total average walk score. Finally, total walk score is evaluated from taking the average walk score from each category and given a single walk score for each street segment.Walk scores are given considering factors that are important to both local and foreign tourists in the city. Road segment *J* on EL Senanayake Street has lowest PLOS value, which calls for widened sidewalks.

When selecting the best walking route from an origin to a destination, a local tourist may not want to select a longer route instead of the shortest path, unless they want to access an ATM or a restaurant etc. For any of these preferences, this study gives sufficient data for a user to take an informed decision. This is done by considering each street segment's length with the total route length.

Outcome of this study has to be developed into a mobile or web application. With such facility, amenities will be indicated on a map. No weightages were given for the amenities as the weightage can vary between local and foreign tourist groups. However, the mobile app could be developed in a way that the user can select their own preference to those amenities and get the output customized to their needs. In that case, this concept can be used by both local and foreign tourists.

This study has assessed how walkable the Kandy city is. Also, the municipal council can recognize the road segments which require improvements and road segments that are lacking the minimum requirements for pedestrians. This can be used when prioritizing funding allocations as well. It is realized from the literature review that improved pedestrian facilities reduce traffic congestion in downtown road segments.

Many road segments got lower PLOS due to frequent obstructions to pedestrians. These include improper garbage disposal, street vendors, unauthorized constructions encroaching into the sidewalks. Hence, it is important to remove such obstructions to optimize the available walking space. One other factor is installing roadside benches where pedestrian crowding occurs, and where sufficient space is available. It should be noted to maintain them clean without bird drops etc.

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Use of Demolished Concrete Waste for Resurfacing of Low Volume Roads in Sri Lanka Using Roller Compacted Concrete (RCC) Technology

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Abstract: Roller Compacted Concrete Pavement (RCCP) is a type of zero-slump concrete product, which has renewed the interests of designers of sustainable pavements with its potential to reduce the cement content of the concrete mixture. RCC is produced with the same ingredients as in conventional concrete but with different blend proportions. RCCP construction procedure is similar to that of asphalt paving, where laying is performed using a modified asphalt paver, and steel drum rollers follow the paver to ensure the laid RCC mixture to be compacted to its desired density.

This research aims to evaluate the applicability of deteriorated concrete pavement to reconstruct new pavement in an economical and sustainable approach. In this study, manually crushed concrete slabs were washed, sieved, and tested for aggregate strength to be used as a substitution for coarse aggregates (CA) in RCC. The soil compaction method is used for mix design, and the Vibratory Hammer Test (VHT) is used in place of the Modified Proctor Test (MPT) in determining the optimum moisture content (OMC) of RCC. The importance of incorporating the VHT in the mixture design process and the possibility of complete replacement of CA of RCC by Recycled Concrete Aggregate (RCA) are elaborated in this research.

Keywords: Roller Compacted Concrete, Optimum Moisture Content, Vibratory Hammer, Soil Compaction Method

1. Introduction

Sri Lanka has a spread-out road network of 116,000km in total and is classified into National, Provincial, Pradeshiya Sabha, and Local Authority roads based on administrative responsibility and functionality [1]. 12,496km of National Highways (“A,” “B,” and “E” class roads, July 2020 update) are constructed mainly using asphalt paving techniques [2]. Even though the national road network contains a limited number of concrete pavements, Pradeshiya Sabha and Local Authority roads have a considerable length of concrete roads. Since 2007, concrete paving has been widely used to construct low volume roads in Sri Lanka. Even though concrete pavements are durable in the norm, owing to poor construction practices and improper maintenance, the concrete surfacing of low volume roads is vulnerable to frequent damages [3]. As a result, these pavements require further attention to rehabilitation by relevant authorities more often. However, the current practices for the repair of these severely damaged concrete roads are either obliterating the pavement slab or using the demolished pavement slab as a base layer to the new surfacing. Therefore, rather than using the old pavement slab as a base for the new pavement, the pavement slab can be recycled to extract aggregates and make RCC using the RCA obtained from the recycled pavement. The challenges faced during this process and the possible optimizations are expected to be revealed scientifically in this paper.

2. Roller Compacted Concrete (RCC)

As implied by the name, the compaction of RCC into its final form is achieved by heavy vibratory steel drum and rubber-tired rollers. Since RCC is a type of non-reinforced concrete, high-density pavers can be used for placing concrete. RCC has similar strength properties and consists of the same basic ingredients as

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conventional concrete: well-graded aggregates, cementitious materials, and water but with different blend of ingredients [4].

The most significant difference between RCC mixtures and conventional concrete mixtures is that RCC has a higher percentage of fine aggregates, which allows for tight packing and consolidation [5], [6]. As pointed out by the U.S. Army Corps of Engineers (USACE) in 1995, RCC has made savings ranging from 14 to 58 percent. This comparative study analyzes 49 different USACE projects [7], [8].

Table 1 - A Typical Comparison between Conventional Concrete and RCC Pavements Mix Design [9], [10]

Pavement type		Roller Compacted Concrete	Conventional Concrete
Max. Aggregate Size		19mm	38mm
Unit Weight (kg/m^3)	Water	105	140
	Cement	260	329
	Fine Aggregate	946	606
	Coarse Aggregate	1254	1356
Water Content (%)		5.4	7.8

Intensive usage of natural resources in construction activities will cause negative impacts on the environment. The cement industry is responsible for 5% of global anthropogenic carbon dioxide emissions. For every 1000kg of cement produced, nearly 900 kg of CO_2 will be disposed of to the environment. [11]. However, the advancements in cement production have decreased the amount of CO_2 emission in the recent past [12]. RCC can further reduce the percentage of cement used in pavement applications and the energy required for transportation [13]. A typical RCC mix proportion is compared with a conventional concrete mix proportion in Table 1.

When compared to conventional concrete, RCC placed with new high-density pavers offers many technical and economic advantages. It is possible to achieve high quality in terms of strength, durability, and surface finish at the relatively low device and labour costs. Table 2 shows a comparison of the properties of RCC and conventional concrete.

2.1 Construction Method

The construction method of RCC is similar to that of asphalt laying, and the following steps are followed during the construction sequence [14], [15].

1) *Subgrade, Subbase, and Base Course Preparation:*
   The subgrade should be uniformly compacted to a minimum of 95% of the maximum dry density and sub-base, and the base course also is prepared according to fundamental practices.
2) *Transporting RCC:*
   Dump trucks are used to transport RCC, and relevant preventive measures should be taken to avoid segregation and moisture loss.

Table 2 - Comparison of Properties of RCC vs Conventional Concrete [16]

Property / Task	Roller Compacted Concrete	Conventional Concrete
Aggregate Gradation	Well graded aggregates are used to minimize air voids	Less graded when compared to RCC
Cementitious Material Content	For pavement applications, cement content is decided on the basis of the percentage of weight.	Depends on the design w/c ratio of the mix and the desired compressive strength
Moisture Content	Optimum moisture content (OMC) is used as the moisture content of the mix	Determined based on the w/c ratio of mix
Concrete Mixing	Pugmills or Mixers	Mixers
Transportation	Dump Trucks	Transit Mixers
Laying	High-density paving machines	Manually/Slipform paving machines
Compaction	Steel drum rollers	Vibratory machines
Strength	High (For constant cement content)	Lower than RCC (For constant cement content)
Permeability	Relatively high	Relatively less

3) *Trial Construction (Test Strips):*
This is performed mainly to verify whether the design requirements are met.
4) *Placement:*
Placement should be carefully done using a paver, and the steel drum rollers should compact the mix at the same time with the recommended number of roller-passes.
5) *Curing:*
White concrete curing compound can be used conforming to ASTM C309.

Construction methodology will be faster than the usual practice, and the release of the pavement to traffic will depend on the strength gain of RCC. Typically, in warm climatic conditions, pavement can be released to traffic after two days since construction [5], [15].

2.2 Mix Design of RCCP

The four main proportioning methods are the soil compaction test, concrete consistency test, solid suspension model, and the optimal paste volume method. The soil compaction method is the most used technique for RCC pavements [17]–[19].

In this study, the soil compaction method is used for RCC mix design as in ACI 211.3R-12 – Guide for Selecting Proportions for No-Slump Concrete by ACI Committee 211 [20]. The mix design steps of the soil compaction method can be listed as,

1) *Aggregate Gradation*:
2) *Calculating Mix Proportions*:
3) *Calculating Mix Proportions*:
Aggregates were sieved and prepared to meet Roller Compacted Concrete Pavement (RCCP) gradation. Figure 1 shows the gradation bands used for the mix design. Coarse aggregates are defined as passing 19mm and retained on 4.75mm passing 4.75mm sieve sizes. Sieves of 25mm, 19mm, 12.7mm, 9.5mm, 4.75mm, 1.18mm, 0.15mm, and 0.075mm were used for aggregate gradation.
4) *Selecting Cementitious Content*:
Determination of the cementitious content is required to optimize the mix design. The available literature and previous RCC projects clearly show that the cementitious content lies typically between 11-13% by weight of dry materials in the mixture. Therefore, the fixed cement content of 12% was used for casting RCC samples.
5) *Moisture-Density Plot (Proctor compaction test ASTM D1557) and selection of optimum moisture content:*
To determine the optimum moisture content (OMC) for the mix, the standard specifies to use the Modified Proctor Compaction Test (ASTM D1557). To simulate the actual site condition of compaction, a compaction test was carried out by a Vibratory Hammer (BS1377: Part 4: 1990) in this study to compare it with the Modified Proctor Test.

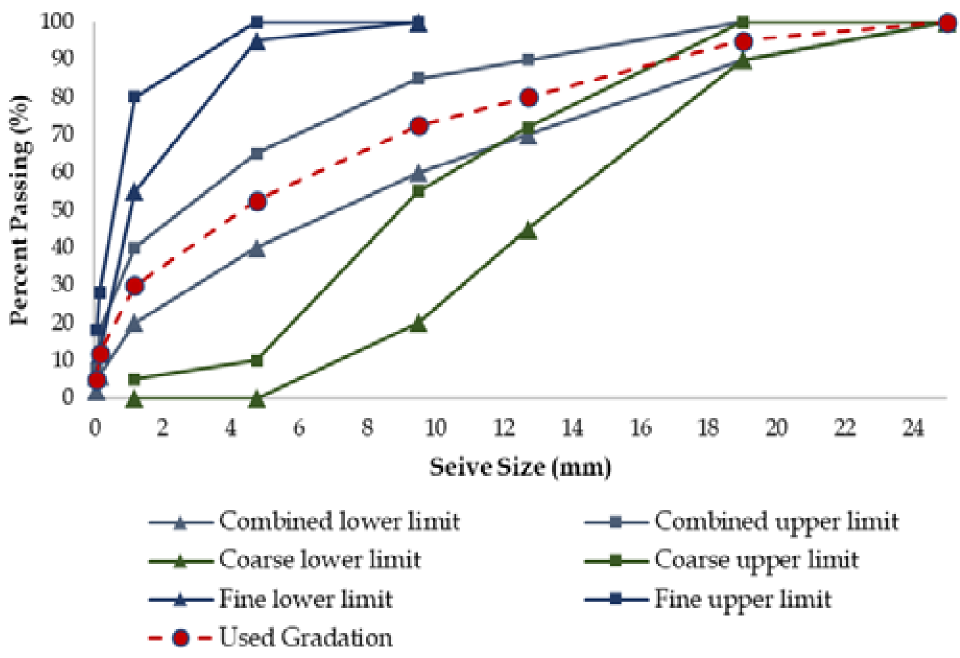

Figure 1 - RCCP Gradation Bands

Since the cementitious material content of the mix is 12% of the total dry mass,

$$W_c/(W_c+W_a) = 0.12 \quad (1)$$

After establishing the OMC,

$$W_w/(W_c+W_a) = (OMC) / 100 \quad (2)$$

For 1m³ of RCC mix, assuming 1.5% of air voids,

$$W_a(1/SG_a - A)+W_c/SG_c+W_w/SG_w = 985 \quad (3)$$

Where,

W_c = *Dry Weight of cement*
W_a = *Dry Weight of aggregates*
W_w = *Weight of water*
SG_c = *Specific Gravity of cement*
SG_a = *Specific Gravity of aggregates*
SG_w = *Specific Gravity of water*
A = *Water absorption of aggregate mix*

The mixing ratio of coarse and fine aggregates was as follows,

Coarse = 53.33% of total aggregates
Fine = 46.67% of total aggregates

6) *Compressive Strength Test:*
After determining the mix proportions, RCC was mixed and cast into cylindrical moulds of 152.4mm diameter and 300mm height. The vibration was applied by a vibratory hammer, and the concrete was compacted in four layers. When a mortar ring appeared around the tamping plate, the vibration was stopped. ASTM C1435 describes the method of moulding RCC into cylindrical moulds in detail.

2.3 RCC made with Recycled Concrete Aggregates (RCA)

Recycled aggregates are different from natural aggregates due to the presence of cement gangue of old mortar, which remains attached to the natural aggregates after crushing of the original concrete and induces lower densities and greater capacity of water absorption [21].
A polished cylindrical specimen prepared only using coarse RCA and white cement is shown in Figure 2. The white spaces in the left photo are new white mortar, and the darker spots are the virgin aggregates in RCA. Virgin aggregates of RCA are already bounded by the old mortar, and this results in weaker aggregate properties [22].
RCC consisting of only crushed concrete is comparable in compactness with the RCC containing only natural aggregates. However, the compressive strength of the latter is higher due to the better quality of aggregates [24].

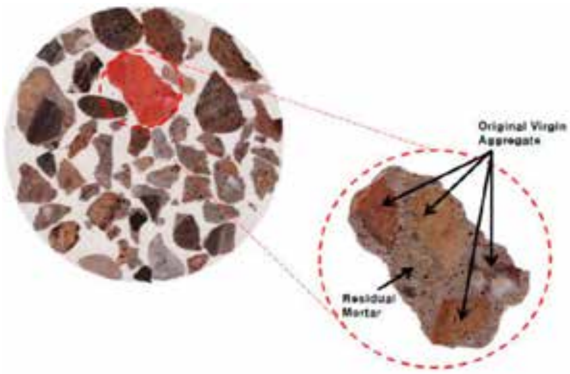

Figure 2 - Old Mortar/Residual Mortar in RCA [23]

The compactness of a material can be defined as the ratio between the volume of material and the total volume. However, efficient solid compactness is defined as the summation of solid compactness and absorbed water compactness. Solid compactness for both RCC made with RCA (RCA-RCC) and RCC made with virgin crushed aggregate (VCA-RCC) is in the same range. However, efficient solid compactness is quite different due to the higher water absorption coefficient of recycled aggregates.
In previous studies, it is observed that the compressive strength is higher in VCA-RCC than RCA-RCC in 28 days, mainly due to the better quality of aggregates. In contrast, water absorption is significantly high in RCA. Table 3 shows a comparison of compressive strengths and solid compactness of RCA-RCC and VCA-RCC. The recycled concrete aggregates used in the following study has a high water absorption value of 4.58% and has some parts of bitumen and clinker pavements which have led to a significant strength difference when compared to VCA-RCC [25].

Table 3 - RCA-RCC vs. VCA-RCC

	RCA-RCC	VCA-RCC
Solid compactness	0.809	0.820
Efficient solid compactness	0.864	0.820
7-day compressive strength	23	41
28-day compressive strength	28	46

3. Tests on Materials

The materials used were tested for Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Water absorption, and Specific gravity to assess their conformity with the specifications.

3.1 Aggregate Crushing Value (ACV)

ACV is a measure of the resistance of an aggregate sample to get crushed under a gradually applied compressive load. Virgin crushed aggregates in Sri Lankan quarries usually satisfy the specified ACV limits. However, ACV is tested for both RCA and VCA.

The average ACV obtained for the recycled aggregate test samples was 28, and it is less than 30, which is the specified maximum ACV for the aggregates used in pavement wearing surfaces.

3.2 Aggregate Impact Value (AIV) Test

AIV is a measure of the resistance of aggregates upon a sudden impact repetitively. AIV measures a different attribute from ACV. The percentage of particles that disintegrate upon sudden, repetitive impact is presented as a percentage in this test method.

The average AIV obtained for the recycled aggregate test samples was 21, and it is below 30, which is the specified maximum AIV for the aggregates used for pavement wearing surfaces. Table 4 shows the range and mode of AIV and ACV test results obtained for virgin aggregates in Sri Lanka. According to the limits specified, manually crushed RCA can be used for pavement wearing surfaces, although it is not permissible to use for heavy-duty concrete finishes.

Table 4 – ACV and AIV Test Results Obtained by NBRO [26]

Statistics of test results	Aggregate Property	
	AIV	ACV
Range	17-41	17-41
Mode	23	24
Specified maximum limit	25 for heavy-duty concrete finishes 30 for pavement wearing surfaces. 45 for others	25 for heavy-duty concrete finishes 30 for pavement wearing surfaces. 45 for others

3.3 Water Absorption and Specific Gravity Test

Water absorption of coarse aggregates was tested for both recycled concrete aggregates and virgin crushed aggregates. Since fine aggregates were not replaced by recycled aggregates, water absorption and the specific gravity of sand were extracted from average test results obtained from the National Building Research Organization (NBRO). A summary of the results is included in Table 5. The typical range of values for the test results are given within brackets [26].

Table 5 - Water Absorption and Specific Gravity Test Results

	Specific Gravity	Water Absorption
RCA	2.44	3.79%
VCA	2.76 (1.95-2.87)	0.44% (0.2-0.6)
Fine Aggregate	2.61 (2.42-2.72)	0.90% (0.4-2.2)

4. Analysis of Results

2.1 Results of Compaction Tests

In the optimum moisture content determination, compaction was carried out using the Modified Proctor Test (ASTM D1557) and Vibratory Hammer Test (BS1377: Part 4: 1990). In the proctor compaction test, the compaction is only due to an impact force. However, in vibratory hammer test impact compaction, a vibratory effect and a surcharge load are applied on compacting specimens.

The summary of all the compaction test results is summarized in Table 6.

Table 6 - Summary of OMC and Maximum Dry Density (MDD) Test Results

	Design OMC (%)	MDD (kgm^{-3})
Proctor Test - VCA	7.77	2305.50
Proctor Test - RCA	12.04	2173.04
Vibratory Hammer - VCA	6.56	2318.66
Vibratory Hammer - RCA	11.67	2169.47

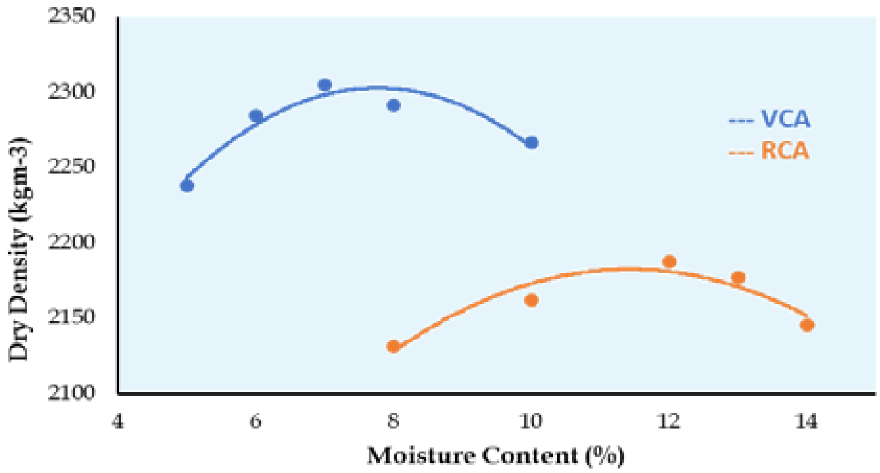

Figure 3 - VCA vs RCA (Modified Proctor Compaction Test)

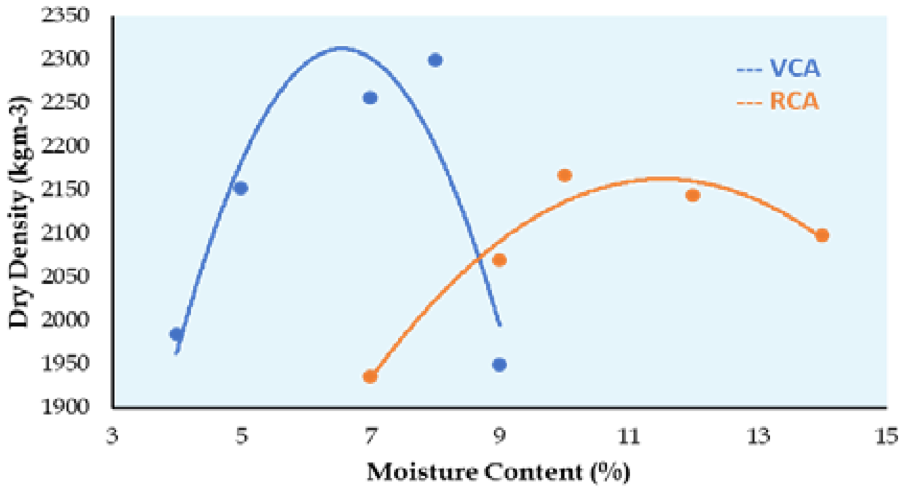

Figure 4 - VCA vs. RCA (Vibratory Hammer Test)

The dry density – moisture content relationship of RCC mixtures for the modified proctor compaction test method is shown in Figure 3. The design OMC observed by modified proctor test for RCA and VCA was 12.04% and 7.77%, respectively. MDD of RCA and VCA were 2173.04kgm^{-3} and 2305.50kgm$^{-3,}$ respectively. VCA density is 6.1% higher than that of RCA.

Figure 4 shows the moisture content - dry density relationship of RCA and VCA aggregate, obtained using the vibratory hammer test method. Design OMC observed by Vibratory Hammer Test for RCA and VCA was 11.67% and 6.56%, respectively.

Compaction test results of VCA-RCC samples are shown in Figure 5, and Figure 6 shows the compaction results of RCA-RCC. The two compaction methods are compared in each case. Both compaction methods resulted in an almost similar MDD value for VCA, but the moisture content at which it was achieved, was different.

For VCA-RCC, the vibratory hammer method requires only 6.56% moisture to reach the MDD, while the modified proctor test method requires 7.77%.

For RCA-RCC, the vibratory hammer method requires only 11.67% moisture to reach the MDD, while the modified proctor test method requires 12.04%.

MDD is considerably higher in VCA-RCC samples than RCA-RCC samples. The main reason is the quality of aggregates. Virgin aggregates have higher specific gravity than recycled aggregates. Therefore, the density of VCA-RCC samples was significantly higher than that of RCA-RCC.

Optimum moisture content (OMC) is considerably higher in RCA-RCC samples than VCA-RCC samples. The main reason is the higher water absorption of RCA.

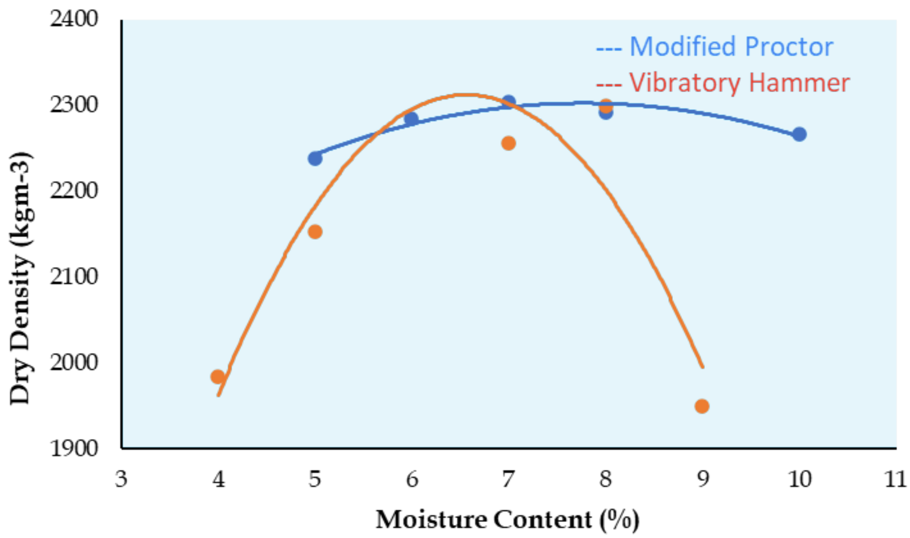

Figure 5 - Modified Proctor Test vs Vibratory Hammer Test for VCA

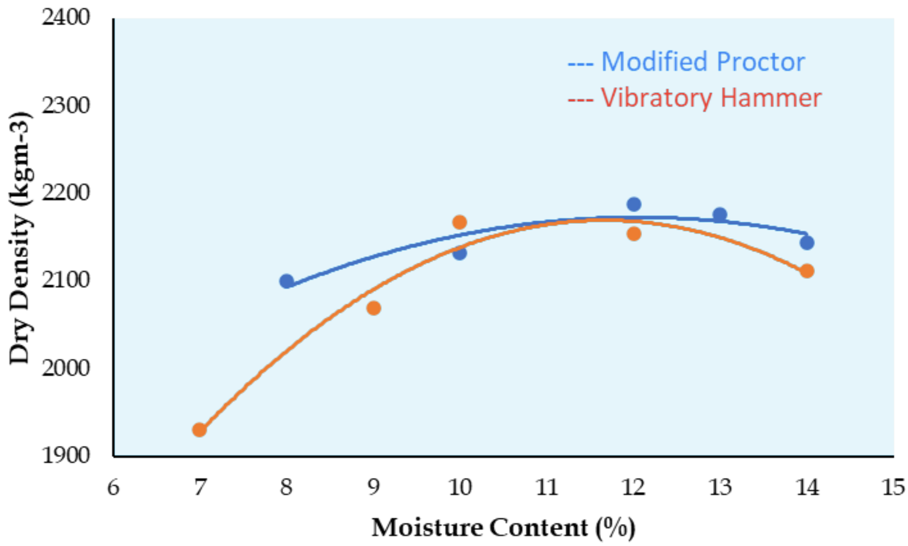

Figure 6 - Modified Proctor Test vs. Vibratory Hammer Test for RCA

When two compaction methodologies are compared, it clearly shows that both methods yield almost the same MDD but at different moisture levels. The vibratory hammer method requires low moisture for compaction, while Modified Proctor Compaction requires more moisture to reach MDD.

Figure 5 and Figure 6 show that the vibratory hammer method is very sensitive to moisture content than the modified proctor method. Even a little change in moisture content in the vibratory hammer test method can drastically decrease the dry density of the mix when compared with the modified proctor test method.

In compacting RCC at the site, steel drum rollers apply a surcharge, a vibration, and an impact force on dry RCC mix. Therefore, this scenario can be simulated using a vibratory hammer than the modified proctor test method. This shows the importance of maintaining correct OMC at the site and the importance of finding the optimum moisture content by the vibratory hammer test method.

2.2 Results of Compressive Strength Tests of RCC Cylinders

Six samples, each from RCA-RCC and VCA-RCC, were cured to check 7-day and 28-day compressive strength. VCA-RCC specimens were cast in parallel with RCA-RCC samples to be used as control samples of this experiment.

The 12 RCC cylinders were tested, and Figure 7 shows the graphical representation of test results. Values shown in Figure 7 are based on the average compressive strength of three RCC cylinder samples.

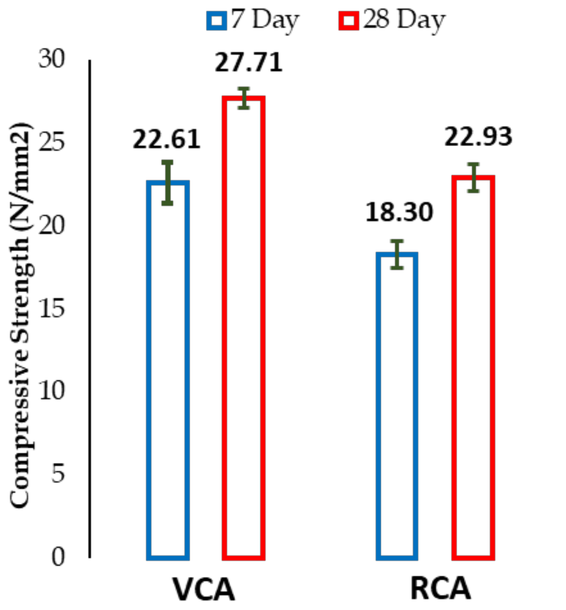

Figure 7 - Summary of Compressive Strength Results

The 28-day strength of all the samples was above 20MPa. RCA-RCC samples were below 25MPa in compressive strength, while all the control samples exceeded 25MPa in compressive strength.

Even though RCA-RCC has less strength than VCA-RCC, the standard error of strength results is not significant. Therefore, the consistency of compressive strength of samples is satisfactory.

VCA-RCC samples have increased 22.6% of their strength at 28-days relative to 7-day strength, while RCA-RCC samples have increased by 25.3%. In RCA-RCC, the increment is higher than that of VCA-RCC.

Almost all the RCC cylinders showed the same failure pattern despite being VCA-RCC or RCA-RCC. As shown in Figure 8, the failure pattern was a combination of splitting and shear.

(a) (b)

Figure 8 - Failure Pattern Observed (a) VCA-RCC, (b) RCA-RCC

5. Conclusion

It is possible to cast roller-compacted concrete using RCA. Therefore, instead of using deteriorated concrete pavements for landfilling or as a base layer for a new pavement, the entire pavement can be recycled and replaced with roller-compacted concrete with 100% replacement of coarse aggregates by recycled concrete aggregates. Even though a slight decrease in strength could be observed, it is good enough for traffic applications in a low-volume road.

Summary of the research outcomes are listed out below:

- The dry density achieved by vibratory hammer compaction for the optimum moisture content obtained by the proctor compaction test is significantly lower than MDD. Therefore, for the determination of optimum moisture content for RCC, it is better to use the vibratory hammer method rather than using the modified proctor method since modified proctor compaction does not simulate the vibratory action of vibratory rollers.
- OMC vs MDD plot is more sensitive to the moisture content in the vibratory hammer test method than the modified proctor test method, which means actual site condition is more susceptible to moisture content than expected from the modified proctor test curve. Therefore, OMC should be appropriately maintained to achieve the desired MDD.
- Coarse aggregates used for RCC construction can be replaced by 100% with RCA without any significant fall of the compressive strength, provided that RCA with specified ACV and AIV are used. 20MPa of compressive strength can be attained from proper compaction of RCA-RCC at 12% cementitious material content.

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Development of a Framework for Identifying Highway Projects for Private-Public-Partnership Financing

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Abstract: In many cases, Public Private Partnership (PPP) projects are looked upon as a sceptical phenomenon due to the involvement of risk factors. However, in order to reduce the financial burden on the government, it is essential to undertake PPP projects. Absence of a supporting framework was identified as one of the key issues in accelerating PPP projects in Sri Lanka. A review was performed in this study to identify and develop the screening criteria in Sri Lanka. As part of the study, criteria which are used in other countries, and World Bank for selection of PPP projects were collected. A Multi Attribute Analysis was used in the research. The criteria identified from other countries are subpackaged under Demand, Financial, Risk and Scale categories.

A questionnaire survey was conducted among highway experts. The ranking of subpackage criteria, top six preferred criteria, and their scores by nine respondents were collected. The preliminary screening criteria were identified using Garrett ranking technique by selecting a single criterion from each subpackage. Based on the guidelines of other countries the percentage responses, and scores for the top six preferred criteria, nine criteria were recommended for secondary screening. Financial viability of a project was identified as the topmost criterion in project screening. Further, PPP candidate nature of 10 selected highway projects was analyzed based on the secondary screening criteria. Due to lack of available information,: financial viability, economic development, traffic congestion reduced from the projects, roles of the road in network and project cost were used for the comparison of projects. Port Access Elevated Highway was received the highest total score from the secondary screening.

Keywords: Public private partnership, Multi attribute, Screening criteria, Garrett ranking technique

1. Introduction

1.1 Background

After the end of three decade war in the country, the Government of Sri Lanka (GOSL) has undertaken rapid highway construction projects to increase the connectivity of the country and boost the economy by connecting major cities and economic hubs. As a traditional practice reserves, loan or grant funds are used for financing purposes. However, when analyzing the debt to gross domestic product (GDP) ratio of Sri Lanka, it has reached a value of 82.9% for the year 2018.

Debt to GDP is one parameter looked upon as one country's ability to payback future payment to the investors. So, increasing Debt to GDP ratio has increased the risk for the lenders and borrowing in the future will be difficult.

Therefore, alternative financing methods should be considered for public investment projects. Public Private Partnership (PPP) is used in many countries and this alternative method can be considered for highway construction financing.

1.2 Problem Statement

Selection of viable PPP projects is a critical phase in PPP development and there should be a framework to support the PPP process in the country. One of the key constraints for PPP development in Sri Lanka is over reliance on unsolicited proposals. Not only in Sri Lanka, in many countries, there are no proper guidelines to screen Highway PPP projects. So, it is crucial to identify key factors to develop a screening tool by considering successful practices of other countries.

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As the preparation for PPP projects demands financial and human resources, it is the key to screen good candidate projects for PPP to utilize limited resources. This research will mainly focus on Road projects.

1.3 Objective of the Study

Develop a framework to assist identification, selection and prioritization of projects from pipeline to finance under PPP and create a list of viable PPP projects.

Under the main objective, following sub-objectives are identified.

1. Develop Criteria to identify candidate PPP projects.

2. Compare completed, ongoing and future projects in Sri Lanka for the viability as a PPP project.

2. Literature Review

2.1 PPP Project Selection Methods in Sri Lanka

In Sri Lanka, the National Agency for Public Private Partnership (NAPPP) uses a two step process for screening projects. In the first step, the following five filters are used to shortlist the projects (Redup, 2019).

- Project readiness filter
- Investment cost filter
- Public investment plan filter
- PPP definition filter
- Sector exclusion project

In the second step, the following nine criteria are used for the second step of project screening (1).

- GoSL Priority
- Management/ Technical Gaps and Service Levels
- Line Ministry Readiness
- Status of Project Preparation
- Project Implementation Timeline
- Project Feasibility
- Financing
- Private Sector Appetite
- Availability of Information

2.2 Identification of Criteria for PPP Development

In order to identify criteria for selection of road projects for PPP development, criteria which have been considered for the similar purpose were collected from USA (US Department of Transportation, Virginia Transportation, Commonwealth of Pennsylvania), Pakistan, Philippines, and World Bank guidelines.

3. Methodology

In this research, selection criteria were identified from literature review from specific guidelines used by other countries. The criteria were further shortlisted using the questionnaire survey analysis. In the next step, the finalized criteria were compared with past, ongoing and future Sri Lankan projects.

3.1 Selection of Criteria

3.1.1 Multi Attribute Analysis

Multi-attribute analysis is a method used to select a project based on a criteria package. There can be sub criterion packages under main packages. Weightages can be given to main criteria and sub criteria. There should be maximum attainable score to each criterion. Each project can be evaluated against the criteria and a total score can be calculated. This method is developed based on similar research on PPP to Select concessionaire by Zhang (2).

3.1.2 Selection of Appropriate Criteria for each Sub-package

3.1.2.1 Demand Related Factors

The following five criteria were selected under demand sub-package.

1. Urgency of the project to reduce congestion
2. National, regional economic development
3. Safety needs
4. National, regional social benefits
5. Role of the road in network development

3.1.2.2 Financial Related Factors

The following four criteria were selected under financial sub-package.

1. Financial viability
2. Long range revenue potential from the project

3. Impact of project on viability of existing toll roads
4. User pricing (Toll rates)

3.1.2.3 Risk Related Factors

The following seven criteria were selected under risk sub-package.

1. Value for money from the project
2. Transfer of significant operational & management risk to private team
3. Design of the project to achieve best practice by PPP
4. Cost and revenue risks
5. Land acquisition
6. Resettlements
7. Meeting environment safeguards

3.1.2.4 Project Scale Related Factors

The following four criteria were selected under project scale sub-package.

1. Project cost
2. Project functional scope
3. Public agency capability in funding the project
4. Project design and construction complex

3.2 Questionnaire Survey

Questionnaire survey method was used to verify the criteria and its relevancy to Sri Lanka, shortlist crucial preliminary and secondary screening criteria and find out the score of the key criteria. One of the major problems was that very limited number of participants were available to get these details.

The questionnaire survey was conducted among nine respondents from Road Development Authority (RDA), National Agency for Public Private Partnership (NAPPP), and private consultants. Responses were collected from experts who are experienced in both highway and PPP projects.

As a first step of questionnaire survey, ranking was carried out for each subpackage. Respondents were asked to rank all criteria under the subpakage. For example, the respondents were requested to rank 1 to 5 for each criterion under demand subpackage. In order to find out the preferred criterion, Garrett's ranking technique was used (3). Using Garrett's ranking technique all the ranks were converted to score values. The following formula and Garrett's table were used to convert ranks into scores.

Percent Position = 100 (R_{ij}-0.5) / N_j .... (1)

Where;

Rij= Ranked given for i^{th} criterion by j^{th} respondent

Nj= Number of criteria ranked by j^{th} respondent

Thus, a most significant criterion to represent each subpackage can be selected.

In the next step, to identify the importance of each criterion, a 1-10 numerical rating scale is used. This 10-point scale used to indicate the following importance of the criteria in decision making. One (1) implies least significant for the decision making while Ten (10) implies most significant for the decision making.

3.3 Case Study

Ten (10) Sri Lankan expressway projects were selected. The feasibility study report of these projects was used to collect details about the projects. Further, interviews with directors and project engineers were carried out.

4. Identifying Preliminary and Secondary Selection Criteria from Questionnaire Analysis

4.1 Data Analysis

4.1.1 Demand Related Criteria

The purpose of the question is to select a criterion to better represent demand of the project. A Rank from 1 to 5 was assigned for most important to least important criterion by respondents. Figure 1 shows the percentage of ranks given by nine respondents for each demand related criterion. The following abbreviations are used in Figure 1.

Urgency: Urgency of the project to reduce congestion

Economic: National, regional economic development

Safety: Safety needs

Social: National, regional social benefits

Network: Role of the road in network development

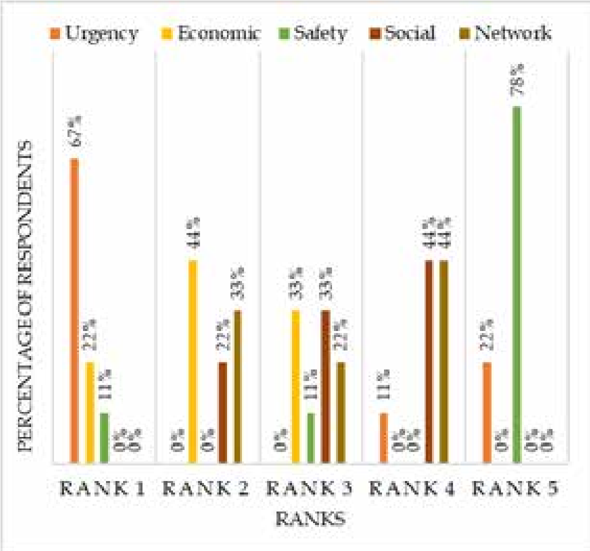

Figure 1 - Demand Criteria from Questionnaire Survey

For further analyses, using Garrett's ranking technique, all the ranks were converted to score values. The Garrett formula and Garrett's table were used to convert ranks into scores. Average score calculated for each criterion is shown in Table 1.

Table 1 - Average Score Each Demand Related Criterion

No	Criterion	Average Score
1	Urgency of the project to reduce congestion	60.0
2	National, regional economic development	60.2
3	Safety needs	33.3
4	National, regional social benefits	47.7
5	Role of the road in network development	48.9

4.1.2 Financial Related Factors

The percentage of respondents ranked each financial related criterion are presented in Figure 2. The following abbreviations are used in Figure 2.

Financial: Financial viability

Revenue: Long rang revenue potential from the project

Toll roads: Impact of project on viability of existing toll roads

Pricing: User pricing

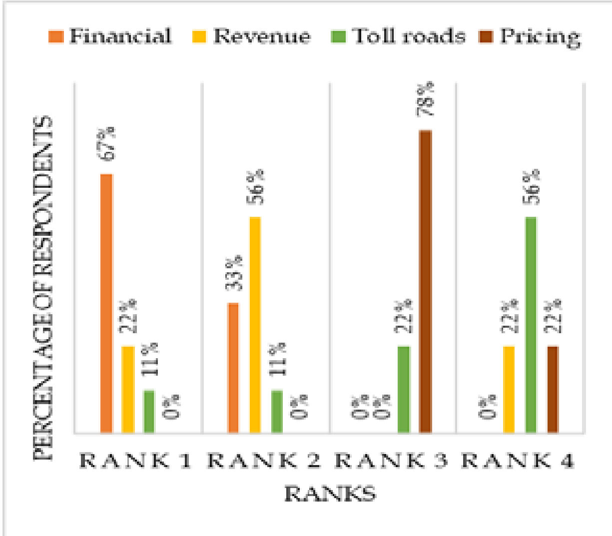

Figure 2 - Financial Criteria from the Questionnaire Survey Analysis

Garrett scoring technique was used to convert the rankings of financial criteria into score, and the average score is shown in Table 2.

Table 2 - Criterion Score using Garrett's Technique

No	Criterion	Average Score
1	Financial viability	67.2
2	Long range revenue potential from the project	53.5
3	User pricing	40.1
4	Impact of Project on viability of existing toll roads	39.3

4.1.3 Risk Related Factors

The percentage of respondents ranked each risk related criterion as shown in Figure 3. The following abbreviations are used in Figure 3.

VfM: Value for Money from the project

O&M: Transfer of significant Operational & Management risk to Private team

Design: Design of the project to achieve best practice by PPP

Risk: Cost and Revenue risks

Land: Land acquisition

Resettlement: Resettlements

Environment: Project meeting environment safeguards

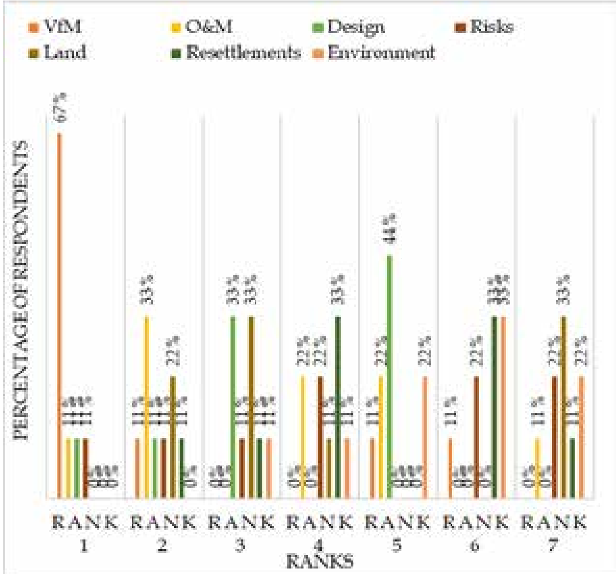

Figure 3 - Risk Criteria from Questionnaire Survey Analysis

Garrett scoring technique was used to convert the rankings of risk criteria into score as shown in Table 3 below.

Table 3 - Garrett Technique used for Risk Related Subpackage

No	Criterion	Average Score
1	Value for Money from the project	68.2
2	Transfer of significant Operational & Management risk to Private team	53.6
3	Design of the project to achieve best practice by PPP	54.1
4	Cost and Revenue risks	45.9
5	Land acquisition	46.4
6	Resettlements	44.2
7	Project meeting environment safeguards	37.7

4.1.4 Project Scale Related Criteria

The percentage of respondents ranks for each scale related criterion are given in Figure 4. The following abbreviations are used in Figure 4.

Cost: Project Cost

Scope: Project Functional Scope

Capability: Public Agency Capability in funding the project

Complex: Project Design and Construction complex

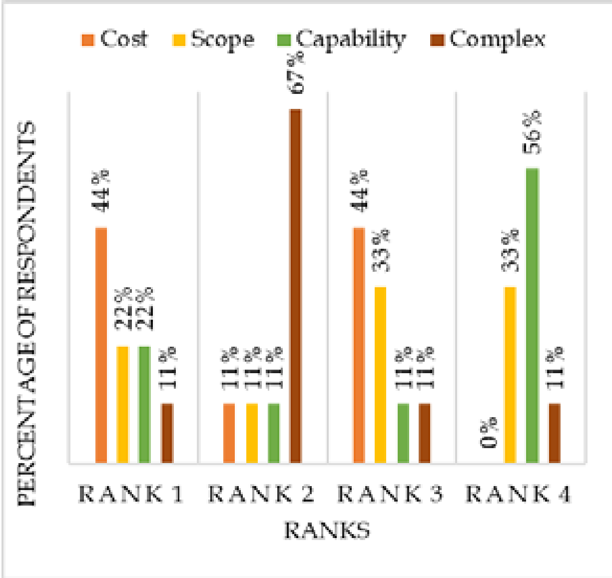

Figure 4 - Scale Criteria from the Questionnaire Survey Analysis

Table 4 used to presents the average score for each project scale related criterion using Garrett technique.

Table 4 - Garrett Technique used for Scale Related Subpackage

No	Criterion	Average Score
1	Project Costs	57.9
2	Project Design and Construction complex	53.5
3	Project Functional Scope	46.1
4	Public Agency Capability in funding the project	42.5

4.1.5 Ranking and Rating of Six Preferred Criteria for Selection of Project

All the respondents were requested to select most important criteria from the twenty criteria and their suggestions if any. Further, respondents were requested to provide a 1-10 score for first six criteria they preferred. Purpose of the selection is to shortlist most important criteria for secondary screening. the percentage of the total score for the criteria divided the summation of score for all criteria was calculated in Table 5.

Table 5 - Total Rating given for Criteria by Respondents

	Criteria	TS	AS
1	Financial viability	71	17%
2	Value for Money from the project	52	12%
3	Long range revenue potential from the project	42	10%
4	Transfer of significant Operational & Management risk to private team	42	10%
5	National, regional economic development from the project	40	9%
6	Urgency of the project to reduce congestion	34	8%
7	Design of the project to achieve best practice by PPP	22	5%
8	Cost and revenue risks	18	4%
9	Role of the road in network development	15	4%
10	Project cost	15	4%
11	Public agency capability in funding the project	14	3%
12	Project design and construction complex	14	3%
13	National, regional social benefits	9	2%
14	Impact of project on viability of existing toll roads	8	2%
15	Project functional scope	7	2%
16	Resettlements	6	1%
17	Project meeting environment safeguards	6	1%
18	Safety needs	6	1%
19	Land acquisition	6	1%
		427	100%

TS: Total score of the criteria

AS: % of Total score for the criteria/ Aggregated total score for all criteria

4.2 Preliminary and Secondary Screening Criteria Selection

4.2.1 Criteria Shortlisted for Preliminary Screening with Suggested Indicators

Based on the Garrett's Ranking Score, the following criteria were selected for preliminary screening.

1. Urgency of the project to reduce congestion (PCU/day) and National, regional economic development from the project (EIRR)
2. Financial viability
3. Land acquisition (Percentage of the area expected to be acquired for the project)
4. Project cost (Project Cost Value)

4.2.2 Secondary Screening Criteria

The following nine (9) criteria were considered for secondary screening.

1. Financial viability - Maximum recommended score is 17
2. Long range revenue potential from the project – Maximum recommended score is 10
3. Transfer of significant Operational &Management risk to private team - Maximum score recommended is 10
4. National, regional economic development from the project - Maximum score recommended is 9
5. Urgency of the project to reduce congestion - Maximum score recommended is 8
6. Design of the project to achieve best practice by PPP - Maximum score recommended is 5
7. Cost and revenue risks - Maximum score recommended is 4
8. Role of the road in network development - Maximum score recommended is 4
9. Project cost - Maximum score recommended is 4

4.3 Applicability of Screening Criteria

In this study, based on the questionnaire survey results and literature review, preliminary and secondary screening criteria were identified. But no threshold values were identified in this study. It is recommended to follow similar procedure to find preliminary and secondary criteria for any authority to develop screening criteria for highway PPP projects.

Appropriate threshold value for the indicators can be identified by the relevant authorities. For example, relevant authority could set an accepted value of FIRR for financial viability. Similarly, the relevant authorities could set a value for other indicators such as minimum PCU/day, EIRR, land acquisition requirement and minimum project cost.

5. Comparison on Economic Evaluation of the Projects

A case study was performed to compare the viability of existing expressway projects in Sri Lanka. In this study, for the comparison of projects, only the criteria identified for secondary screening were used. Due to non-availability of qualifier threshold value for preliminary screening criteria, no projects were screened out using the preliminary screening.

5.1 Scoring Criteria

Based on the expert judgment from interviews, rating scales from respondents in the questionnaire survey, similar scores and weightages used in other guidelines, and scoring criteria, and maximum score developed. The scoring criteria for secondary screening is shown in Table 6.

Table 6 - Scoring Criteria

	Project	Indicator	` Scoring Criteria and Score	Maximum Score
1	Financial viability	FIRR	**Very High:** FIRR >15% = 17 **High**: 10%< FIRR <15% = 12 **Medium:** 5%< FIRR <10% = 8 **Low:** 0%< FIRR <5% = 4 **Negative:** FIRR <0% = 0	17
2	National, regional economic development from the project	EIRR	**Very High:** EIRR >25% = 15 **High:**15%< EIRR < 25% =10 **Medium:** 12%< EIRR <15% = 7 **Low:** EIRR <12% = 4	15
3	Urgency of the project to reduce congestion	Traffic number expected after 20 years of project opening	Number of traffic attracted to a link (PCU/day) **High:** Over 60,000 = 10 **Medium**: 20,000 – 60,000 = 7 **Low**: Less than 20,000 = 4	10
4	Role of the road in network development	Functional importance of the link	**Very high:** If the link form national integration or directly connects airport, railway hub or port =10 **High:** If link provides flexibility in route selection or indirectly connects airport, railway hub or port =7 **Medium:** Link connect to a brand of backbone transportation link = 4 **Low:** Individual link =2	10
5	Project cost	Project cost	**High:** Over USD 200 million = 10 **Medium:** USD 100 million to USD 200 million = 7 **Low:** Less than USD 100 million = 3	10

5.2 Project Details for Dcoring

The project details are summarized in Table 7. The following abbreviations are used in Tables 7 and 8. The score values of the projects which were selected for second screening are given in Table 8. It is assumed that all criteria have same weightages in decision making.

Thus, total score of the project can be calculated from individual scores.

CKE - Colombo - Katunayake Expressway

PAEP - Port Access Elevated Project

NKB Phase 1- NKB – Rajagiriya Elevated Project

NKB Phase 2 - NKB – Athurugiriya Elevated Project

SE - Southern Expressway

CE (M-K) - Central Expressway- Mirigama to Kurunagela Section

RE - Ruwanpura Expressway

OCH 3 - Outer Circular Highway Section 3

CE (M-K) - Central Express - Kadawatha to Mirigama Section

SEE - Southern Extension Expressway

ETA20 - Traffic number expected after 20 years of project opening

V.H – Very High

H - High

M - Medium

NV- Negative

Table 7 - Project Details

	Project	Indicator	CKE	PAEP	NKB Phase 2	SE	CE (M-K)	NKB Phase 1	RE	OCH 3	CE (K-M)-	SEE
1	Financial viability	FIRR	0.51%	8.42%	4.59%	1%	0.8%	4.59%	NV	NV	NV	NV
2	National, regional economic developmen t from the project	EIRR	14.1%	11.6%,	10.59%	13.33%	12.36%	12.1%	11.8%	14.0%	12.1%	6.2%
3	Urgency of the project to reduce congestion	ETA20	129612	116000	42515	57250	24264	39573	45000	73358	84830	72655
4	Role of the road in network developmen t	Connectivit y	H	V.H	V.H	H	H	H	M	H	M	M
5	Project cost (USD) Million	Project cost	321.5	360	743.8	906	600	257.1	213	535	916	300

Table 8 - Project Score Based on Screening Criteria

	Project	Indicator	CKE	PAEP	NKB Phase 2	SE	CE (M-K)	NKB Phase 1	RE	OCH 3	CE (K-M)-	SEE
1	Financial viability	FIRR	4	8	4	4	4	4	0	0	0	0
2	National, regional economic development from the project	EIRR	7	4	4	7	7	7	4	7	7	4
3	Urgency of the project to reduce congestion	ETA20	10	10	7	7	7	7	7	10	10	10
4	Role of the road in network development	Connectivity	7	10	10	7	7	7	4	7	4	4
5	Project cost (USD)	Project cost	10	10	10	10	10	10	10	10	10	10
	Score		**38**	**42**	**35**	**35**	**35**	**35**	**25**	**34**	**31**	**28**

From the scoring of projects in Table 8, Port Access Elevated Project can be selected as best PPP viable project in Sri Lanka. Other criteria which are not included in the secondary screening also endorsing the project as follows.

- Private land acquisition of the project is zero since the land belongs to Ports Authority.
- There are any direct resettlements from the project.
- The project is not passing through an environmentally sensitive trace.
- The project can bring positive impact to other expressways such as NKB-Athurugiriya, Colombo-Katunayeke.

6. Discussion

The findings of the study could help to screen potential PPP projects in Sri Lanka. Further, the relevant selection criteria which could be considered were identified. This preliminary and secondary screening will help to screen out unviable PPP projects and focus on potential PPP projects.

For screening of PPP projects, the information should be collected from the following analysis.

1. Economic analysis
2. Financial analysis
3. Risk analysis
4. Technical analysis
5. Market analysis
6. Environmental analysis
7. Stakeholder analysis
8. Institutional analysis
9. Value for Money analysis

6.1 Limitations of the Research

The questionnaire survey was carried out from only on nine (9) respondents. Non availability of PPP and highway background experts was one of the limitations to select respondents.

In this research, no qualifier was identified for preliminary screening criteria indicators. For the elimination of projects using preliminary screening criteria, threshold values need to be identified.

After the secondary screening, there should be a minimum threshold score for selection of projects. The purpose of this threshold value is to make sure that no unqualified projects are being selected in the screening process.

From the literature review of other guidelines, it is learned that it is important to identify weightage score for each criterion. Since the importance of the criteria is different for each criterion, weightage can be used to represent that in decision making. But, in this study all the criteria were given equal weightage.

Major limitation in this study is that there are not successfully completed PPP road projects in Sri Lanka, to compare our study with the real-world project scenario.

In addition, another limitation was the lack of availability of detailed documentation in the projects.

6.2 PPP Project Constraints in Sri Lanka

The constraints in Sri Lanka for acceleration of PPP projects were identified from literature review and interviews. This information will help to develop any documents related to PPP such as guidelines.

1. One of the constraints to adopt PPP in Sri Lanka is unstable political environment and frequent policy changes. So, it would be difficult to adopt PPP projects with political risks. For example, New Kelani-Athurugiriya Elevated Road was under concessionaire selection stage in 2019, but after the change of government this project was termed as an unsolicited project.
2. Investors are not motivated with subsidies. Preferential tax policies need to be established to attract private partners.
3. The bankability of projects is a crucial problem for Sri Lankan PPP projects.
4. Due to urgency of the projects with political reasons, PPP is not considered in SL. Availability of loans (Even with high interest rate) with grace period demotivates PPP in SL.
5. There is no legal infrastructure in the country for private partnerships including procurement method.
6. Unsolicited projects are given high priority than solicited projects. While analyzing the PPP projects in Sri Lanka, unsolicited proposals are a big hurdle to carryout best PPP practices in the country. For example, for Northern Expressway, the FNPV calculated for stage 1 Colombo – Mirigama and Stage 2 Mirigama - Kurunagela was -739 million by China Merchants Group (4) where, these calculations were carried out the prospective private party. So, the reliability of the revenue and estimations may not be credible. Thus, unsolicited projects may reduce the benefits of PPP. The Unsolicited projects need to be treated with Swiss Challenge Model.
7. Absence of Toll related policy in Sri Lanka.
8. The affordability to pay tolls is key issue in setting user charges. The Willingness to Pay survey can be used in user charge determination.
9. In Sri Lanka, revenue of the expressway is only expected from the tolls. When a region does not achieve the expected growth after the project, the toll revenue cannot be obtained as expected in the studies. Thus, it can cause the projects to fail when that region very much depends on the revenue for future economic development of the region.
10. The uncertainty in traffic estimation prevails due to change in political proposals. For example, a change in public transportation policy can change the traffic numbers. Developed countries have more long-term plans than developing countries. This makes it difficult to estimate for more than 10 years for developing countries.

7. Research Findings

7.1 Development of Screening Criteria

From the questionnaire survey analysis, a better representing criterion was selected to represent demand, financial, risk and scale subpackages. These criteria were used to develop pre-screening criteria. The following preliminary screening criteria were shortlisted.

1. Urgency of the project to reduce congestion
2. National, regional economic development from the project
3. Financial viability
4. Land acquisition
5. Project cost

Further, nine (9) secondary screening criteria were shortlisted for selection of candidate PPP projects. Secondary criteria and suggested scores are given below in the ranking order by respondents.

1. Financial viability - Maximum recommended score is 17
2. Long range revenue potential from the project – Maximum recommended score is 10
3. Transfer of significant Operational & Management risk to private team - Maximum score recommended is 10
4. National, regional economic development from the project - Maximum score recommended is 9
5. Urgency of the project to reduce congestion - Maximum score recommended is 8
6. Design of the project to achieve best practice by PPP - Maximum score recommended is 5
7. Cost and revenue risks - Maximum score recommended is 4
8. Role of the road in network development - Maximum score recommended is 4
9. Project cost - Maximum score recommended is 4

Financial viability of the project was identified as a key criterion for selection of PPP projects. FIRR can be used to identify financial viability of projects. The long-range revenue potential can be represented by PV of the revenue during the operation period. The transfer of Operational and Management risk can be indicated by risk in monetary terms, transferred to private party from PPP arrangement. The Nation, regional, economic development can be represented by EIRR or BCR of the project.

Furthermore, to represent demand of the project urgency, reduction in traffic congestion can be used. PCU/day can be used to identify this criterion. Design of the project to achieve best practice by PPP is represented by qualitative indicators. Construction complexity of the project can be used to represent the criteria.

Cost and revenue risks are identified as a key failure factor. Thus, projects that come up with more cost and revenue risk should be excluded from PPP candidate list. Role of the particular project in the road network is considered as a criterion in the secondary screening. The national integration from the project can be considered in screening by including the criterion. Functional importance of the road can be used to indicate the criterion.

Whereas Project cost can be considered as a scale representing criterion, in Sri Lanka, due to the preparation involved in PPP, the threshold value for PPP project is set as USD 50 Million.

Even though land acquisition and resettlements are considered as a key PPP project failure factor, from the questionnaire analysis it was evident respondents felt it was not the most important criteria. The reason for this was found in the interview that with existing laws and regulation in the country, land acquisitions can be managed by the institution.

User charges was not selected as a top six factor by any respondents. Since this can be decided by the management, with a proper willingness to pay for survey, appropriate charges can be determined. Currently there is no toll road related policy available in Sri Lanka. This makes it difficult for user charge evaluation for projects.

Value for Money (VfM) analysis is recommended to be carried out in the final screening due to the data required for the analysis. There are many tools to analyze VfM analysis. Public Sector Comparator and Shadow Bid Model tools were used by NAPPP.

Project readiness was included in the existing two-phase selection method in Sri Lanka. Conceptual level project will have less information compared to detailed designed project. This criterion is included in Phillippines guideline as well.

7.2 Comparison of Completed, Ongoing and Future Projects as PPP Candidate

From the total score of the project Port Access Elevated Highway (42/62 score) is the best candidate road of all the considered projects and could have been considered as a candidate PPP project.

8. Recommendation

Identification of qualifiers for indicators of preliminary screening criteria of urgency of the project to reduce congestion (PCU/day) and national, regional economic development from the project (EIRR), financial viability (FIRR), land acquisition (percentage of the total project land need to be acquired from private parties), project cost (project cost) is recommended for further study.

A threshold score is recommended to identify projects after secondary screening. A qualifier threshold score value will help to select only good projects after screening.

Weightages for each criterion should be studied and developed for the better screening of projects.

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Systems Approach to Develop High Mobility Road Network Plan for Sri Lanka

W.A.S.S Weththasinghe and J.M.S.J Bandara

Abstract: Transportation between major commercial and socio economic hubs will play a vital role in the economy. Since existing road networks have developed based on historical and natural reasons and expressways also have come up with individual proposals with very little consideration on overall connectivity, a need for a systematic approach for future network development has become a necessity. This study focuses on developing a high mobility road network taking into account the possibility of upgrading existing roads as well.

Since Administrative Districts and their capitals have already established and developed, 25 District Capitals were selected as the primary centers to be connected and considered as main nodes in the high mobility road network. In addition, all expressway interchanges, other major A-Class road intersections and cities with major traffic attractions were considered as nodes when defining the initial road network.

During the analysis stage, development of minimum distance paths and minimum spanning tree were considered to identify bottlenecks, critical nodes and critical links. To identify the optimum network, two criteria, minimizing overall link length, maximizing network speed and achieving desired average speed levels, were considered. A methodology was developed to identify the links to be added or improved such that overall mobility level of the country is improved.

Keywords: Mobility, Minimum Distance Path, Minimum Spanning Tree, Nodes

1. Introduction

Since transportation systems directly affect the demand and supply level of an economy, it is essential to look forward to investing for establishment of transportation network among major socio economic centres. Transportation demand between critical nodes (regions or cities) has gradually increased over the last few decades. Therefore, the level of service of certain critical links has dropped due to the increase in traffic volume and density with respect to the constant capacity of considering links. Introduction of expressways, widening of the existing roads, increasing the sight distance, and surface re-layering can be considered as solutions provided by the authorities through policy decisions to improve mobility level. Several changes such as, travel time reduction, fuel consumption reduction and job creation have occurred in the transportation system as well as in the economy due to the introduction of expressways and other major road improvements.

Due to the high investment cost, time, space and labour for transportation based developments (especially roads), it is essential to look forward to evaluate the performance of the existing links & develop the entire road network in different perspectives such as sustainability of traffic behaviour, financial sustainability, environmental sustainability and social aspects (Sotiropoulos, 1978).

2. Goals & Objectives

Interpretation of a development plan of high mobility road network can be identified as the goal of the study. The basic objectives are recognition of bottlenecks and critical links and prioritization of necessary improvements to increase average network speed while maintaining minimum average speed between any node pair.

3. Literature Review

3.1 Network Optimization Methods in Other Studies

When considering similar studies in other regions, it was observed that shortest path analysis was considered frequently because of its wide range of Applications. (Winn, 2014.) The road network minimization algorithms were developed by incrementally determining cost, time or distance between source node and

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all other nodes. The values (time/distance/cost) from each source node to all other nodes were repeatedly compared and the least value option was determined. The model then proceeds to the next node until the destination is reached. (Alam et al., 2012) According to (Ahmed et al. 2017) and Winn, 2014), GIS was effectively used to identify the geometric behaviour and the relationships of the considering network.

Ghaffariyan (2010) proposed heuristic methods as well as liner programing methods for network optimization.

3.2 Gravity Model for Demand Analysis

In transportation studies, population and distance can be identified as the major influences of trip generation and trip attraction. Though many advanced demand modeling techniques have developed recently, basic approach was considered as it is less sensitive to any other developments and it is appropriate for early planning stage. Therefore, gravity models can be developed with respect to population density and distance parameters to identify the demand of traffic generation (Jung et al., 2008).

$$G = \frac{PD\ of\ Node1\ \times PD\ of\ Node\ 2}{1000x(Distance\ between\ Nodes)^2} \quad \ldots(1)$$

PD: Population Density

Populations of nodes were indicated as population density in terms of number of total heads in thousands per square kilometer. Population density was considered instead of population since the dispersion of population among entire district does not reflect actual impact on inter district transportation. Therefore, population density can be identified as a mean value which can be applicable for every district. (*Khan Academy*, no date) Distances between node pairs were indicated in kilometers. Since the results of the general calculation without having the constant had a range of 0.00 to 5000.00. Therefore, constant value was used to reduce the dispersion of the scale of the gravity formula from 0.00 to 5.00.

3.3 Minimum Spanning Tree

A tree is a subset of a network not containing loops. Minimum spanning tree is the tree which connects all nodes of the network with a minimum length/travel time of links (Effanga and Edeke, 2016). It gives the most feasible tree for an economy when considering cost of construction & maintenance (Kumar *et al.*, 2014). The Prims Algorithm was used to develop the minimum spanning tree.

3.4 Minimum Distance Path

The path which connects two nodes in a defined network with minimum length/travel time of links can be identified as the minimum distance path (Parsakhoo and Mostafa, 2016). Dijkstra's Algorithm was used to evaluate the minimum distance path between each node pair.

4. Methodology

4.1 Identification of Nodes

The following were considered as nodes for the analysis.

- Administrative district capitals
- Expressway Interchanges
- Major intersections of A-Class roads
- Other considerable nodes based on trip attraction

Since the entire economy was decentralized up to some extent towards district basis, Administrative, Commercial & Socio Economic activities of district capitals were increased. Therefore, district capitals were considered as primary nodes.

Expressway interchanges can be identified as coordinating gateways towards high mobility segment of inter district transportation.

Commercial activities of major intersections of National A-class roads were increased due to increase of through traffic of the junction.

Special nodes such as Katharagama (a religious place where people travel all year around in large numbers) were considered due to high socio economic activities and cultural behaviour.

4.2 Definition of Performance Indices of Nodes & Links

Key performance indices which create a baseline to evaluate overall performance of the network are as follows.

- Trip Generation/attraction level based on a Gravity model
- Average Acceptable Speed for Expressways & A Class roads
- Route Directness (distance of minimum time path/ minimum distance path)

4.3 Data Collection, Matrix Development & Application of Algorithms

Recently, Google traffic data have become the major traffic data source for the analysis when considering the reliability of data with respect to other sources (Vidanapathirana et al., 2020). Real time Google traffic data may vary due to time of the day and travelling season. Average value during office and school hours (0600hrs to 0900hrs and 1600hrs to 1800hr) were taken into consideration. Matrices were developed based on following considerations.

- Distance
- Travel Time
- Average Speed

Minimum spanning trees based on travel time and distances were developed. Minimum distance paths between each district capital node pairs were calculated. Other nodes, such as expressway interchanges, A-class road intersections and nodes with special trip attraction behavior, were also taken into consideration during calculations. But only district capitals were considered when developing resultant Origin Destination matrices since the objectives are more towards administrative districts. Nodes and links which occupy in each minimum distance path were recorded. Average speed of each link was calculated with respect to 25 main district nodes and average speed between all 25 district capitals were estimated. Average speed of expressways including proposed and under construction expressways were assumed as 80km/h based on previously developed driving cycles (Galgamuwa, et al., 2016).

4.4 Approximation of Demand Between District Capital Nodes Using Gravity Model

The matrix of gravity values with respect to 25 district capitals was developed as follows:

- Population density (heads per square kilometer) of Colombo: 3417
- Population density of Gampaha: 1711
- Distance Between Colombo & Gampaha: 34.4km

$$G\ (Gampaha\ \&\ Colombo) = \frac{3417 \times 1711}{1000x\,(34.4)^2} \quad \ldots(2)$$

The gravity value obtained from calculation would reflect the attractiveness between each node pair. Attractiveness is directly proportional to the population density and it is inversely proportional to the distance between nodes. Therefore, demand between each node pair can be approximated with respect to the gravity value. The concept of gravity model was extracted from newton law of gravity which reflects the attractive force between nodes with respect to population density of nodes and the distance (Jung et al., 2008).

4.5 Identification and prioritizing of critical links /nodes

Critical links and nodes can be identified based on the following criteria:

- Links and nodes which have higher frequency of employing in minimum distance paths but having poor average speed (less than 40km/h)
- Links and nodes which relate to minimum spanning tree
- Links and nodes which have high Gravity level with a poor average speed (less than 40km/h)

Since some of the critical links have already developed up to acceptable level (e.g. Expressway links with average speed of 80km/h), links and nodes to be improved were identified and ranked with respect to importance to the entire network and performance.

Introduction of new links and evaluation of impacts to the overall performance of the network due to introduction should be considered after optimisation of existing network.

5. Summary of Results and Discussion

5.1 Critical Nodes and links which were identified through gravity model

Since Colombo, Gampaha & Kalutara have the higher population density among district capitals, such node pairs give the values of gravity which is more than 1.

Table 1 - Links with Highest Gravity

Rank	Link Description	Gravity Value
1	Colombo- Gampaha	4.94
2	Colombo- Kalutara	1.32

Node pairs which have gravity value of more than 0.1 but less than 1 were identified as node pairs with moderate gravity which have heavy potential to impact on traffic behaviour over the next decade.

Table 2 - Links with Moderate Gravity Level

Rank	Link Description	Gravity Value
3	Kalutara- Gampaha	0.30
4	Gampaha Kegalle	0.30
5	Kandy- Matale	0.28
6	Colombo- Kegalle	0.23

7	Kegalle- Kandy	0.23
8	Galle- Matara	0.19
9	Kurunagala- Kegalle	0.16
10	Colombo- Kandy	0.16
11	Colombo- Ratnapura	0.15
12	Gampaha- Kandy	0.15
13	Kandy- Kurunegala	0.13
14	Gampaha- Kurunegala	0.13
15	Colombo- Kurunegala	0.12
16	Colombo -Galle	0.11

Graphical representation was developed to identify the critical intermediate nodes and critical paths with respect to gravity level of node pairs.

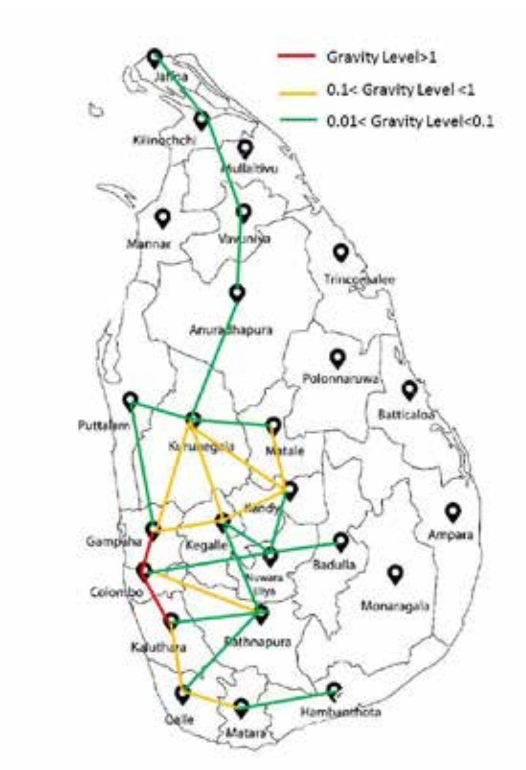

Figure 1- Gravity Model Observations

All the maps show the main 25 nodes at the exact geographical location (City centre of the District capital).

5.2 Development and Graphical Representation of Minimum Spanning Tree

After the implementation of the minimum spanning tree based on distance, it was observed that the following important links with relatively higher gravity were bypassed through other links by the minimum spanning tree algorithm.

- Kandy- Kurunagala
- Colombo- Ratnapura
- Gampaha- Puttalam
- Kurunagala- Matale
- Colombo- Nuwara Eliya
- Galle- Ratnapura

Since the above mentioned deviations were observed through the comparison of distance based minimum spanning tree and the gravity model; travel time based minimum spanning tree was developed to identify the existing network with the optimum level of service.

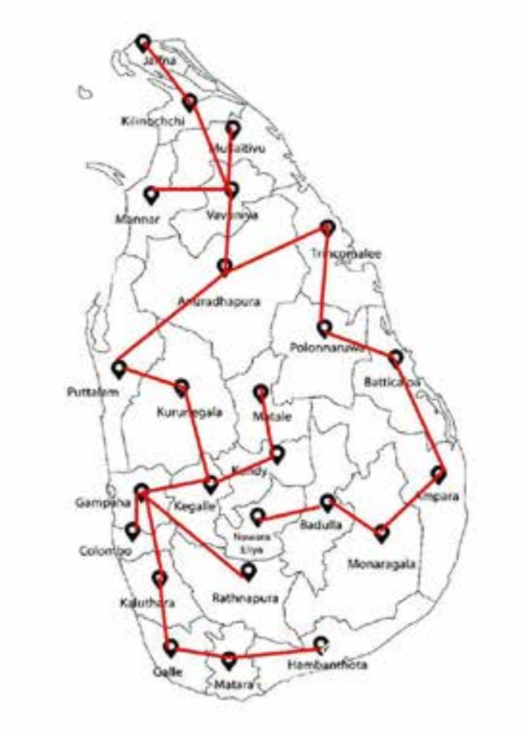

Figure 2 - Minimum Spanning Tree w.r.t Travel Time

Through the travel time optimized minimum spanning tree, it was observed that the following nodes are close to each other by distance but they are linked to each other by alternative paths due to geographical barriers. Level of service of the existing direct links of considering node pairs are relatively low.

- Kandy- Badulla
- Kandy- Nuwara Eliya
- Nuwara Eliya- Ratnapura
- Kegalle- Nuwara Eliya
- Kalutara- Ratnapura
- Matara- Ratnapura

Figure 3 - Geographical Barriers

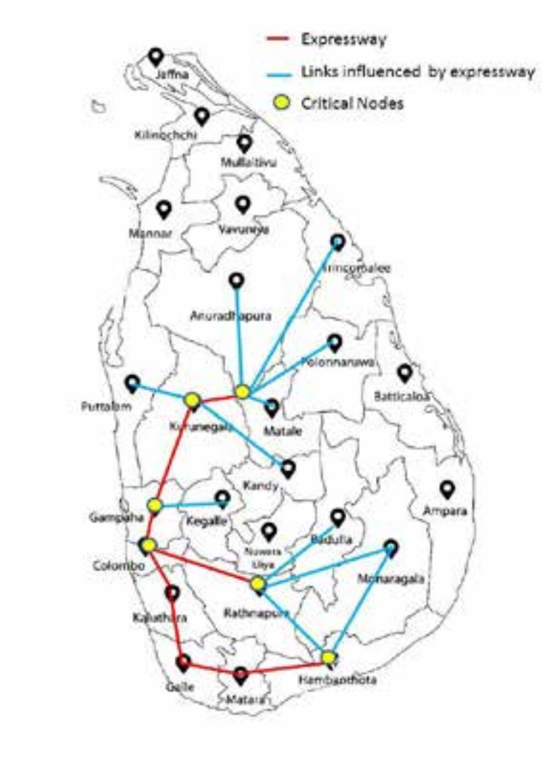

Figure 4 - Influence due to Expressway Network

5.3 Effect of Implementation of Expressway Network

Travel time between the nodes connected by expressway network were optimized up to the maximum level of service. Therefore, following nodes can be identified as the critical nodes when considering the travel time optimization of the network.

- Colombo
- Gampaha
- Kalutara
- Galle
- Matara
- Hambantota
- Kurunegala
- Dambulla
- Ratnapura

Following links can be identified as the links influenced by the expressway which require considerable performance improvement to maintain the mobility level between nodes through expressways.

- Gampaha- Kegalle (35km/h)
- Kurunegala- Puttalam (42km/h)
- Kurunegala- Kandy (30km/h)
- Dambulla- Matale (39km/h)
- Dambulla- Polonnaruwa (50km/h)
- Dambulla- Trincomalee (51km/h)
- Dambulla Anuradhapura (51km/h)
- Ratnapura- Beragala (36km/h)
- Ratnapura- Hambantota(42km/h)
- Hamabantota- Monaragala(48km/h)

5.4 Critical Nodes Identified through the Calculation of Minimum Distance Path of each District Capital Node Pairs

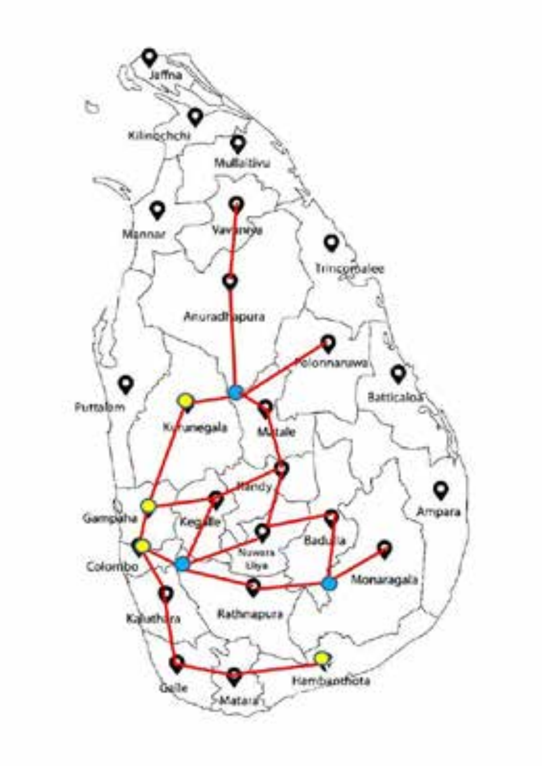

Figure 5 - Frequent Links in Minimum Distance path Calculation

The links which most frequently observed during minimum distance path calculation for node pairs are represented in Figure 5.
Some of the links can be identified as functioning or proposed expressway links. Therefore, they can be categorized as links with adequate mobility level.

5.5 Identification and Ranking of Improvement required links

Since the study provides different observations from different methods such as gravity level, minimum spanning tree & minimum distance path, it is necessary to implement a combined method to extract the most critical links to be improved. Therefore, the following ranking was implemented based on combined criteria.

Table 3 - Combined Ranking of Observed Links

Rank	Link Description	Average Speed
1	Kandy- Matale- Dambulla	25km/h
2	Gampaha- Kegalle	35km/h
3	Kegalle- Kandy	30km/h
4	Kurunegala- Kandy	30km/h
5	Kegalle- Kurunegala	34km/h
6	Kandy- Nuwara Eliya- Badulla	30km/h
7	Colombo- Avissawella- Nuwara Eliya	35km/h
8	Kurunagala- Matale	36km/h
9	Gampaha (Katunayake)- Puthtalam	37km/h
10	Ratnapura- Bearagala(Badulla & Monaragala)	36km/h

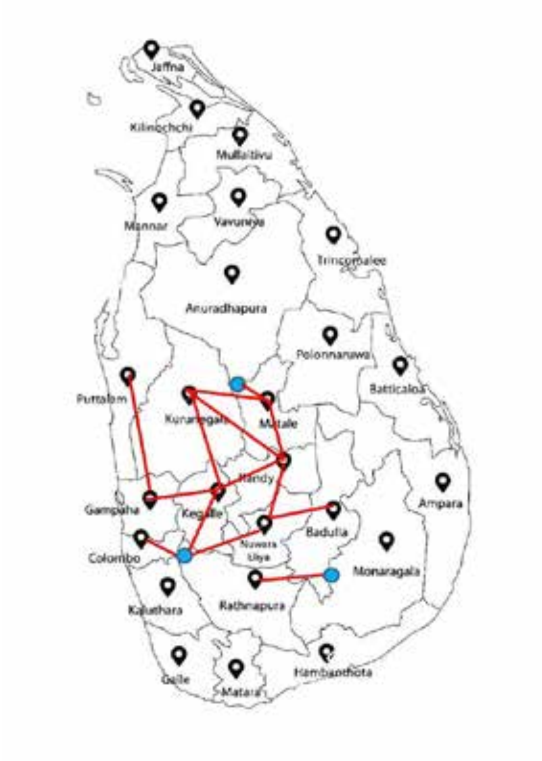

Figure 6 - Critical Nodes to be Improved

6. Conclusions

Links with low level of service and high demand for occupancy have been identified through a systematic approach. During the study, it was identified that population density plays a vital role with respect to transportation demand. Therefore, most of the links with considerable demand were located in the west and the central region of the country (Refer Figure 1). Minimum spanning tree with respect to travel time was developed to utilize the link improvements towards connecting all district capitals with minimum number of links. But node pairs with considerable attraction not connected by minimum spanning tree were observed. Therefore, minimum distance path was taken into consideration and frequently used links with low level of service was identified (Refer Figure 5).
Since expressway network and the proposed traces were confirmed through policy decision level and the strategic level of the economy, the

study focused towards effective utilization of existing expressway network to increase the overall network performance.

As an economical initiation, 10 links with poor level of service and high demand were obtained and ranked through the combined system approach (Refer Table 3 & Figure 6).

Most of the links which require improvements are located in the central region of the country. It reflects that the level of service dropped due to the geographical issues related with the considering links. Therefore, advanced engineering aspects towards landslide mitigation and slope stabilization should be considered effectively during improving of roadway infrastructure of existing traces.

Soil nailing, ground anchoring, shotcreting, construction of lightweight embankments, construction of drainage wells with horizontal perforated drilling and installation of anti-rockall nets can be identified as mitigation measures for ground improvement parallel to the existing roadway infrastructure development.

After implementing necessary improvements to the existing nodes and links, the strategy developed by the study could be applied towards the improved network to identify the necessity of introduction of new links to the network.

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