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All inquiries to be directed to:

Editorial Office of JSALT

Sri Lanka Society of Transport and Logistics (SLSTL)
34, MJC Fernando Mawatha, Idama, Moratuwa 10400, Sri Lanka
Telephone: +94 11 264 6702 Email: editor-jsalt@slstl.lk

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Aims and Scope

South Asia, and Sri Lanka in particular, are currently facing many transitional challenges; transport and logistics being among those most critical and important ones. Rapid economic growth and increasing income levels have radically changed the aspirations of people and thus, their demands, while expanding global markets and international competition have made meeting such demands highly complex and knowledge intensive. Ever expanding motorization increasingly generate negative externalities, pushing the transport industry to the limits of being unsustainable in the medium term. These factors make it imperative for transport and logistics professionals, including industrialists and academics, to focus on research and dissemination of results in view of addressing the challenges the mankind is facing in meeting mobility needs. The Journal of South Asian Logistics and Transport (JSALT) seeks to fulfill this mandate.

The JSALT is a refereed bi-annual English language journal published by the Sri Lanka Society of Transport and Logistics (SLSTL). It creates a space where findings of original research can be disseminated, and thereby contributes to the knowledge base and thought process in the discipline of Transport and Logistics. Critical evaluation of policies, investment, expansion, service delivery, pricing, equity and social welfare, technological progress and challenges posed to such fundamentals, in regard to transportation and logistics, are the major areas of interest of the journal. Sub-sectoral issues, such as Public Transportation, Railways and Roads, Ports and Shipping, Aviation and Airports, Freight and Passenger Haulage, Logistics and Supply Chain related issues also are addressed through dissemination of industry-related research, particularly focusing on the South Asian context.

Apart from the research articles the journal carries a special section titled ’Reviews’ which articulates alternative strategic thoughts and policy approaches.

All articles in this journal are subject to a rigorous double-blind peer-review process initially, and are then reviewed by the Board of Editors prior to final acceptance for publication.

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AN INVESTIGATION OF THE EFFECTS OF NEW BYPASS ROADS ON BUILD FORM IN SMALL TOWNS IN SRI LANKA

S Sewwandi [a] and A Jayasinghe [b]*

[a] Research Assistant, Urban Simulation Lab, Department of Town & Country Planning, University of Moratuwa, Moratuwa, Sri Lanka.

[b] Senior Lecturer, Department of Town & Country Planning, University of Moratuwa, Moratuwa, Sri Lanka.

* Corresponding author E-mail address*:* *amilabj@uom.lk*

ABSTRACT

This study explores the effects of bypass roads on the build form of small towns in Sri Lanka. The small towns analysed are Avissawella, Mawanella, Balangoda and Piliyandala.

The results of the study indicate three impact scenarios: i) the bypass road has more accessibility than the existing main road and new land uses, and high-density areas emerge along the by-pass road, making this the town centre; ii) both bypass road and the existing main road show similar levels of accessibility and attractiveness. iii) accessibility of the existing main road remains higher than the bypass road and very new developments are attracted towards the bypass road - thus the existing main road remains the main centre of the town. The results confirm that spatial and economic forces are closely interrelated as indicated in the theory of the natural movement economic process. However, the study found that the above forces are constrained by natural barriers.

These findings are useful for transport engineers when making new strategies to implement bypass roads and to urban planners to develop local development plans after constructing bypass roads.

Keywords: *Bypass road, Accessibility, Network centrality, Land use changes, Transport planning*

1. INTRODUCTION

Economic and urban developments that grow along major arterial roads are the most common spatial characteristics of small and medium sized towns in Sri Lanka [1]. These create a number of problems such as traffic congestion, safety, noise and air pollution etc [2]. Bypass roads have been introduced to overcome these problems. A bypass road is one that avoids an existing high-density built-up area in a city or town, allowing traffic to flow without interference from local traffic in that area: typically, a city- or town centre. A bypass road also replaces the main transport route outside the town or city. The main objectives of bypass roads are to reduce the traffic congestion of the town centre while improving mobility. The bypass construction usually focuses on redirecting vehicles that travel through the existing high-density built-up areas in cities and towns with no intention of engaging in activities such as shopping. This improves overall travel time and mobility, reducing the adverse impacts of traffic congestion. A bypass road can dramatically change land use and growth patterns in small and medium sized towns. It also has the potential to positively or adversely affect the physical and socio-economic setting of those towns [3]. Therefore, transport and urban planning agencies have the responsibility to identify and demonstrate the potential physical and socio-economic impacts before constructing a new bypass road development project. However, a limited number of studies have been carried out in Sri Lanka to study the impact of bypass roads in towns when the main transport route is replaced by another thoroughfare outside the town. In this context, the present study explores the effects of a bypass road on build form of a town and investigates the changes in land use and building density that accompany changes in accessibility. This study also analyses the before and after situations for bypass roads in four small towns in Sri Lanka: namely, Avissawella, Mawanella, Balangoda and Piliyandala.

There are few research studies which have investigated the impact of a newly introduced bypass road on land use and build densities in cities. For example, in 1995 Falleth et. al [4] conducted a research on how new bypass roads affect the land use of towns in Norway. The authors observed that new economic activities shifted towards the junctions where bypass roads touch existing settlements. Van Nes et. al [5] investigated how inner and outer ring roads affect the location pattern of shops. The results of that study show "shops located themselves along the highest integrated [highest accessible] street". Van Ness and Stolk [6] analysed two road proposals for the Dutch city Leiden. Both cases show that new roads integration [accessibility] values surpass the existing city centres integration [accessibility] values after constructing bypass roads and new investments begin to emerge in these areas. Sander, et. al [2] and Jayasinghe et. al [7] claim that integration [accessibility] is the major factor affecting new attractions, investments and urbanization. Results of those studies indicate that a new bypass road changes the integration value [accessibility] of the road network and will affect the location pattern of shops [land use and built density]. The results of these studies are consistent with the theory of the movement economy. The theory, "built on the notion of natural movement, proposes that evolving space organization in settlements first generates the distribution pattern of busier and quieter movement pattern flows, which then influence land use choices, and these in turn generate multiplier effects on movement with further feedback on land use choices and the local grid as it adapts itself to more intensive development" [8]. Munasinghe [1] has demonstrated that most of the urban areas in Sri Lanka have grown spontaneously as the result of a self-organizing process: this relates to the theory of the natural movement process. He notes that when a new road is constructed, it creates land-use changes and activities due to new levels of accessibility. However, he argues that the process of self-organising is disturbed due to growing social, economic and environmental issues. Perera [9] has demonstrated that powerful companies, institutions, and individuals also create a physical and political space based on income and social and political power. These theories and ideologies argue that the movement economy can be disturbed due to the above factors. Against this background, this study explores the effects of bypass roads on build form of the town and the factors that influence such changes.

2. METHOD OF STUDY

2.1. Case Study Areas

Figure 1: Location of case study areas
Source: Compiled by Author

The selected case study areas are Avissawella, Mawanella, Balangoda and Piliyandala. Of these, Avissawella and Piliyandala are located in the Western Province and the Mawanella and Balangoda bypass roads are located in the Sabaragamuwa Province of Sri Lanka.

Table 1 below provides a brief description of these areas. secondary data and the year that the bypass road has been implemented are key factors considered in selecting these case study areas. The data collected is related to road network, land use and buildings, considering different time periods ie, before and after the bypass road implementation.

Table 1: Selected four case study area and its characteristics.

Case study area	Extent Km^2	Population (2012)	Year of bypass road implemented	Use before bypass road implemented
Avissawella	19.7	30,308	1991	Railway line
Mawanella	5.43	8,993	2000	Vegetation cover
Balangoda	26.5	16,510	2006	Vegetation cover
Piliyandala	35.28	185,22	2014	Paddy land

Source: Compiled by author

2.2. Data

Table -A1 and Table-A2 appended provide brief description about the data used in this analysis. (Refer Appendices).

2.3. Data Preparation and Analysis

The primary and secondary data were entered and stored in a Geographic Information System (GIS). Then, the study analysed the temporal changes utilising spatial analysis tools in the GIS environment; and utilised three parameters of land use intensity, building density and accessibility to capture temporal changes in selected case town areas. The following section explains three parameters in detail.

2.3.1. *Land-use intensity*

The study utilised the category level land-use intensity analysis to capture temporal changes. Category level land-use intensity analysis captures the "intensity change of each land category within a particular time interval" [10]. The study utilised the following equations (Eq 1 & Eq 2) to compute land use grain intensity (Gtj) and annual loss intensity (Lti). Figure -A1 under appendices illustrates the steps that follow to compute temporal changes in land use intensity. (Refer appendices)

$$G_{tj} = \frac{\left[\left(\sum_{i=1}^{j} C_{tij}\right) - C_{tjj}\right] / (Y_{t+1} - Y_t)}{\sum_{i=1}^{j} C_{tij}} * 100\% \text{ ………………...(1)}$$

$$L_{ti} = \frac{\left[\left(\sum_{j=1}^{j} C_{tij}\right) - C_{tii}\right] / (Y_{t+1} - Y_t)}{\sum_{j=1}^{j} C_{tij}} * 100\% \dots\dots\dots (2)$$

Where,

i = index for a category at the interval's initial time point

j = index for a category at the interval's final time point

t = index for a time point,

C_{tij}= numbers that transit from category i at time Y_t to category j at time Y_{t+1}

G_{tj} = annual intensity of gross gain of category j for time interval

Lti = annual intensity of gross loss of category i for time interval

2.3.2 *Building density*

There are several methods to measure building density such as the Floor Area Ratio (FAR), Plot coverage and Building block coverage [11]. Of these, Floor Area Ratio (FAR) and plot coverage methods were used to compute building density. The study utilised space matrix to capture temporal changes in building density. Space metrics explains density as a multi-variable phenomenon and relates density to build mass (urban form). The Space Matrix method helped to clarify the confusion in terms used by urban planners who work with urban density. The most important contribution of the space matrix method, apart from a clear definition of density, is that it relates density to urban shape and other events [12]. Figure-A2 under appendices illustrates the steps followed to compute temporal changes in building density. (Refer appendices)

$$FAR = \frac{Floor\ area\ (building\ footage)}{Lot\ area(land\ area)} * 100 \ldots\ldots\ldots (3)$$

$$Plot\ coverage = \frac{Building\ area}{Site\ area} * 100 \ldots\ldots\ldots\ldots..(4)$$

2.3.3 *Accessibility*

In this step, accessibility was analysed using the network centrality assessment (NCA) [13] approach. The study computes the level of accessibility based on closeness and betweenness centrality parameters. Closeness centrality (CC) explains, “the notion of accessibility of a road segment measures how close the road segment is to all others road segments in the network along the shortest path” [14], [15], [16]. Betweenness captures (BC) “a special property in a particular road segment that does not act as either origin or destination but as a pass-by location… which is the number of shortest paths between two nodes that contain the given node” [14], [15]. CC captures the volume of trip attraction to a given road segment due to accessibility and BC captures the volume of pass-by trips which bypass the given road segment due to the intermediacy [13]. “BC performs a key role in explaining traffic volumes in locations where there are more pass-by trips such as regional roads that connect residential townships to a major city. CC is the key to explain the variations in traffic volumes at trip-generation locations such as shopping districts [13].The study utilized the Spatial Design Network Analysis (SDNA) tool [17] in Geography Information System (GIS) environment to compute BC and CC. The tool requires a ‘network graph’ file as the input and ‘analysis option’ to compute BC and CC [18]. This study utilizes the ‘road-segments’ graph method [19], [20] and the ‘angular analysis’ option to compute the shortest-path. Furthermore, the study considered two radiuses of a node to the network influence area as 500m and 10km to capture the attraction of pedestrian movement and the attraction of vehicle movement respectively. Figure-A3 under appendices illustrates the steps that follow to compute temporal changes in BC and CC. (Refer appendices)

$$CC^r(\mathrm{i}) = \frac{1}{\sum_{\mathrm{j}\neq\mathrm{i}} \mathrm{d}_{ij}} \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$BC^r(\mathrm{i}) = \sum_{\mathrm{j}\neq\mathrm{i}\neq\mathrm{k}} \frac{\mathrm{p}_{jk}(i)}{\mathrm{p}_{jk}} \ldots\ldots\ldots\ldots(6)$$

Where:

CC^r(i)= Closeness centrality of road segment 'i' within the search radius r,

BC^r(i)= Betweenness centrality of road segment 'i' within the search radius r,

N = Total number of road segments [i.e. nodes in dual graph] in the network,

d_{ij} = Distance between road segments 'i' and 'j' along the shortest path,

$\mathrm{p}_{jk}(i)$ = Number of geodesics [shortest paths] between road segments 'j' and 'k 'that passing through road segment 'i',

p_{jk}= Number of geodesics [shortest paths] between segments 'j' and 'k'

3. ANALYSIS AND FINDINGS

The study analysed the temporal changes in selected case study areas utilizing three parameters as land use intensity, building density and accessibility to capture the impact of bypass roads. Accordingly, the following sections explain the key findings of each case study area.

3.1.1 *Avissawella*

Avissawella is a small town (population =30,308) situated on the A4 route from Colombo to Rathnapura. The bypass road in Avissawella was constructed in the year 1991. Figures 2,3 and 4 illustrate the variations of accessibility in the road network of Avissawella town over four different time periods ie., 1989, 1992, 2007, 2019. The level of accessibility is computed based on closeness (CC) and betweenness (BC) centrality parameters. BC-n values of the road network has been dramatically changing over the last two decades after the construction of the bypass road. As depicted in Figure 2, the prominence of the main road has been reduced while the bypass road has attracted higher BC values. It indicates that the bypass road has more potential to capture pass by trips than the existing road. As depicted in Figure 3, CC-500m values have gradually increased in both roads over the last two decades.

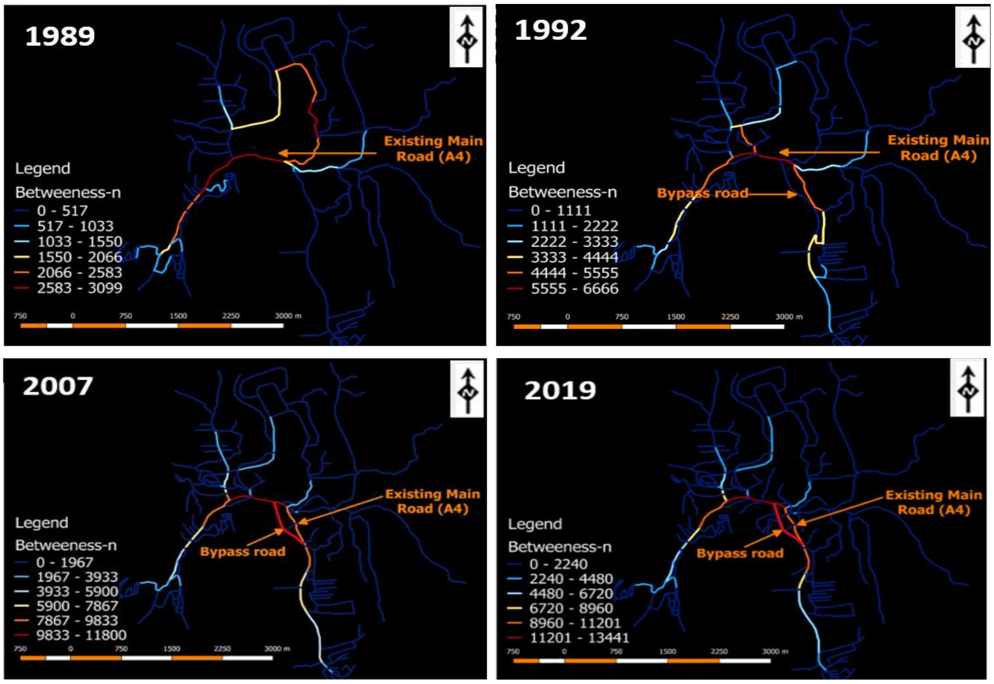

Figure: ***2:*** **Variation of betweenness values in road network of Avissawella town before and after bypass road construction.**

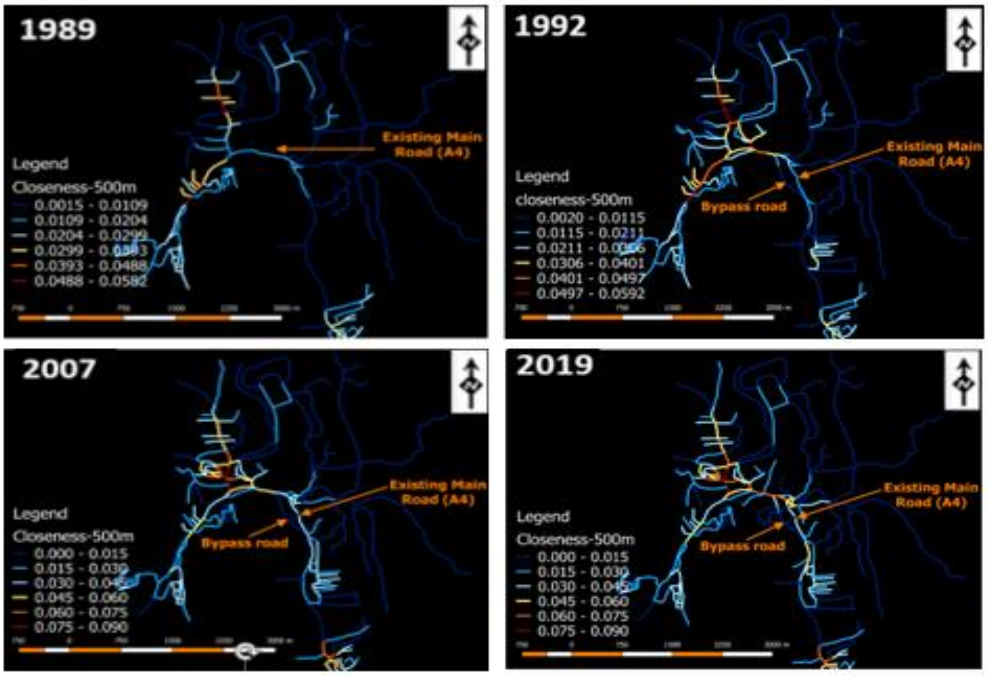

Figure 3: Variation of Closeness-500m values in road network of Avissawella town before and after bypass road construction.

However, the existing road records a higher CC-500m value compared to the bypass road. Furthermore, there are very few connections between the bypass road and the existing road. It indicates that the bypass road has less potential to attract pedestrian movement, compared to the existing road.

As depicted in Figure 4, CC-n values have been very much similar in both roads over last two decades. It indicates that both roads have a similar level of potential to attract vehicle movements. (In the reference map series, changes in value of BC and CC are visible through the six colour ranges in the maps. The highest BC and CC values are shown in red and the lowest values are shown in blue. Accordingly, the use of colour range (Red to Blue) or values mention in legend help to identify BC and CC changes along the bypass and the existing road.)

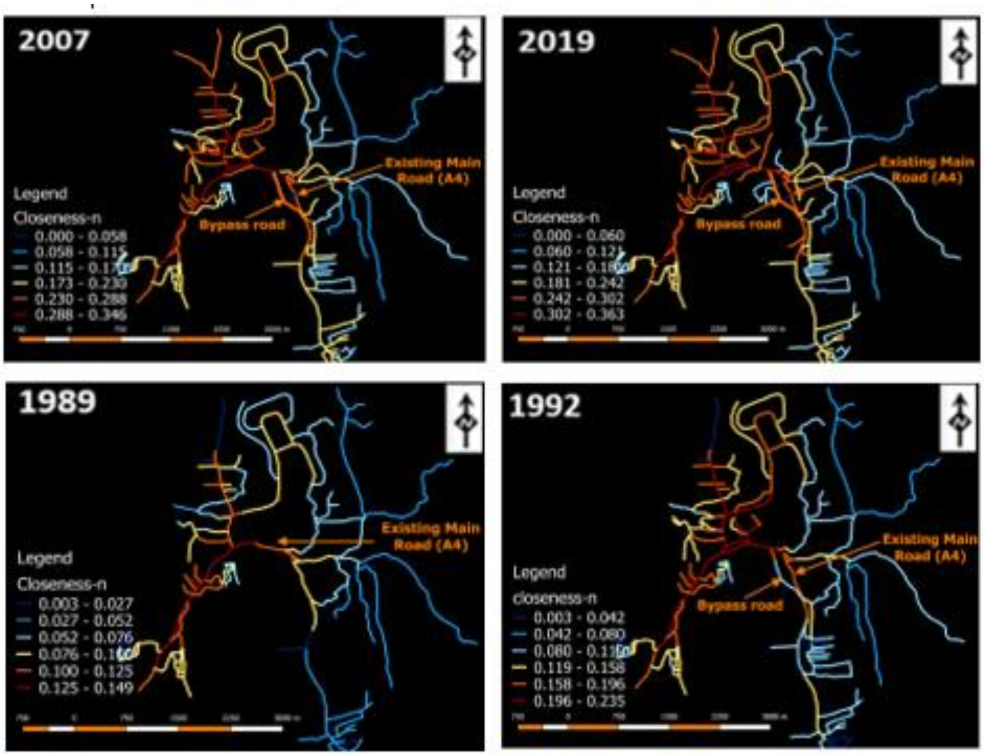

Figure 4: Variation of Closeness-n values in road network of Avissawella town before and after bypass road construction.

Figure 5 depicts the changes in building density in Avissawella from 1989 to 2019 with floor area ratio maps. With the construction of the new bypass road, new buildings have gradually appeared along new bypass road. However, building density along the existing main road (FAR = 2) remain higher than the building density along the bypass road (FAR = 1).

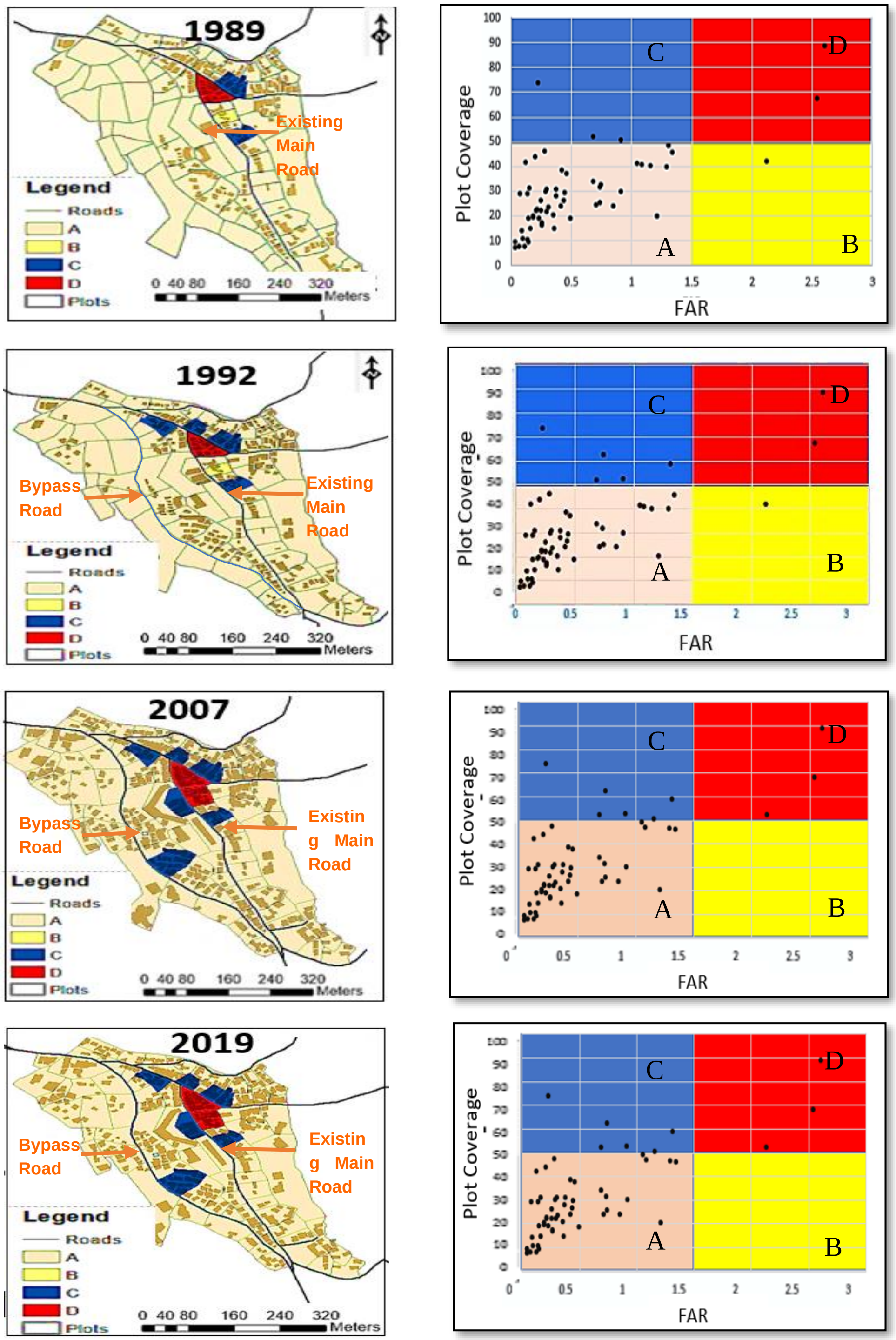

Figure 5: Variation of FAR values in building density of Avissawella town before and after bypass road construction

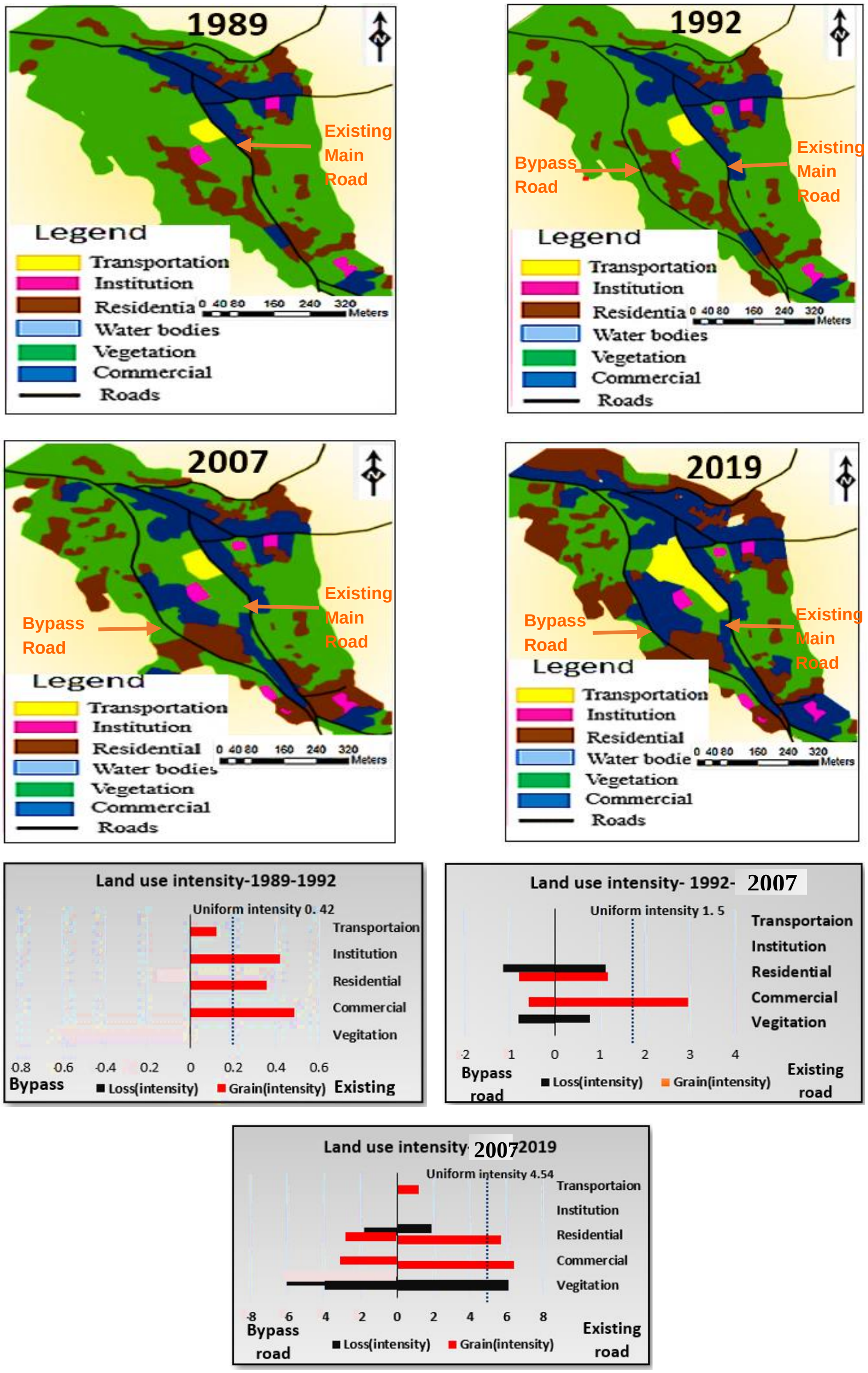

Figure 6: Variation of land use intensity values in land use of Avissawella town before and after bypass road construction.

Figure 6 above depicts the results of the land use intensity analysis. As per the results, there was significant growth in commercial land uses along the existing road during the period of 1989 to 1992 (after bypass roads). Further, many residential land uses have been converted into commercial sectors along the existing road. In the early stages (1992-2007) the bypass road was able to attract residential land uses and gradually the bypass road was also able to attract commercial land use during the period of 2007 – 2019.

Table 2 : Summary of changes in Avissawella town area.

Parameters	**Existing/ Bypass**	**Years**			
		1989	**1992**	**2007**	**2019**
Building density	Existing	1.2	1.2	1.2	2
	Bypass	-	0.42	1	1
Betweenness	Existing	1699	20187	3246	3495
	Bypass	-	244	7296.5	7935
Closeness_500m	Existing	0.0182	0.0507	0.025	0.091
	Bypass	-	0.005	0.0195	0.0485
Closeness	Existing	0.107	0.194	0.314	0.35
	Bypass	-	0.1295	0.359	0.3686
Land use type	Existing	2	1	1	1
	Bypass	-	3	3	2
Land use mix	Existing	-	1= (+0.5) 2= (+0.4) 3= (0.15) 4= (+0.4) 5=(+0.05)	1= (+3) 2= (+1), (-0.9) 3= (-0.85)	1= (+6.5) 2= (+6), (-2) 3= (-6.2) 5= (+1)
	Bypass	-	-	1= (+0.5) 2= (+0.7),(-1.3) 3= (-1.8)	1= (+3) 2= (+3.5), (-2) 3= (-4)

*1= Commercial, 2= Residential, 3= Vegetation, 4=Institution, 5= Transportation

*+ = Grain intensity, - = Loss intensity

The changes in the Avissawella case study area due to the bypass road can be summarised as follows: With higher BC values, the bypass road was able to attract more pass-by trips than the existing road. The analysis of result of the previous section indicates that the accessibility (CC values) had increased in both roads. Accordingly, land use along both roads have gradually changed. However, the bypass road was unable to attract commercial land uses and high density, when compared to the existing road. Furthermore, the existing main road remains as the centre of the town. Avissawella town centre is located below 35 m elevation MSL, but the bypass road elevation is more than 50 m. Besides, there is a mountain along the bypass road (refer Figure 7), that restricts the space to grow and acts as a barrier to attract new activities along the bypass road. The case study results indicate that the natural movement of economic process is disturbed due to lack of space. Table 3 show existing traffic flow data on both existing and bypass roads and it confirms that the bypass road has a high level of service relative to the existing road.

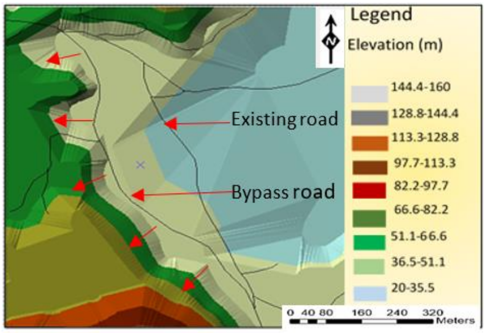

Figure 7: Elevation of the Avissawella case study area

Table 3: Existing Level of service in bypass road and existing road in Avissawella case study area

Level of Service-Avissawella : 2019	
Bypass Road	Existing Road
A (0.30)	B (0.47)

Source: Compiled by author

3.1.2 *Mawanella*

Mawanella is a small town (population = 111,727) situated on the A1 route from Colombo to Kandy. The bypass road in Mawanella was constructed in year 2000. Figures 8,9 and 10 illustrate the variations of accessibility in the road network of Mawanella town over three different time periods (1999, 2010, 2019). BC-n values of the road network has been dramatically changing over the last two decades after the construction of the bypass road. As depicted in Figure 8, the prominence of the main road has been reduced while the bypass road has attracted higher BC values. This indicates that the bypass road has more potential to capture pass by trips than the existing road. As depicted in Figure 9, CC-500m values have gradually increased in both roads over the last two decades. However, the bypass road records a higher CC-500m value when compared with the existing road. Furthermore, there are good connections between the bypass road and the existing road. This indicates that the bypass road has a high potential of attracting pedestrian movement.

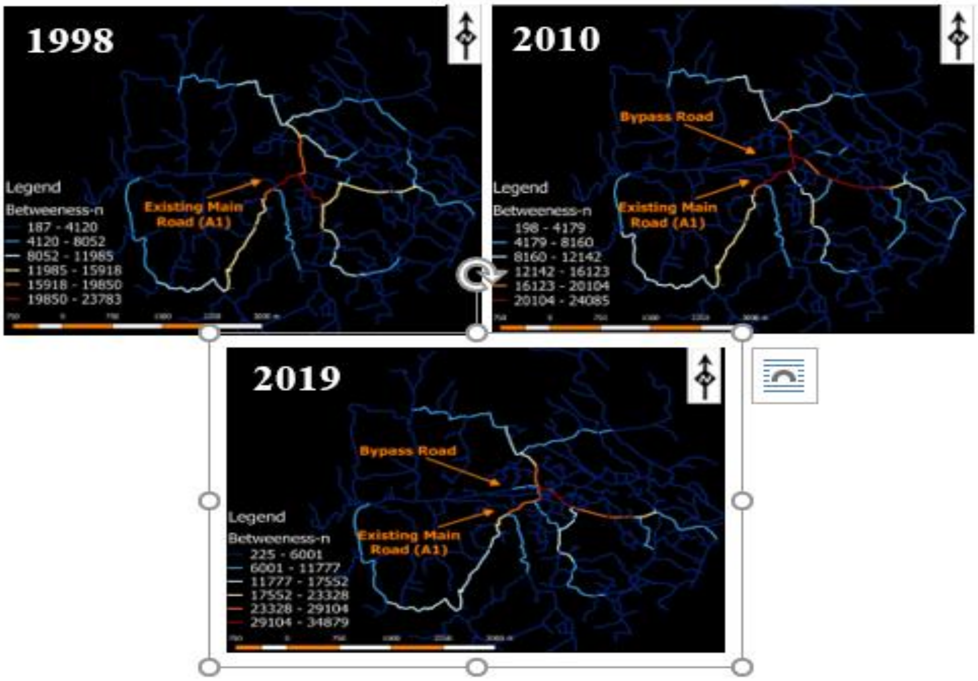

Figure 8: Variation of betweenness values in road network of Mawanella town before and after bypass road construction

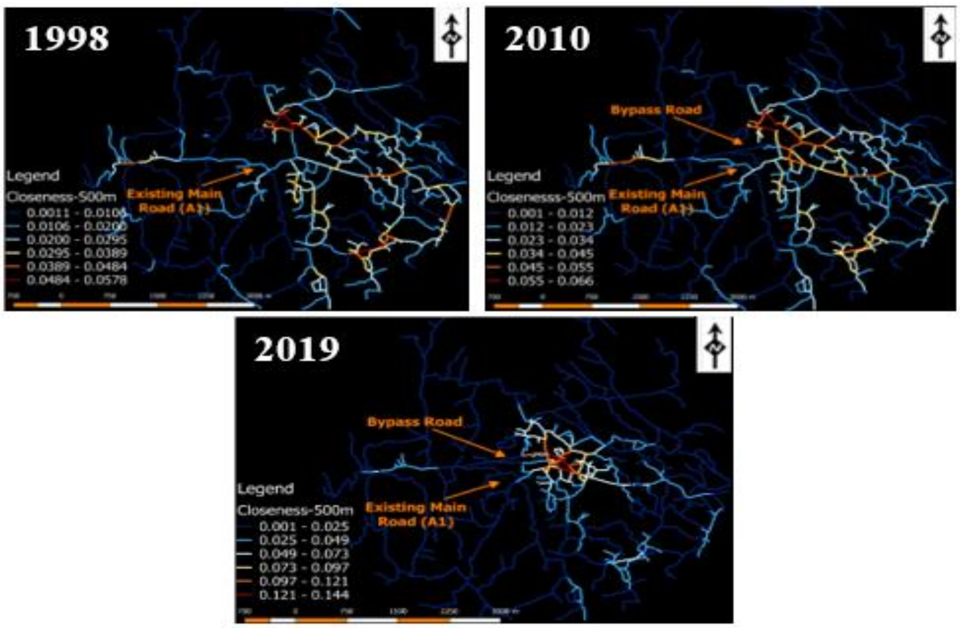

Figure 9: Variation of Closeness 500m values in road network of Mawanella town before and after bypass road construction

Figure 10 below presents the variation of Closeness-n values in road network of Mawanella town before and after the construction of the bypass road.

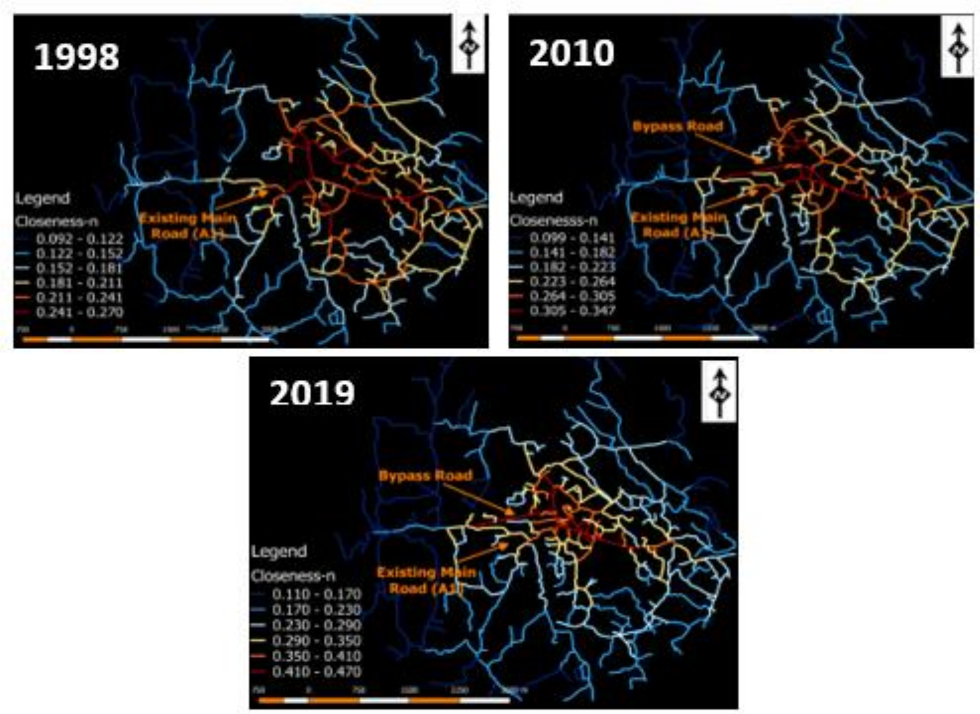

Figure: 10 Variation of Closeness-n values in road network of Mawanella town before and after bypass road construction.

As depicted in Figure 10, the CC-n values for both roads have increased gradually over the last two decades. However, the bypass road records a higher CC-n value when compared to the existing road. It indicates that the existing road has less potential to attract O-D trips, compared to the bypass road.

In the reference map series, changes of BC and CC are visible through the six colour ranges in the maps. The highest BC and CC values are shown in red and the lowest values are shown in blue. Accordingly, the use of colour range (red to blue) or values mentioned in legend help to identify BC and CC changes along the bypass and the existing road.

Figure 11 depicts the changes in building density in Mawanella from 1999 to 2019 with floor area ratio maps. New buildings have gradually appeared along with the construction of the new bypass road. However, building density along the bypass road (FAR = 0.8) remains higher than the building density along the existing road (FAR = 0.72).

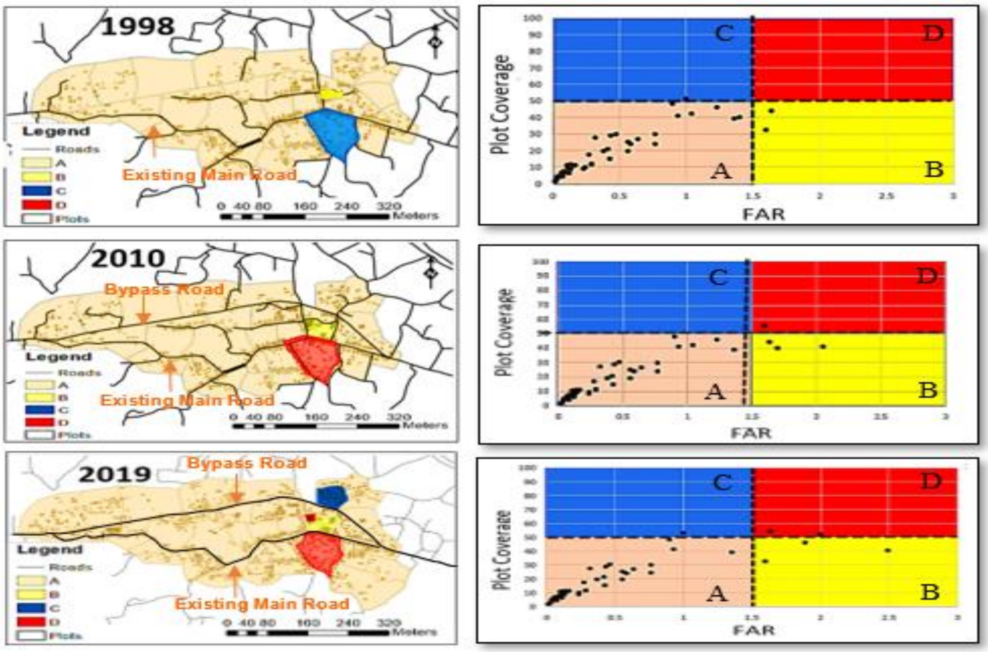

Figure 11: Variation of FAR values in building density of Mawanella town before and after bypass road construction

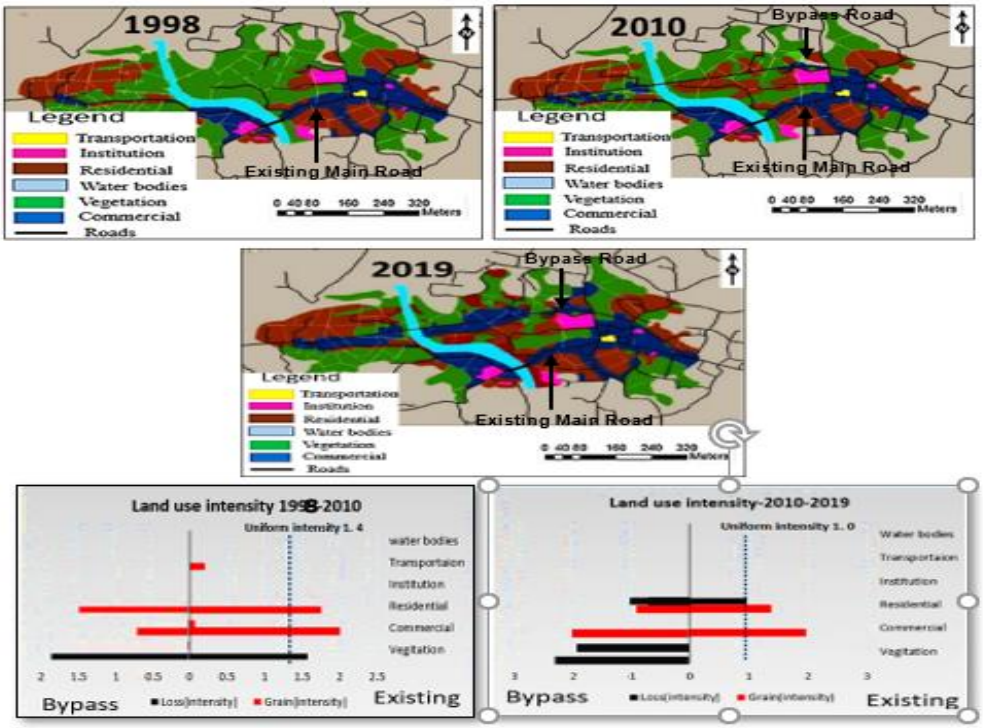

Figure 12: Variation of land use intensity values in land use of Mawanella town before and after bypass road construction

Figure 12 depicts the results of the land use intensity analysis. As per the results, there was slow growth in commercial land use along the existing road during the period of 1999 to 2010 (after bypass roads). In early stages (1999-2010), the bypass road was able to attract residential land uses and gradually the bypass road was also able to attract a fast growth of commercial enterprises during the period of 2010 – 2019.

Table 4: Summary of changes in Mawanella town area

Parameters	**Existing/ Bypass**	**Years**		
		1999	**2010**	**2019**
Building density	Existing	0.583	0.52	0.72
	Bypass	-	0.63	0.8
Betweenness n	Existing	69183	11305	10505
	Bypass	-	10517	13491
Closeness 500m	Existing	0.1228	0.0267	0.0746
	Bypass	-	0.0345	0.0913
closeness n	Existing	0.24	0.314	0.365
	Bypass	-	0.314	0.4135
Land use type	Existing	1	1	1
	Bypass		2	1
Land use mix	Existing	-	1= (+2.4), (-0.3) 2= (+1.8) 3= (-1.7) 5= (+0.4)	1= (+1.8) 2= (+1.5), (-1) 3= (-1.8)
	Bypass	-	1= (+0.6) 2= (+1.5) 3= (-1.7)	1= (+2.5) 2= (+0.8), (-0.9) 3= (-2.5)

*1= Commercial,2= Residential, 3= Vegetation, 4=Institution, 5= Transportation

*+ = Grain intensity, - = Loss intensity

The changes in the Mawanella case study area due to the bypass road can be summarised as follows: with higher BC values, the bypass road was able to attract more pass-by trips than the existing road. The analysis of the previous section indicates that the accessibility (CC values) has increased in both roads. Accordingly, land use along both roads has gradually changed. However, the bypass road was able to attract commercial land use and high density, compared to the existing road. Furthermore, the bypass road was converted into the main centre of the town. The Mawanella town centre is located below 215 m elevation and the bypass road elevation does not exceed 215 m. There is vegetation along the bypass road (refer Figure 13).

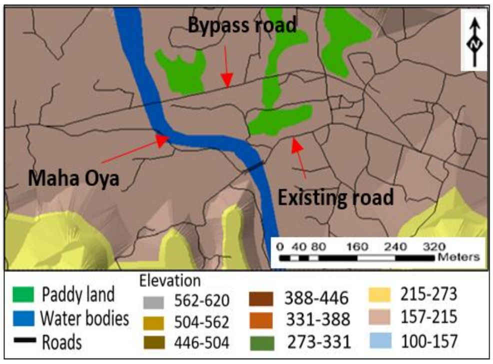

Figure 13: Elevation of the Mawanella case study area

Table 5: Existing Level of service in both bypass road and existing road in Mawanella case study area

Level of Service- Mawanella : 2019	
Bypass Road	Existing Road
E (1.03)	C (0.75)

Source: Compiled by author

Due to this, there is enough space to grow along the bypass road a factor that attracts new activities. Moreover, the location of the Old brick bridge and Maha Oya create a barrier to expand activities along the existing road and it helps to attract new investment to the bypass road. The case study results indicate that natural movement economic process has taken place owing to the available space for growth along the bypass road. Table 5 show existing traffic flow data on both of existing and bypass roads and it obviously confirmations both of bypass road and existing road have low level of service and not achieved the aim of the bypass road construction.

3.1.3 *Balangoda*

Balangoda is a small town (population = 81,563) situated on the A4 route from Colombo to Batticaloa. The bypass road in Balangoda was constructed in 2006. Figures 14,15 and 16 illustrate the variations of accessibility in road network of Avissawella town over three different time periods: 2004, 2010, 2019. The level of accessibility is computed based on closeness (CC) and betweenness (BC) centrality parameters. BC-n values of the road network has been dramatically changing over the last decade after the construction of the bypass road. As depicted in Figure 14, the main road has been attracting higher BC values than the bypass road. It indicates that the existing road has more potential to capture pass by trips than the bypass road. As depicted in Figure 15, CC-500m values have gradually increased and the CC-500m values have been quite similar in both roads over the last decade. It indicates that, both roads have a similar level of potential to attract vehicle movements. Furthermore, there are very few connections between the bypass road and the existing road. It indicates that the bypass road has less potential to attract pedestrian movement compared to the existing road.

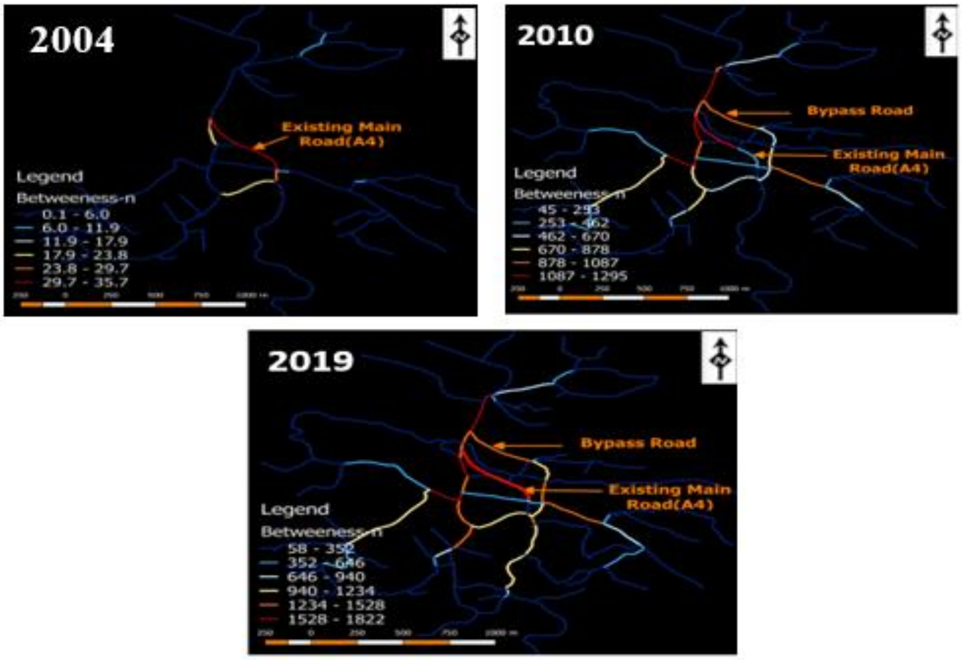

Figure 14: Variation of betweenness values in road network of Balangoda town before and after bypass road construction

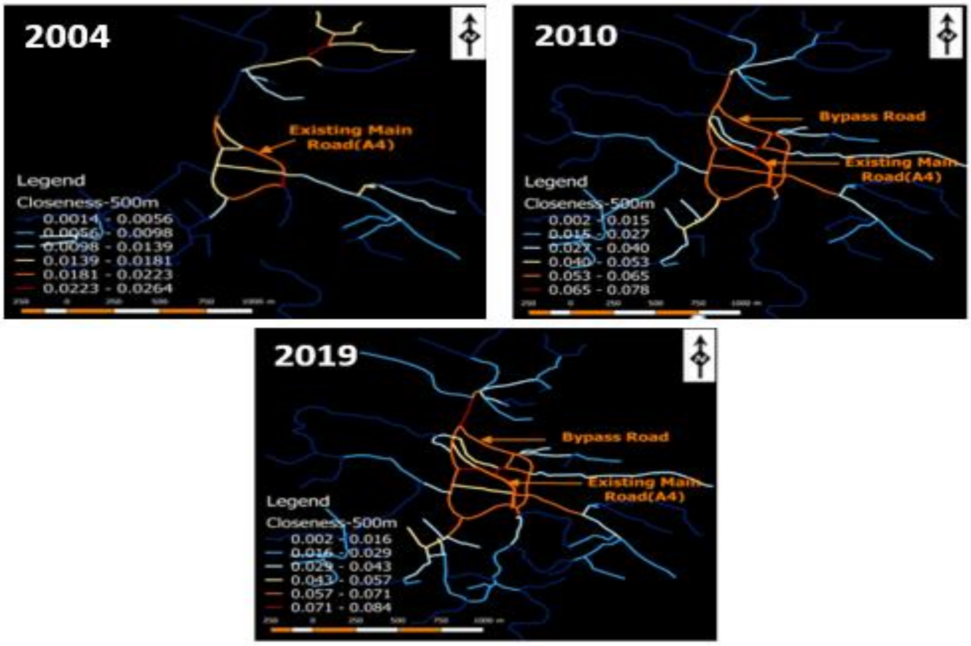

Figure 15: Variation of closeness-500m values in road network of Balangoda town before and after bypass road construction.

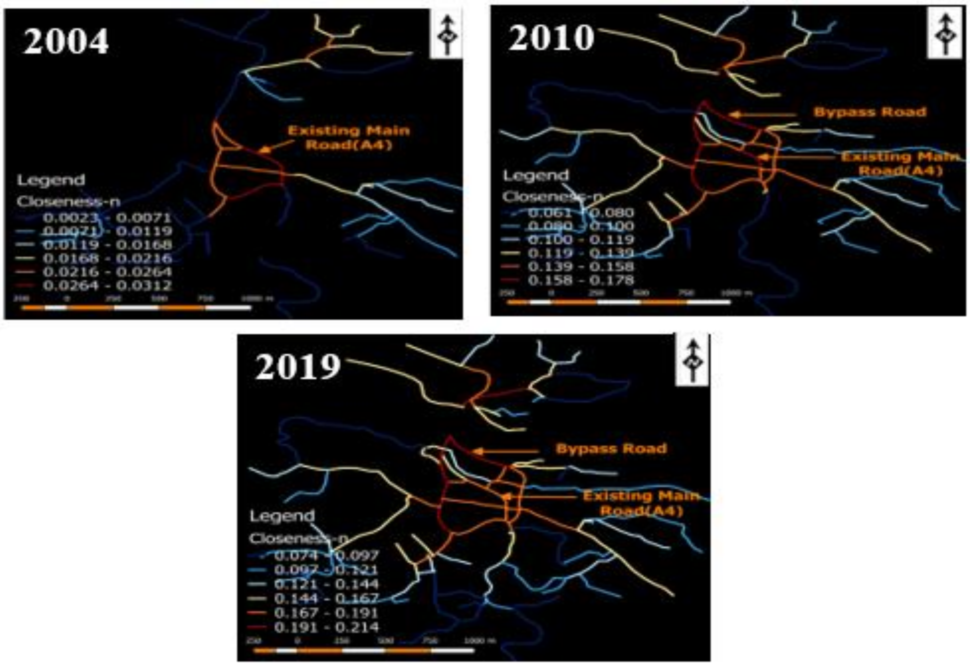

Figure 16: Variation of closeness-n values in road network of Balangoda town before and after bypass road construction.

As depicted in Figure 16, CC-n values have gradually increased in both roads over the last decade. However, the bypass road records a higher CC-n value compared to the existing road, it indicating that the existing road has less potential to attract O-D trips movements comparatively. (In the reference map series, changes in value of BC and CC are visible through the six colour ranges in the maps. The highest BC and CC values are shown in red and the lowest values are shown in blue. Accordingly, the use of colour range (red to blue) or values mentioned in legend help to identify BC and CC changes along the bypass and the existing road.)

Figure 17 depicts the changes in building density in Balangoda from 2005 to 2019 with floor area ratio maps. New buildings have gradually appeared, with the construction of the new bypass road. However, building density along the existing main road (FAR = 1) remain higher than the building density along the bypass road (FAR = 0.83). Figure 18 depicts the results of land use intensity analysis. As per the results, there was significant growth in commercial land use along the existing road during the period of 2005 to 2011 (after bypass roads). Moreover, many residential land uses have been converted into commercial operations along the existing road. Gradually, the bypass road was also able to attract residential land use during the period 2011 – 2019.

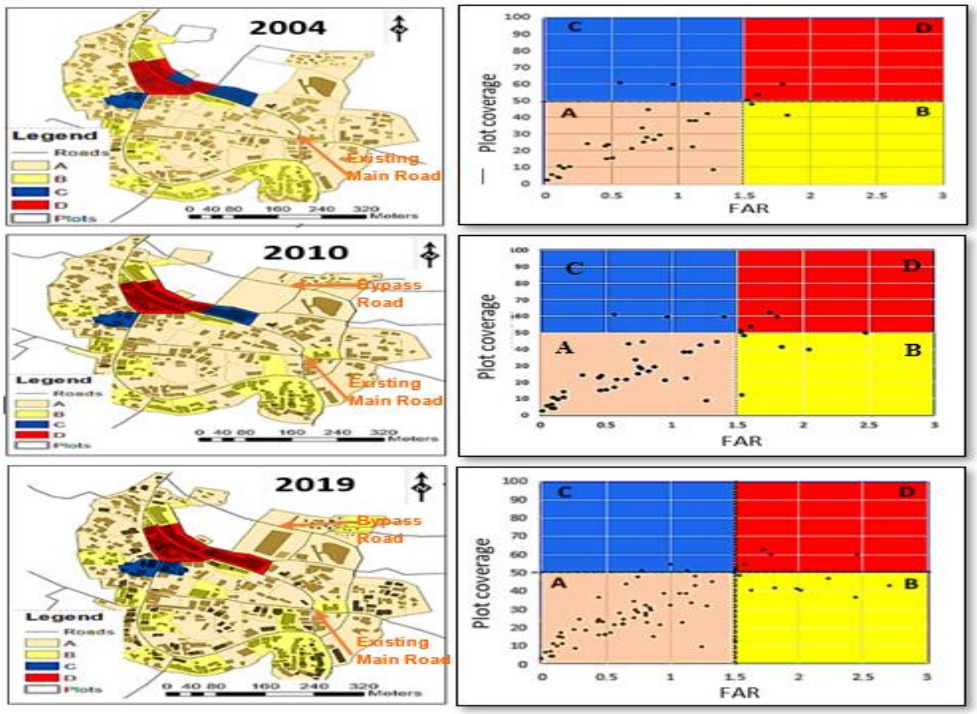

Figure 17: Variation of FAR values in building density of Balangoda town before and after bypass road construction

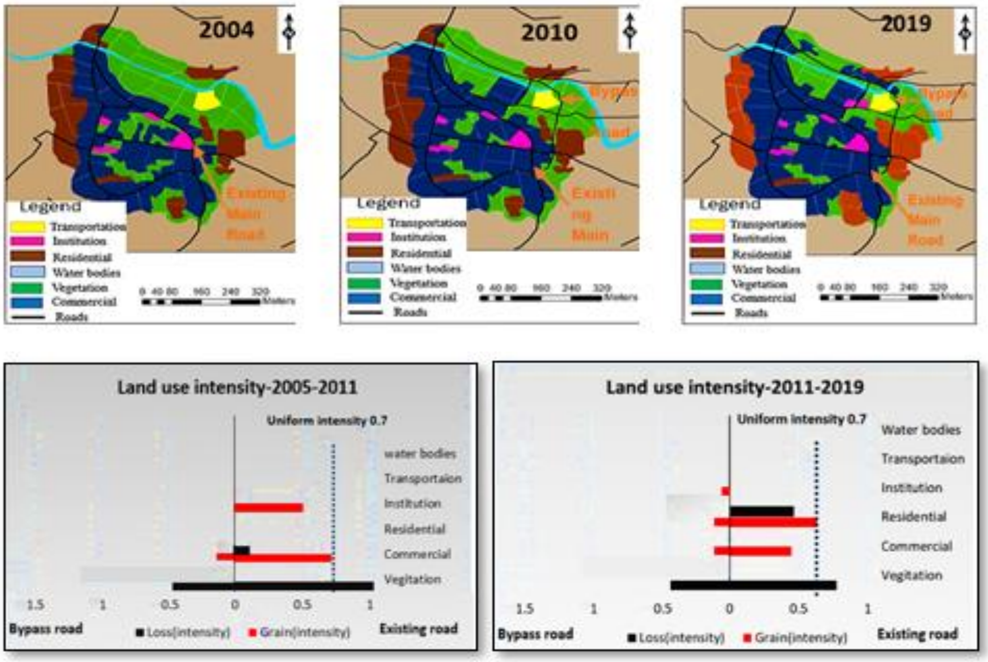

Figure 18: Variation of land use intensity values in land use of Balangoda town before and after bypass road construction.

Table 6: Summary of changes in Balangoda town area.

Parameters	Existing/ Bypass	Years		
		2005	2011	2019
Building density	Existing	1.3	1.36	1
	Bypass	-	0.73	0.83
Betweenness n	Existing	10.56	894	1428
	Bypass	-	658	1157
Closeness 500m	Existing	0.0182	0.0571	0.064
	Bypass	-	0.0905	0.064
closeness n	Existing	0.123	0.159	0.132
	Bypass	-	0.154	0.184
Land use type	Existing	1	1	1
	Bypass	-	3	2
Land use mix	Existing	-	1= (+0.7), (-0.2) 3= (-1.2) 4= (+0.5)	1= (+0.4) 2= (+0.7), (-0.5) 3= (-0.8)
	Bypass	-	1= (+0.2) 3= (-0.4)	1= (+0.1) 2= (+0.1) 3= (-0.4) 4= (+0.05)

*1= Commercial,2= Residential, 3= Vegetation, 4=Institution, 5= Transportation

*+ = Grain intensity, - = Loss intensity

The changes of the Balangoda case study area due to the bypass road can be summarised as follows: With higher BC values, the existing road has been able to attract more pass by trips than the bypass road. The analysis result of the previous section indicates that the CC-500m values have increased in both roads, but the bypass road records a higher CC-n value when compared to the existing road. Accordingly, land use along both roads have changed gradually. However, the bypass road has been unable to attract commercial land uses and high density compared to the existing road. Furthermore, the existing main road remains as the main centre of the town. The Balangoda town centre is located below 350 m elevation, and close to the bypass road, the elevation goes up to more than 560 m. There is a mountain along the bypass road (refer Figure. 19). Dorawale Oya flows near the bypass road and there is a playground and a Pola area to the left side of this road. These factors obstruct the space to grow and act as a barrier to attract new activities along the bypass road. The case study results indicate that natural movement economic process is disturbed due to lack of space for growth along the bypass road. Table 7 show existing traffic flow data on both of existing and bypass roads and it confirms that the bypass road has a high level of service relative to the existing road.

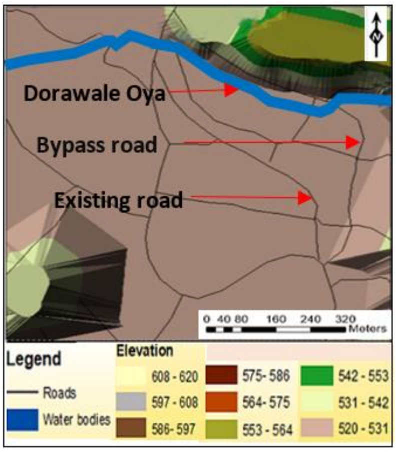

Figure 19: Elevation of the Balangoda case study area.

Table 7: Existing Level of service in both bypass road and existing road in Balangoda case study area

Level of Service - Balangoda: 2019	
Bypass Road	Existing Road
E (0.11)	C (0.46)

Source: Compiled by author

3.1.4 *Piliyandala*

Piliyandala is a small town (population = 185,22) situated on the B84 route from Colombo to Horana. The bypass road in Piliyandala was constructed in the year 2014. Figures 20, 21 and 22 illustrate the variations of accessibility in the road network of Piliyandala town in 2011 and 2019. The level of accessibility is computed based on the closeness (CC) and betweenness (BC) centrality parameters. BC-n values of the road network has been dramatically changing over the last five years after the construction of the bypass road. As depicted in Figure 20, the prominence of the main road has reduced while the bypass road attracts higher BC values. It indicates that the bypass road has more potential to capture pass-by trips than the existing road.

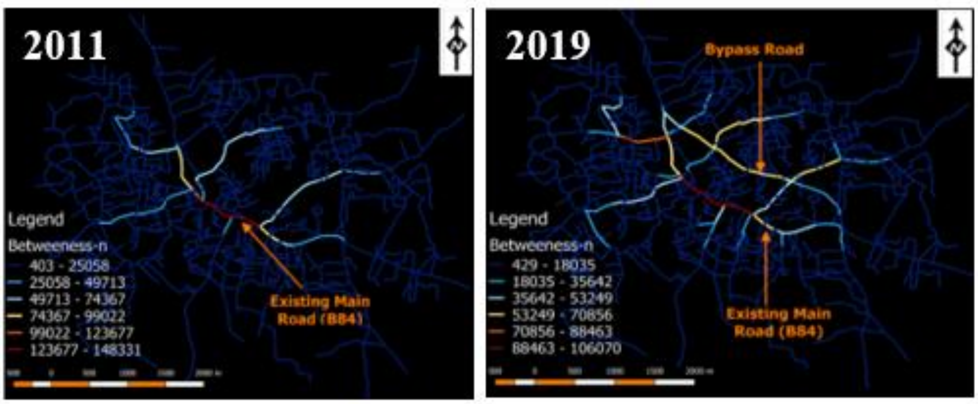

Figure 20: Variation of betweenness values in road network of Piliyandala town before and after bypass road construction

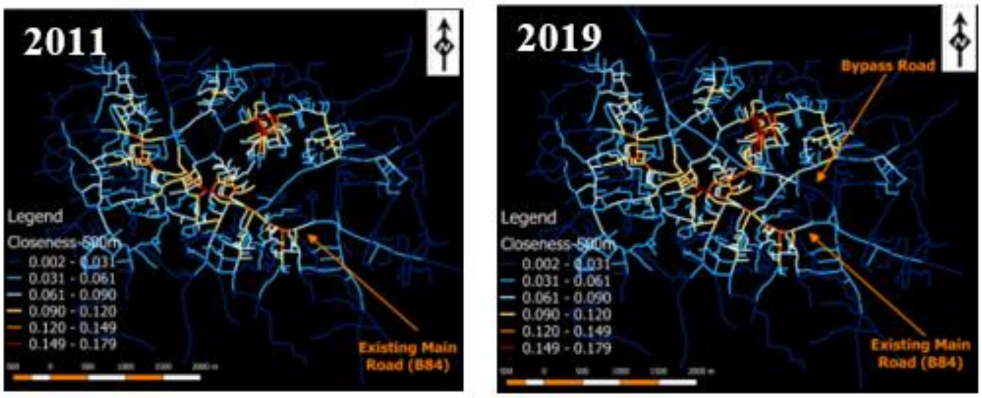

Figure 21: Variation of closeness-500m values in road network of Piliyandala town before and after bypass road construction.

As depicted in Figure 21, CC-500m values have increased in existing roads and the CC-n values have been quite similar in both roads over the last seven years. It indicates that both roads have a similar level of potential to attract vehicle movements. (in the reference map series, changes in value of BC and CC are visible through the six colour ranges in the maps. The highest BC and CC values are shown in red and the lowest values are shown in blue. Accordingly, the use of colour range (red to blue) or values mentioned in legend help to identify BC and CC changes along the bypass and the existing road.)

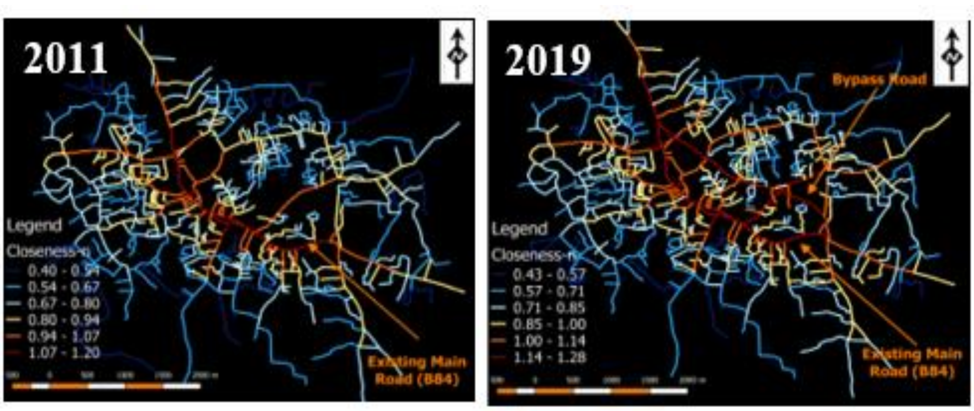

Figure 22: Variation of closeness-n values in road network of Piliyandala town before and after bypass road construction

Figure 23 depicts the changes in building density in Piliyandala from 2011 to 2019 with floor area ratio maps. New buildings have gradually appeared on the bypass road with the construction of the new bypass road. However, building density along the existing main road (FAR = 2) remains higher than the building density along the bypass road (FAR = 0.6).

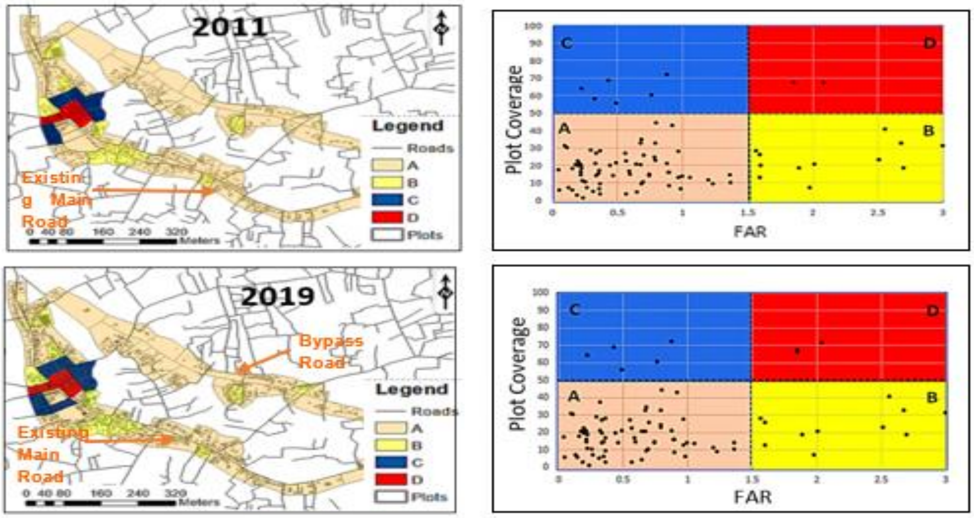

Figure 23: Variation of FAR values in building density of Piliyandala town before and after bypass road construction.

Figure 24 depicts the results of the land use intensity analysis. As per the results, there has been significant growth in commercial land uses along the existing road after the bypass road implementation (2019). Furthermore, many residential land uses have been converted into commercial activities along the existing road. However, there has not been a significant growth of varying types of land uses along the bypass road after the bypass implementation.

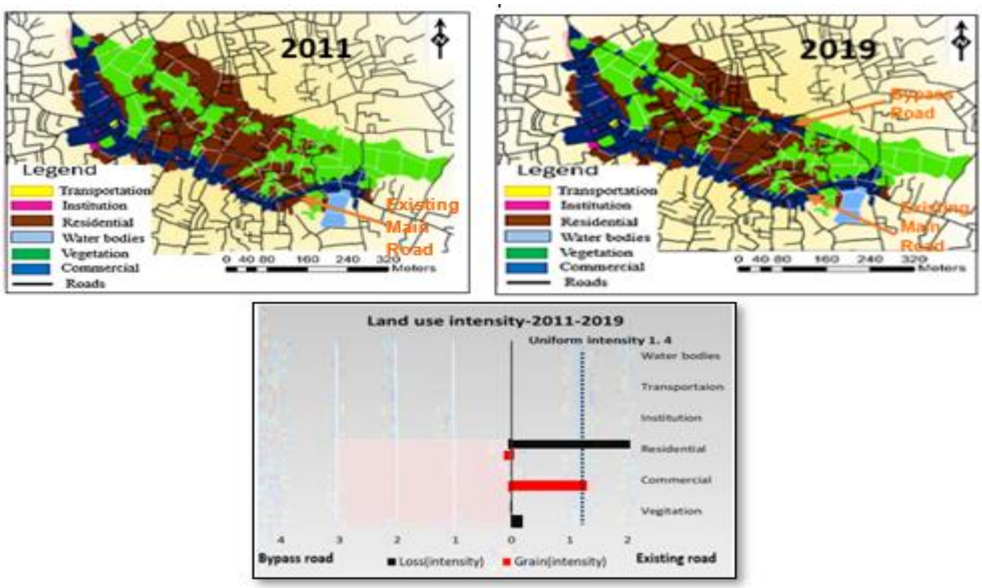

Figure 24: Variation of land use intensity values in land use of Piliyandala town before and after bypass road construction.

Table 8 summarised the above mentioned changes in Piliyandala town area.

Parameters		Years	
		2005	2019
Building density	Existing	2	2
	Bypass	-	0.6
Betweenness n	Existing	81117	66775
	Bypass	-	83644
Closeness 500m	Existing	0.0598	0.0656
	Bypass	-	0.0543
closeness n	Existing	0.68	1.2
	Bypass	-	1.2
Land use type	Existing	2	1
	Bypass	-	3
Land use mix	Existing	-	1= (+1.5) 2= (+0.01), (-2) 3= (-0.2)
	Bypass	-	1= (+0.01) 2= (+0.25), (-0.0) 3= (-0.012)

*1= Commercial, 2= Residential, 3= Vegetation, 4=Institution, 5= Transportation

*+ = Grain intensity, - = Loss intensity

The changes of the Piliyandala case study area due to the bypass road can be summarised as follows: With higher BC values the bypass road has been able to attract more pass-by trips than the existing road. The analysis of the previous section indicates that the CC-n values have increased in both roads, but higher CC-500m values have increased in the existing road than the bypass road. Accordingly, land use along both roads has altered gradually. However, the bypass road has been unable to attract significant land uses and high density, when compared with the existing road. Furthermore, the existing main road remains the main centre of the town. According to rules and regulation introduced, no building can be constructed within 15 m along the Piliyandala bypass road or get direct access from the bypass road to buildings or street vendors' activities etc. The abandoned paddy land along the bypass road has been identified as a wetland protection zone, resulting in lack of space to grow along the bypass road. This acts as a barrier to attract new activities. The case study results indicate that natural movement economic process is disturbed owing to the lack of space for growth along the bypass road. Table 9 shows existing traffic flow data on both of existing and bypass roads. It confirms that the bypass road has a high and good level of service relative to the existing road.

Table 9: Level of service in both bypass road and existing road in Piliyandala case study area

Level of Service-Piliyandala - 2019	
Bypass Road	Existing Road
A (0.17)	B (0.54)

Source: Compiled by author

4. CONCLUSION

Limited studies have been carried out in Sri Lanka to study the impact of bypass roads in towns where the main transport route is replaced by another outside the town. This study explores the effects of a bypass road on build form of a town. The study investigates the changes in land use and building density along with accessibility changes and analysed the before and after situation for bypass roads in four small towns in Sri Lanka. The study analysed the temporal changes using spatial analysis tools in a GIS environment; and used three parameters as land use intensity, building density and accessibility to capture temporal changes in selected case town areas. Only four cases were studied, and the study was predominantly based on available secondary data. Analysis focused only on accessibility, land use and density parameters. The study recommends incorporating analysis related to temporal changes in traffic characteristics such as traffic volume -AADT, speed and the road characteristics such as number of lanes, carriageway dimensions of the existing and bypass road in future studies.

The results of the above case studies indicate three scenarios: i) Bypass road accessibility improves more than the existing main road and new land uses and high-density areas emerge along the by-pass road, and the bypass road becomes the main centre of the town; ii) The bypass road and the existing main road show similar levels of accessibility and attraction; and iii) Accessibility of the existing main road remains higher than the bypass road and very few new lands uses and built-up area is attracted towards the bypass road ensuing that the existing main road continues as the main centre of the town. The results indicate that if accessibility to the new bypass is higher than to the existing main road, the commercial activities and buildings move towards the bypass road. However, if accessibility does not change in the town after the introduction of the new bypass road, the commercial activities and buildings do not move. The results confirm that spatial and economic forces are closely interrelated as indicated in the theory of the natural movement economic process. However, the study found out that certain forces such as mountains, paddy fields etc. which are natural barriers constrain the space to grow. Accordingly, the study suggests that the findings of this study is useful for transport engineers in making new strategies to implement bypass roads as well as for urban planners to develop local development plans after constructing bypass roads.

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APPENDICES

Table - A1: Description about secondary data

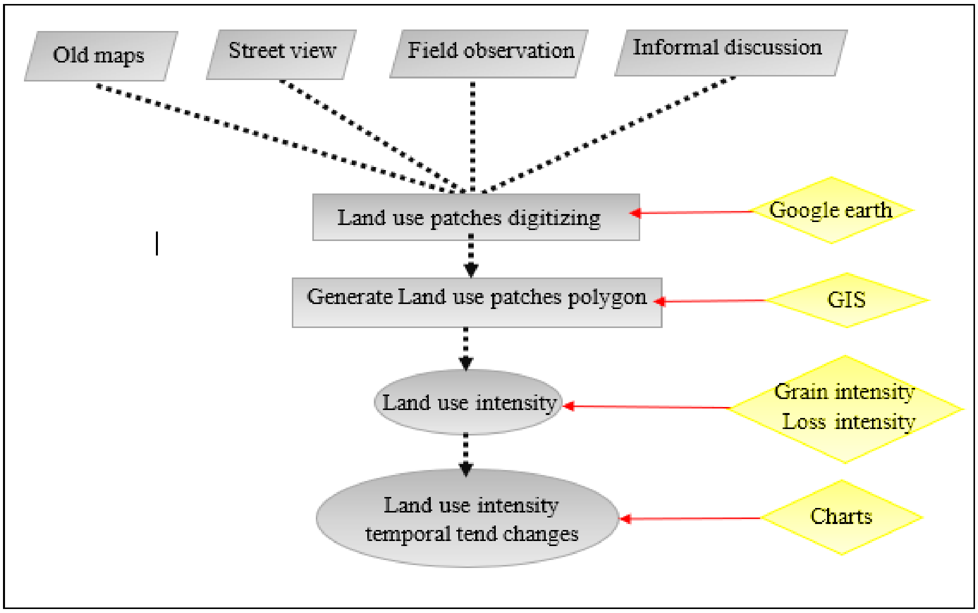
Data type	Year	Source
Land use	1989	**Newspaper** The island newspaper under the heading of *Rampala* regime in the local Railway History. Newspaper: http://www.sundayobserver.lk/2017/08/29/spectrum/lost-glory-kv-railway-line **Old maps** Avissawella land use maps (Collected from Seethawakapura Urban Council)
	1992	**Reports** Report of transport plan for Avissawella town development project done by UDA **Old maps** Avissawella land use map (Collected from Seethawakapura Urban Council)
	2007	Google earth
	2019	Google earth
Building	1989	**Newspaper** The island newspaper under the heading of *Rampala* regime in the local Railway History
	1992	**Report** Report of transport plan for Avissawella town development project done by UDA
	2007	Google Earth,
	2019	Google Earth,
Road network	2006	**Newspaper** The island newspaper under the heading of *Rampala* regime in the local Railway History. Newspaper: http://www.sundayobserver.lk/2017/08/29/spectrum/lost-glory-kv-railway-line **Old maps** Avissawella land use map (Collected from Seethawakapura Urban Council) **Reports** Report of transport plan for Avissawella town development project done by UDA
	2010	Google Earth
	2019	Google Earth

Source: Compiled by author

Table- A2: Description about primary data

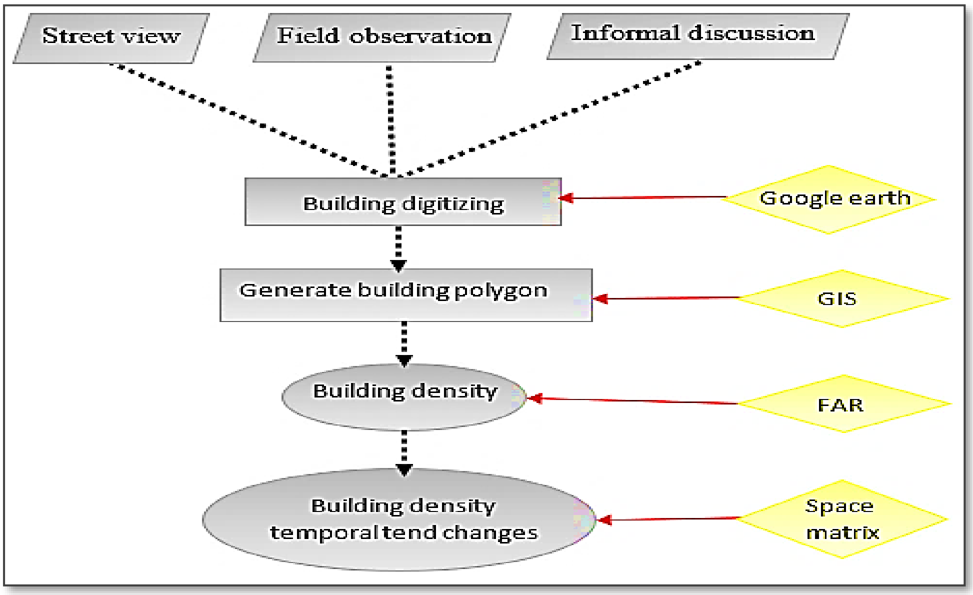
Data type	Method of data collection	Sample
Land use	Field observation= Observe the case study area and take photographs, Observe the area and mark a map including important data.	-
	Informal discussion= Specially discuss with elderly people and urban council officers and according to the collected data maintain a map within the field.	50
Building	Field observation= Observe the case study area and take photographs, Observe the area and mark a map including important data	-
	Informal discussion= Specially discuss with elderly people and urban council officers and according to the collected data maintain a map within the field.	35
Road network	Field observation= Observe the case study area and take photographs, Observe the area and mark a map including important data.	-
	Informal discussion= Specially discuss with elderly people and urban council officers and according to the collected data maintain a map within the field.	20

Source: Compiled by author



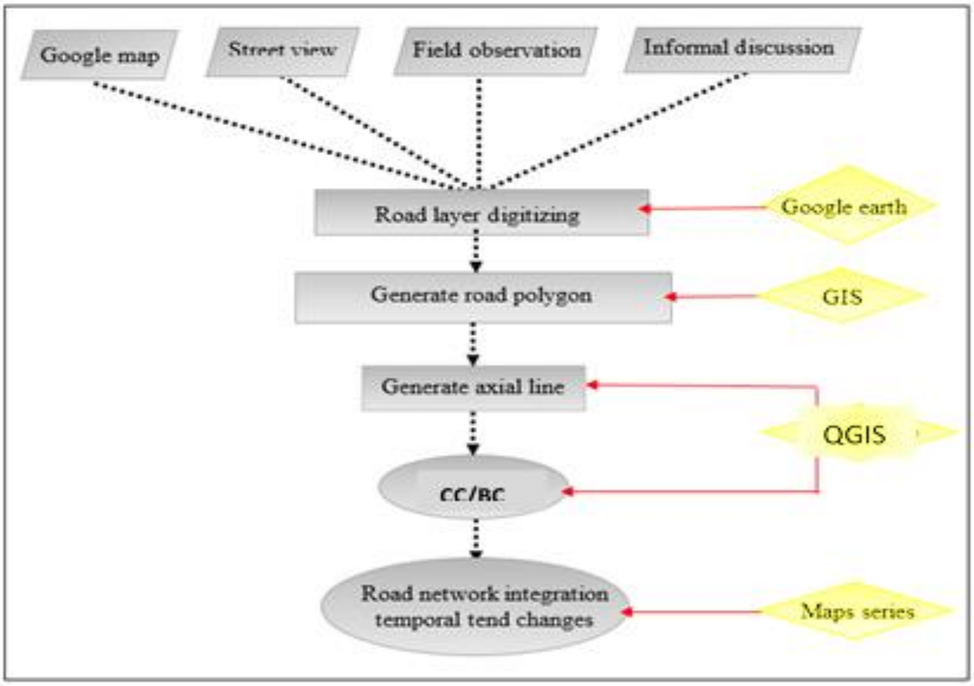
Source: Compiled by author

Figure- A1 Steps of land use intensity temporal trend changes analysis



Source: Compiled by author

Figure -A2: Steps of building density temporal trend changes analysis



Source: Compiled by author

Figure -A3: Steps of accessibility temporal changes analysis

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ANALYSIS OF VEHICLE OWNERSHIP ATTRIBUTES IN WESTERN PROVINCE, SRI LANKA

K P Dilini [a]*, P T Amalan [b] and A S Kumarage [c]

[a,b,c] Department of Transport and Logistics Management, Faculty of Engineering, University of Moratuwa, Moratuwa, Sri Lanka

* Corresponding author E-mail address: *dilinikp1991@gmail.com*

ABSTRACT

This paper develops a mathematical model to predict motor vehicle ownership based on household (HH) characteristics. The model is tested using household visit surveys in the Western Province of Sri Lanka (CoMTrans, 2014). The province which has the country's highest population density (1,600/km^2) and road density (0.9 km/km^2) as well as a motor vehicle ownership of 206 vehicles per 1,000 people. The modelling is disaggregated into motorcycles, three-wheelers, vans, and cars (including jeeps and pick-ups). The motor vehicle fleet comprises 51% motorcycles, 20.2% three-wheelers, 6.7% vans, and 17.7% cars apart from commercial vehicles. The purchasing cost of motor vehicles in Sri Lanka varies widely due to different taxes imposed at importation.

A binary logistic regression with cross-validation statistical theories was used to predict the HH ownership of different vehicles, based on an income-based testing scenario for determining a HH's likelihood of owning a particular type of vehicle. Motorcycles, three-wheelers, vans, and cars listed in ascending order of cost of ownership and operation were tested against the characteristics of 35,850 HHs using R, a software analytical tool. The analysis found that private vehicle ownership depends on attributes of a HH, such as its size, average monthly income, and the percentage of workers, school and kindergarten children, and males in that HH.

Keywords: *Vehicle Ownership, Household Characteristics, Regression Analysis, Western Province, Household Visit Survey*

1. INTRODUCTION

Vehicle ownership affects the ability of road transport infrastructure capacity in a country to cope with traffic congestion and delays; particularly when demand exceeds the road space supply. Vehicle ownership depends on several factors, including HH income, HH size, HH composition, gender, and social status [1],[2]**.** Increased income makes vehicles more affordable to own and operate, and the rate of multiple vehicle ownership also increases. Ingram and Liu (1999) having tested income elasticity of car ownership for fifty countries found that it ranges from 1.02 to 1.21, indicating that for every 10% increase in income, car ownership increased by 12% [3]. David Bannister (2006) observes that the car has become “an icon of the twentieth century” and Urry (2001) states that the car has become a “symbol of social status” [4][3]. When the quality, including the reliability and comfort of public transport, slackens, and private vehicle ownership increases, people become reluctant to use public transport.

Western Province, the central administrative and commercialized province in Sri Lanka consists of three districts: Colombo, Gampaha, and Kalutara. It has a land area of 3,684 km^2 wherein 28.73% population of Sri Lanka resides. The population sample used for the analysis consists of 35,850 HHs made up of 124,673 individuals. This data was collected by a CoMTrans (urban transport system development project for Colombo Metropolitan Region and Suburbs) study from 2013 to 2014, and classified HH income into three groups, as shown in Table 1.1.

Table 1.1 Summary of Income by Group

Group	Income Range	Mean Household Income	Percentage of Households
A	More than LKR 80,000	LKR 186,164	5%
B	LKR 40,000- 80,000	LKR 56,810	19%
C	Less than LKR40,000	LKR 24,009	76%

Note: 1 USD = approx. 127 LKR in 2013

2. LITERATURE REVIEW

The decision to own a private vehicle and the type of vehicle depends on different HH characteristics, such as its income, size, the number of license holders, composition in full-time workers and children, education level, gender and age[1],[2]. Ha, et al. (2019), using important variable ranking methods as Multi-nominal Logit model, Neural Networks and Random Forests, found that income is the most potent variable influence on motorisation among other HH characteristics [5]**.** Schievelbein et al. (2016) surveyed India to predict the type of vehicle, including motorised two wheels and four wheels that a HH will own by using a Multi-Nominal Logit model (MNL). It was found that the likelihood of four-wheel vehicle ownership increases with income and the HH size [6]. In some cases, it was evident that the strong influence of HH income on HH car ownership had diminished quite remarkably and the effect of HH size had increased significantly. However, Ritter et al. (2013) have found that even though HH size declined in Germany, the number of cars on German roads increased moderately, at about 0.2% per annum: a trend that will continue until 2030 [7]. Maltha, Y. (2016) found that the HH income was the most influential factor in vehicle ownership together with HH size, gender, age, education, suburbanisation, and working status in the Netherlands between 1987 and 2014 [2].

Moreover, it was found that high-income HHs tend to own luxury vehicles rather than own more vehicles [2]. In Phnom Penh in 2019, Ha et al. has applied the MNL, neural networks, and random forest and found that the presence of children in a HH appears to be another factor that determines the type of vehicles and results in a higher level of mobility, convenience and safety [5]. Kim et al. has used MNL and found that HHs in the United States commonly choose vans when they have more children under 8, or have older primary drivers [8].

3. RESEARCH METHODOLOGY

This study examines the vehicle ownership pattern in the Western Province of Sri Lanka with a comprehensive set of socio-economic characteristics of HHs observed in the Home Visit Survey (HVS). It was conducted by CoMTrans from 2013 to 2014 to prepare a comprehensive long-term transportation plan for Western Province. After removing HHs with missing values for any of the variables used, the sample consisted of 35,850 HHs. The availability of the motor vehicle in a HH was used as the dependent variable in the modelling. The following independent variables were selected to test their influence on HH vehicle ownership.

- (i) Household income
- (ii) Household size,
- (iii) Household composition
    - a. Percentage of workers in a household
    - b. Percentage of school and kindergarten children in a household (i.e., children > 5years)
    - c. Percentage of males in a household

Vehicles in the HH survey were categorised into three basic categories including as 2W (motorcycle), 3W (three wheels) and 4W (car, jeep and pickup) with Vans as a subcategory. This data has been analysed descriptively using MS Excel and modelled mathematically using the R software. Six different scenarios of motor vehicle ownership in a HH were examined using the logistic regression technique as follows:

- **Case 1:** Households having any motor vehicle: Households with any vehicle are assigned "Yes" with all other households assigned "No".
- **Case 2:** Households having just one 2W or 3W vehicle: Households owning just one 2W or 3W are assigned "Yes" while all other households are assigned "No".
- **Case 3:** Households having more than one 2W or 3W: Households owning more than one 2W or 3W but not having 4W and van are assigned "Yes" and all other households assigned "No".
- **Case 4:** Households having just one van irrespective of any 2W or 3W but not having a 4W vehicle: These are households owning just one van irrespective of the number of less expensive vehicles identified as 2W or 3W, but excluding those households owning more expensive 'non-van' 4Ws.
- **Case 5:** Households having just one 4W, irrespective of the number of 2W, 3W or vans: Households owning just one 4W irrespective of any 2W, 3W and vans are assigned as "Yes" and all other households assigned as "No".
- **Case 6:** Households having more than one 4W irrespective of the number of 2W, 3W or vans. In this case, households with more than one 4W irrespective of other vehicles were assigned "Yes" while all other households were assigned "No".

Models for each of these six scenarios were generated using binary logistics regression with cross-classification.

3.1 Logistics Regression Theory

Let, $P_i = Pr(Y = 1 | X = x_i)$ ………………………………… (1)

which can be written as

$\text{Log}\,[P_i / (1 - P_i)] = \text{logit}(P_i) = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i$ ……… (2)

where, P_i is the probability of having a HH owning a particular type of vehicle, and x_i is the variables which affect the vehicle ownership. β_o, β_1 are parameters.

The probability of owning a vehicle is:

$$P_i = \exp \text{logit}(P_i) / [1 + \exp(\text{logit}(P_i)] \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Conversely, the probability of not owning that particular vehicle type is

$$1 - P_i = 1 / [1 + \exp(\text{logit}(P_i)] \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)[9]$$

In the regression, the total sample of 35,850 HHs were divided into two groups as a training data set and the testing data set in keeping with the 80:20 rule. The predicted models were generated using the training data set comprising 28,704 HHs and validated with the balance 7,146 HHs. The models, therefore, give the probability (P) of “Yes” relative to “No”.

$$PV \begin{cases} 1, & P > 0.5 \\ 0, & P <= 0.5 \end{cases}$$

If the probability is more than 0.5, the predicted value (PV) will be rounded as “1” and if otherwise as “0”. Misclassification error and accuracy of the model are calculated using the confusion matrix.

4. ANALYSIS

The analysis is organized into two sections. Section A includes the descriptive analysis of variables assumed to be correlated with owning a motor vehicle (yes or no) and Section B, which includes the models calibrated using binary logistics regression.

4.1. Section A: analysis of vehicle ownership from HVS data

In the Household Visit Survey (HVS), the study team collected the previous day’s travel activity information of each of the residents from each of 38,500 HHs in the survey sample along with the socio-economic information of that HH and its occupants over the age of 5 through a structured interview survey. This survey also documented vehicle ownership of the HH by type of vehicle.

The sample's socio-economic profile shows that 36% of all individuals in these HHs are employees, while 23% are classified as school, kindergarten, and tertiary students. The remaining 41% is made up of the unemployed, retired, housewives, and others. It is also noted that 21% of HH members are below 18 years and that 64% are between 18 and 60 years.

The distribution of the data on (a) HH size, (b) the number of workers in a HH, (c) number of students in the HH, and (d) the number of males in the HH as shown in Figure 4.1 were tested with the Anderson-Darling test to check the normality in the distribution of the data set. The resulting P values were found to be less than 0.05, showing that the histograms are right-skewed distributed.

Since the variables are not normally distributed, the Wilcoxon rank test was used for continuity correction, confirming a significant relationship between vehicle ownership and the four socio-economic variables discussed.

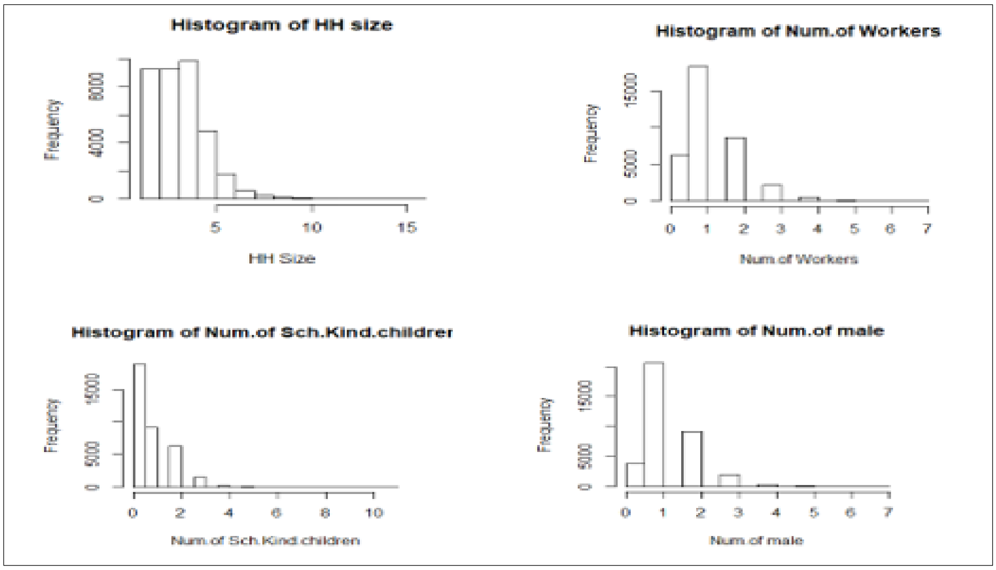

Figure 4.1: Histograms of Socioeconomic Data

The vehicle ownership in the different HHs categorized as being in Income Group A, B or C where A: High income = HH monthly income being more than Rs. 80,000, B: Middle income = HH monthly income being between Rs. 40,000, and Rs. 80,000 and C: Low income = HH monthly income being less than Rs. 40,000 was tested and found to be significant using the Chi-Square test as it resulted in a P value less than 0.05. Therefore, it can be concluded that there is a significant association between the HH income and the decision to own a vehicle.

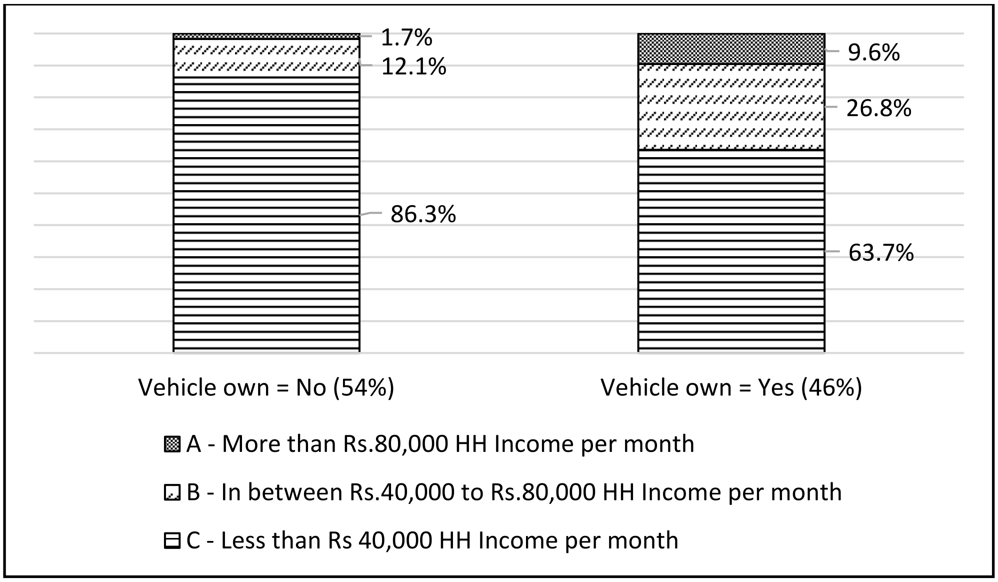

Figure 4.2: Distribution of HH vehicle ownership with HH income

When considering the residual analysis of income groups, HH income contributes to vehicle ownership on HHS in Income Group A and B more than Income Group C. Figure 4.2 above shows income to be an influential factor in deciding to own a vehicle.

The analysis shows that approximately 46% of HHs in the province own a vehicle. Out of the total vehicle owning HHs, 20% of HHs own more than one vehicle. Figure 4.3 shows the percentage of HHs relative to the number of HH members for the number of vehicle ownership separately.

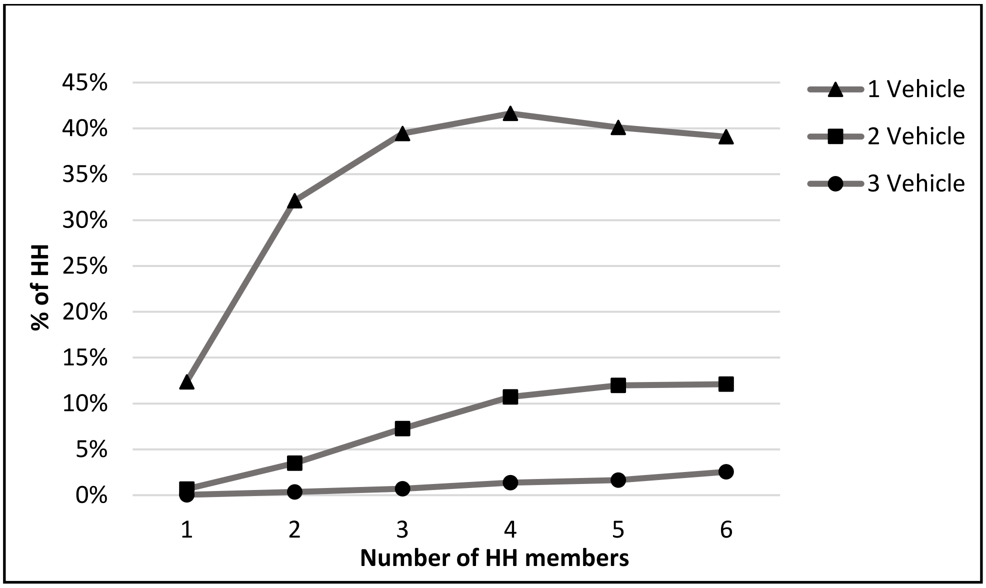

Figure 4.3: Variation in the Number of Vehicles Owned by a HH by the Number of HH members

This reveals that most HHs own only one vehicle even though they have five or six members. However, the percentage of HHs owning one vehicle decreases when there are four or more HH members; the percentage of HHs owning two or more vehicles increases with the number of HH members.

Figure 4.4 shows the vehicle ownership of a HH when compared with the Income Groups. It is seen that most of the low and middle-income HHs (Group B and C respectively) have more than two 2W or 3W vehicles. Most low-income HHs (Group C) have 2W and 3W, and middle income HHs (Group B) have 2W and 4W. Since the capital and operating cost increases from 2W to 3W to van to 4W, most low and middle-income HHs tend to own 2W or 3W, while the high-income HHs own 4Ws. Consequently, it appears that middle and low income HHs use vans for commercial purposes and 2W for personal use.

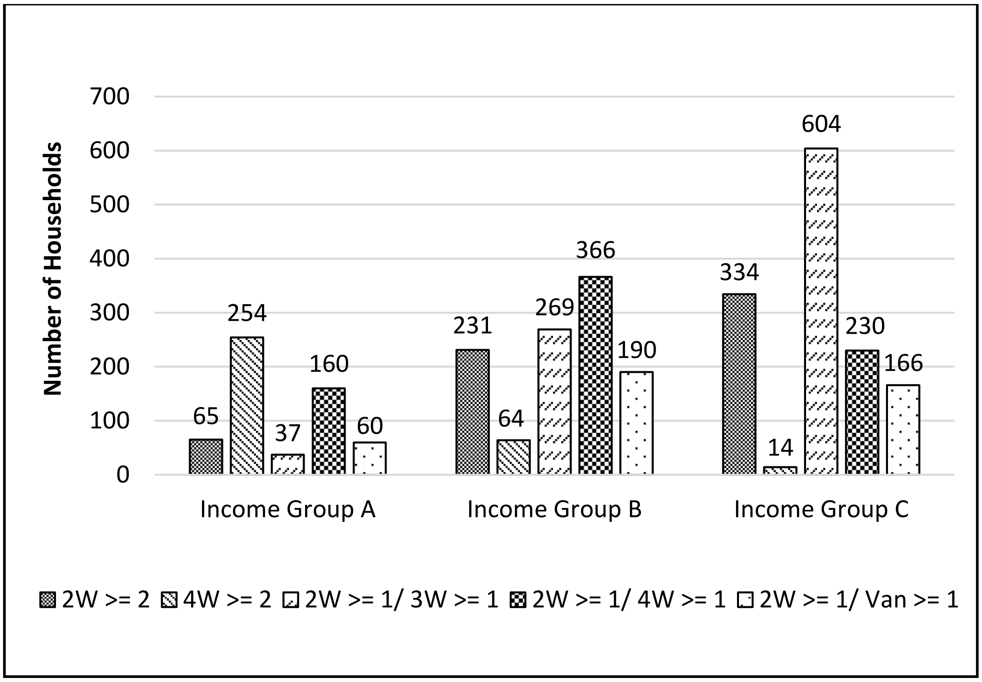

Figure 4.4: Vehicle Composition with Different Income Groups

Figure 4.5 shows the type of vehicle owned by HHs in each income group. Most of the low-income HHs in Group C own a 2W or 3W while most high-income HHs in Group A own a 4W and most middle-income HHs (Group B) own 2Ws. Even though the capital and operating cost of 3W is higher than a 2W, most of the low-income HHs own a 3W.

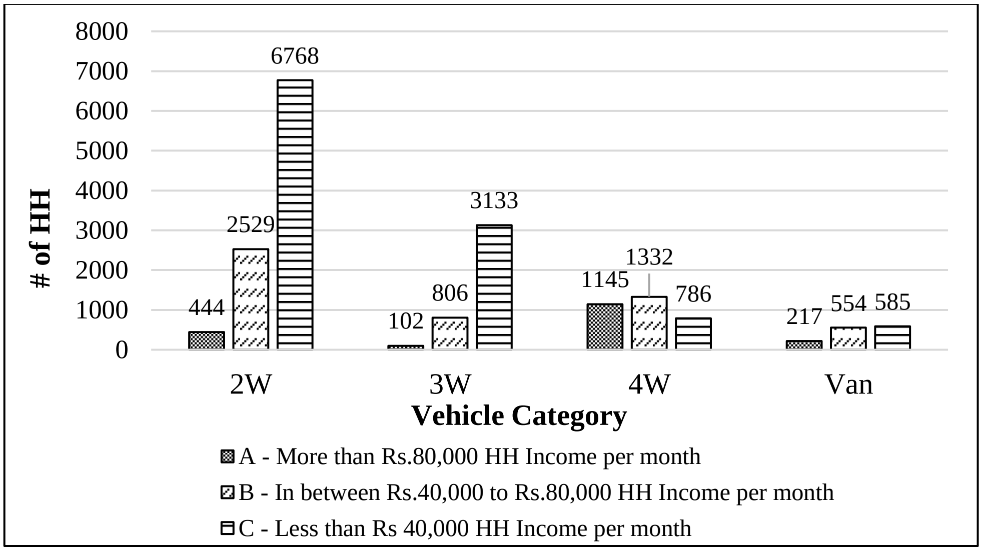

Figure 4.5: Distribution of Vehicle Category by HH Income Group

Table 4.1: Vehicle Ownership with Household Composition

	4W ownership	2W ownership
% of workers in HH < 50%	8%	25%
% of workers in HH >= 50%	11%	31%
% of sch/kind. members in HH <50%	9% (8.98%)	27%
% of sch/kind. members in HH >= 50%	9% (9.22%)	28%

Table 4.1 shows the variation between the number of workers and the number of school children relative to HH vehicle ownership. It shows that parents tend to own either a 4W or a 2W when they have school children. However, this does not influence the vehicle ownership as much as the percentage of workers in a HH does. It can also be seen that the percentage of workers in a HH has a greater influence on 2W ownership than 4W ownership.

4.2. Section B: Prediction Models for Different Types and Number of Vehicles

Table 4.2 A: Binary Logistics Regression results- Case 1

Case 1: Households having any vehicle				
	Estimate	Std. error	Z value	P-value
Intercept	0.0944472	0.0791376	1.193	0.233
HH size	0.1581206	0.0097131	16.279	<2e-16***
Household Income Group B	-0.8904475	0.0707832	-12.580	<2e-16***
Household Income Group C	-1.8584546	0.0666605	-27.879	<2e-16***
% of workers in a HH	0.0070714	0.0005159	13.707	<2e-16***
% of sch. &kind. students in a HH	0.0067407	0.0006492	10.384	<2e-16***
% of males in HH	0.0120167	0.0005961	20.157	<2e-16***
Accuracy	62.82%			
95% CI	0.6169, 0.6394			
Sensitivity	71.70%			
Specificity	52.10%			

*Note: ***, **, * refer to p-value at the three ranks of less than 0.001, 0.01 and 0.05, respectively.*

Table 4.2 B: Binary Logistics Regression results- Case 2

Case 2: Households having just one 2W or 3W				
	Estimate	Std. error	Z value	P-value
Intercept	-2.9145060	0.0728893	-39.98	<2e-16***
HH size	0.1657130	0.0083243	19.91	<2e-16***
Household Income Group B	1.2653976	0.0612229	20.67	<2e-16***
Household Income Group C	1.4087321	0.0584063	24.12	<2e-16***
% of workers in HH	0.0092014	0.0004586	20.06	<2e-16***
% of sch. &kind. students in a HH	0.0070525	0.0005547	12.71	<2e-16***
% of males in HH	0.0111966	0.0005347	20.94	<2e-16***
Accuracy	56.24%			
95% CI	0.5508, 0.5740			
Sensitivity	51.99%			
Specificity	66.75%			

*Note: ***, **, * refer to p-value at the three ranks of less than 0.001, 0.01 and 0.05, respectively.*

Table 4.2 C: Binary Logistics Regression results- Case 3

Case 3: Households having more than one 2W or 3W only				
	Estimate	Std. error	Z value	P-value
Intercept	-3.5334597	0.0645403	-54.748	<2e-16***
HH size	0.4936797	0.0078771	62.673	<2e-16***
Household Income Group B	0.8213394	0.0455818	18.019	<2e-16***
Household Income Group C	0.4941094	0.0436329	11.324	<2e-16***
% of workers in HH	0.0147712	0.0004556	32.422	<2e-16***
% of sch. &kind. students in a HH	-0.0031693	0.0005083	-6.236	4.5e-10***
% of males in HH	0.0112119	0.0005424	20.670	<2e-16***
Accuracy	65.31%			
95% CI	0.6419, 0.6641			
Sensitivity	65.32%			
Specificity	65.02%			

*Note: ***, **, * refer to p-value at the three ranks of less than 0.001, 0.01 and 0.05, respectively.*

Table 4.2 D: Binary Logistics Regression results- Case 4

Case 4: Households having just one van irrespective of 2W and 3W but no 4Wvehicles				
	Estimate	Std. error	Z value	P-value
Intercept	0.2673233	0.0500656	5.339	9.32e-08 ***
HH size	0.0651332	0.0075617	8.614	<2e-16 ***
Household Income Group B	-0.0438927	0.0364731	-1.203	0.229 ***
Household Income Group C	-1.4450727	0.0347124	-41.630	< 2e-16 ***
% of workers in HH	-0.0038323	0.0004023	-9.525	< 2e-16 ***
% of sch. &kind. students in a HH	0.0040626	0.0004977	8.162	3.29e-16 ***
% of males in HH	0.0098639	0.0004838	20.390	< 2e-16 ***
Accuracy	75.24 %			
95% CI	0.7423, 0.7624			
Sensitivity	76.14%			
Specificity	50.20%			

*Note: ***, **, * refer to p-value at the three ranks of less than 0.001, 0.01 and 0.05, respectively.*

Table 4.2 E: Binary Logistics Regression results- Case 5

Case 5: Households having just one 4W, irrespective of the number of 2W, 3W and vans				
	Estimate	Std. error	Z value	P-value
Intercept	3.0093457	0.0556340	54.092	< 2e-16 ***
HH size	-0.1695371	0.0088840	-19.083	< 2e-16 ***
Household Income Group B	-1.3272376	0.0408924	-32.457	< 2e-16 ***
Household Income Group C	-3.5429937	0.0403872	-87.726	< 2e-16 ***
% of workers in HH	-0.0081569	0.0004427	-18.427	< 2e-16 ***
% of sch. &kind. students in a HH	0.0025536	0.0005709	4.473	7.71e-06 ***
% of males in HH	0.0044182	0.0005148	8.582	< 2e-16 ***
Accuracy	79.71%			
95% CI	0.7876, 0.8064			
Sensitivity	80.27%			
Specificity	73.37%			

*Note: ***, **, * refer to p-value at the three ranks of less than 0.001, 0.01 and 0.05, respectively.*

Table 4.2 F: Binary Logistics Regression Results- Case 6

Case 6: Households having more than one 4W irrespective of the number of 2W, 3W and vans				
Intercept	3.0856231	0.0591624	52.155	< 2e-16 ***
HH size	-0.0635705	0.0112819	-5.635	1.75e-08 ***
Household Income Group B	-2.8347234	0.0349123	-81.196	< 2e-16 ***
Household Income Group C	-5.6656974	0.0414249	-136.770	< 2e-16 ***
% of sch. &kind. students in a HH	-0.0136984	0.0007322	-18.709	< 2e-16 ***
% of males in HH	0.0148247	0.0022622	6.553	5.63e-11 ***
Accuracy	85.81%			
95% CI	0.8498, 0.8661			
Sensitivity	85.77%			
Specificity	88.60%			

*Note: ***, **, * refer to p-value at the three ranks of less than 0.001, 0.01 and 0.05, respectively.*

Vehicle ownership prediction models were developed for the six different cases identified earlier using Binary Logistics Regression. Table 4.2 shows the results and accuracy of each of these six models. It is seen that most of the coefficients are statistically significant, except the percentage of workers in HHs, which is not significant in Case 6.

This sample appears to predict better the ownership of 4W vehicles than the ownership of 2W, 3W and Vans. The highest sensitivity that explains the probability of accurately predicting a HH owning more than one 4W is the highest at 85.77% which also gives the highest specificity of 88.60% being the probability of accurately predicting a HH not owning more than one 4W.

In the model for Case 1, the HH size is the most influential factor in ownership of any motor vehicle. Simultaneously, the percentage of males in a HH is seen to have a higher impact than the percentage of school/kindergarten students and workers. Based on the Case 2 results, it is seen that mostly the middle and low-income HHs demonstrate 2W or 3W ownership. Moreover, HH size and percentage of males in a HH appear to have a more positive impact than the percentage of school/kindergarten and workers in a HH when a HH owns just one 2W or 3W vehicle. Also, HHs with more members and more male members and HH workers tend to own more than one 2W and 3W (Case 3). Middle income HH has a high possibility of owning more than one 2W or 3W than low-income HH.

The prediction model for Case 4 shows that HHs having a van instead of a car has a positive coefficient for HH size, number of school/kindergarten students and males in a HH. Furthermore, the HH size has the largest positive coefficient influencing van ownership, together with the percentage of males in a HH.

The intercept and coefficient for the percentage of school/kindergarten students in a HH and the percentage of male members in a HH have a positive impact on just one 4W in the predicted model for Case 5. However, low income has a more negative impact on 4W ownership than van ownership. Percentage of HH workers does not affect predicting more than one 4W ownership (Case 6). Middle and low-income HHs have a more negative impact on the ownership of more than one 4W than all other cases.

5. DISCUSSION OF RESULTS

Binary Logistics Regression is developed in this study for six different scenarios to investigate the effect of five different socioeconomics factors on the ownership of different vehicles in a HH ranging from the least to the most expensive vehicle category in Sri Lanka. Findings of this study provide further evidence on the contribution of different socio-economic factors on the ownership of each vehicle type.

5.1 Household Monthly Income

The middle and low-income HHs demonstrate a positive impact on 2W and 3W ownership, while high income HHs show a greater likelihood of 4W vehicle ownership. Results confirm that HH income has a positive effect on both the number of vehicles and the type of vehicle that a HH owns. This confirms Ha et al's finding that income is the most potent variable influencing motorisation, among other attributes[5]. This means vehicle ownership is most affected by HH income.

5.2 Number of Members in a Household

The result shows that the number of members in a HH has a positive impact on 2W, 3W and vans ownership. It also means that HHs with more members prefer to own a van than a car. The number of members in a HH is also observed to have a positive impact on both the type of vehicle and the number of vehicles.

5.3 Percentage of Males in a Household

It is found that the ownership of motor vehicles in a HH increases when the percentage of males increases. By comparison of coefficients, this was found to be most significant in the case of the ownership of 2W and 3W vehicles and vans.

5.4 Percentage of School/Kindergarten Students in Household

Based on the Case 2 results, it is seen that middle income HHs mostly own a 2W or 3W. It was found that owning a van is influenced by the number of school and kindergarten students. This compares well with Kim et al., who found that in the USA, that HHs having more children aged under eight commonly choose vans [8]. However, in some countries like Japan, HHs are more concerned about vehicle quality and ability to meet their requirements of mobility, convenience, and safety rather than the HH composition and economic level (Ha et al. (2019) [5].

5.6 Percentage of Workers in a Household

Results show that the percentage of workers in a HH has less influence on 4W vehicle ownership than 2W vehicle ownership. HHs tend to have more than one 2W when there have more workers. Kim et al. have also found that the number of workers is associated with a negative coefficient on minivans, midsized, or large sedans called family cars[8].

6. FUTURE RESEARCH

This research has some missing variables when compared to other models used for predicting vehicle ownership of a HH such as the demand to public transportation [10], the number of drivers, age of drivers in a HH [10], perception of the quality of public transportation services [5]and land use attributes [2], [11]. These variables can be used in future research to improve the accuracy of the model.

7. CONCLUSION

This paper can be viewed as an initial attempt to study the impact of HH's socio-economic attributes and composition on their vehicle ownership in Western Province, Sri Lanka. HVS data collected in 2013 was used to analyse the variation in vehicle ownership between different HHs attributes.

The monthly income, number of members, number of males and number of workers in a HH, show significant impact on vehicle ownership. Six models have been calibrated to estimate the level of ownership of different types of vehicles. This model could be applied in different parts of Sri Lanka and countries with similar vehicle taxation regimes to estimate the demand for different types of vehicles based on different socio-economic characteristics.

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SELF-REPORTED HABITUAL PRACTICES AND PERCEPTIONS OF YOUNG DRIVERS IN SRI LANKA

N Amarasingha [a]* and H M M Firdhaws [b]

[a,b] Department of Civil Engineering, Sri Lanka Institute of Information Technology, New Kandy Road, Malabe, Sri Lanka

* Corresponding author E-mail address: *niranga.a@sliit.lk*

ABSTRACT

Crashes on the road have become a significant socio-economic problem. Younger generations, who have lesser experience in driving, are at greater risks of facing road accidents. It is therefore important to identify driving practices and perceptions of young and inexperienced drivers at an early phase of exposure so that factors that improve safe driving can be identified.

This study analysed 400 young and inexperienced drivers' self-reported habitual practices and perceptions based on a questionnaire survey. The questionnaire focused on supervision of early driving, limitation made by parents, accident and traffic offenses by these youngsters as drivers as well as other habitual driving practices. Analyses were done using reliability statistics, inter-item correlation, likelihood ratio tests, and parameter estimates. The highest inter-item correlation value was 0.467 for the pair of overtaking vehicles in restricted areas and taking the chance to speed and run a yellow light when it is about to change to red. Driving after alcohol consumption, mobile phone usage, taking an illegal U-turn at restricted areas, non-use of signals when changing lanes and overtaking a slow driver from the left side were influenced non-use of seat-belts by young drivers. These habitual practices while driving highlighted the importance of early intervention to improve road safety.

In conclusion, there is always one or more habitual driving practices that have affect the other driving habits of a young driver.

Keywords: *Inexperienced Drivers, Driver Perception, Driving Practices, Road Safety, Sri Lanka*

1. INTRODUCTION

One of the problems that people face and hear every day are crashes on the road. When the crash rates or traffic violations are considered, the younger generation is in more risk as they have the least experience in driving. A study done in the State of Qatar showed drivers aged 18 years or less frequently committed driving violations and caused accidents, followed by the drivers aged 18 to 25 years [1]. Young drivers start to drive with more caution but overestimate their skill and start multi-tasking with mobile phones, eating and talking with other passengers while driving: all sources of distraction [2]. Also, the most common reason which leads to high crash rates is speeding [3]. Young people drive faster when they are with peer passengers to show confidence and skill [4]. When there is an aggressive behaviour involved while driving, there are higher chances of drivers taking risks. Aggressive behaviour occurs when there is less attention to road safety, pressure from friends, and less commitment and communication shared by the person who monitors the young driver's behaviour while s/he is driving [5]. The roles of parents and friends are important in shaping good driving behaviour among young drivers. Since young drivers have less experience, they may easily get involved in a traffic crash [1]. These highlight the need for a better driver education, a strict licensing process, and proper guidance for young inexperienced drivers.

As per authors' knowledge, a proper study has not been conducted in Sri Lanka to investigate the young inexperienced drivers' crash risk, characteristics, or driving behaviour. Therefore, the objective of this study was to identify the negative habitual practices while driving among young inexperienced drivers in Sri Lanka.

2. LITERATURE REVIEW

The study began by reviewing similar studies in the past that identify risk factors among young drivers.

Shaaban et al. studied the cell phone usage habits of young drivers in Qatar [6]. This covered awareness among those drivers about their dangerous habits and the factors influencing their habits using a self-reported questionnaire. The survey was done for a sample of 403 of young drivers of the age 18 to 25 years old who had valid driving licenses. The analysis was done using a Structural Equation Modeling technique. The results showed that holding public campaigns may decrease cell phone usage while driving. Young drivers involved in a crash in the past tend to use their cell phones less than those who never had a cell phone related crash. The driving experience and the duration where the driver can be safe by keeping his eyes away from the road when driving had a significant effect on cell phone usage. In this study most of the participants (90.8%) agreed that they used their cell phone while driving. The participants were asked about their first action when they received a phone call. Most of the participants (73.2%) mentioned that they usually answer the phone and continue driving, while 11.2% mentioned that they stop the vehicle first then answer the phone, and 9% stated that they answer first then stop the vehicle. When participants were questioned about how talking over the phone affected their driving, 20.5% answered that talking while driving had no effect on driving performance. Remaining participants stated that their driving was affected in many ways, like slower driving and drifting in and out of lanes. Based on these results, it was suggested to provide road safety campaigns to educate the young drivers on the risks associated with calling, answering, texting and browsing while driving.

Soliman et al. examined the young drivers' behaviour using a Driving Behaviour Questionnaire (DBQ) across different age groups considering different demographics such as gender, car type, seatbelt use, occupation, and education level in the State of Qatar [1]. The questionnaire was distributed to participants who were divided into five age groups. The DBQ was used to measure the various driving behaviour using a six-point scale. Results showed vast differences between the five age groups. The age group that most frequently committed driving violations were those aged 18 years or less, and it was followed by those who were aged 18 to 25 years. Also, individuals who did not wear seatbelts reported more driving violations; results showed that 36.6% of the participants did not use seatbelts while driving. Those with low or medium levels of education reported that they were more likely to commit driving violations than those who were well educated. The results also showed that the female drivers drove safer than male drivers and reported significantly fewer driving violations. Also, female drivers with higher levels of education wore seatbelts more often and committed driving violations much less frequently than male drivers. Moreover, the young male drivers aged less than 25 years who had low levels of education had the highest frequency of committing driving violations. This study highlighted the need for a better driver education and licensing process in Qatar.

Alreesi et al. developed a valid, modified and reliable measurement tool that can be used by young drivers in Oman [7]. A self-reported questionnaire was developed to find risky driving behaviour among a sample of Omani inexperienced drivers aged between 17 and 25 years. There were 1,319 young drivers who completed the questionnaire of which 27.1% were female. An exploratory factor analysis was used to find the best factor structure for the 40-items behaviour scale that was selected from the questionnaire. This factor analysis revealed seven dimensions for the behaviour which explained 49.28% of the variance in the behavioural scale of the young drivers. Those factors were transient violations, speeding, mood driving, fatigue driving, distracted driving, seatbelt usage and close following. In the composite behaviour an excellent internal consistency (a = 0.939) was shown where the transient violations showed the highest internal consistency (a = 0.927) and the lowest internal consistency (a = 0.700) was shown for close following. Logistic models between all seven behavioural dimensions and crash involvement adjusted for drivers' characteristics were conducted and the results showed that moody, fatigued and distracted driving were reasons for crash incidence among young drivers. The composite scales showed a good internal consistency for the crash involvement by the drivers. Although it was suggested that the subscale factors required further investigation on reliability, the strongest predictor for crash involvement was shown by the distraction subscale factor.

Ben-Ari et al. compared young drivers from Queensland (Australia) and Israel and investigated the contributors of the risky driving behaviour of young drivers [8]. The aim was to examine the relationship between the willingness to take risks while driving and the young driver's perceptions. For this study young drivers aged 17- 22 from Queensland (n = 164) and Israel (n = 161) participated in a set of reliable self-reported questionnaires. The Bayesian estimation of the linear regression model was used for the analysis of this study. The results indicated that the Israeli young drivers regarded their parents as providing more role modelling and good communication, messages and feedback than those in Queensland. The young drivers from Queensland reported less commitment to road safety in their families. Similarly, young Israeli drivers associated less cost to driving with friends and at the same time took in more communication and experience from their friends than the young drivers from Queensland. In both the samples, higher intention to take risks involved a higher tendency towards aggressive behaviour, less family orientation towards road safety, greater friends' pressure and less commitment by friends while these young people are driving. Women from this survey reported much less willingness to take risks than young male drivers. The young drivers with divorced or separated parents answered higher will to drive more recklessly than those young drivers from intact families. Little variation existed with specific factors which contributed differently for both the Queensland and the Israel sample. The findings from this study from two different samples from two different countries yielded quite similar results. An important finding was that the central roles of parents and friends must be taken into consideration in every attempt to reduce the rates of risky driving by young drivers.

Scott-Parker et al. studied the Graduated Driver Licensing (GDL) systems which was introduced in 2007 at Queensland, Australia [9]. The GDL system was designed facilitating young drivers get experience in low risk environments and situations. This system has three stages the young drivers need to pass: namely learner's permit, provisional license, and full driver's license. They start off by obtaining the learner's permit, followed by a provisional license which is also known as the intermediate license and finally the full driver's license. All these three stages of this system had their own limitations and restrictions. Initially there were restrictions on driving in night-time and expressways but those restrictions were lifted once the full driver's license was obtained after several testing. For this study there were 1,032 young drivers: 609 female and 423 male aged 17 to 19 years. They volunteered and participated in a 30 minute survey as the learner drivers. After six months another 30 minutes survey was done for the intermediate license stage. The non-parametric Wilcoxon signed-rank tests and matched-pair analysis, were used for the non-normally distributed Likert scale questions. The Cronbach's alpha was also used to measure the internal consistency of data. Participants reported on driving experience, difficulties, and the offenses they committed like taking an illegal U-turn, using mobile phones, and crashing the vehicle while reversing. Most of the young drivers in this study reported that they complied with the GDL requirements and the general rules that need to be followed on the road. This study showed that speeding should be targeted since speed limit was a rule the young drivers obeyed less.

Young inexperienced drivers' risk has been identified using the questionnaire surveys effectively in many countries in the world as shown in above literature studies. In particular Sri Lanka as a developing country has limited crash data which developed countries use to identify crash risk. Therefore, in this study the young inexperienced drivers' behaviour on the road and habitual practices were investigated through a questionnaire survey.

3. OBTAINING DRIVER LICENCE IN SRI LANKA

In Sri Lanka there are two licence categories: light vehicle licence and heavy vehicle licence which is an extension of the light vehicle licence. Under the light vehicle category, the licence classes A1, A, B1, B and G1 and under the heavy vehicle, licence classes C1, C, CE, D1, D, DE, G and J are issued [10]. Table 1 shows vehicles under each licence class in Sri Lanka according to the Section 122 of Motor Traffic Act amended by Act no.08 of 2009.

According to guidelines provided by the Motor Traffic Act amended by Act No.08 of 2009 to obtain a driver license, a person can register and sit for the written test for light vehicle category (classes A1, A, B1, B) when 17 years of age has been completed [10]. Prior to filling the application for driving license, an aptitude medical certificate has to be obtained from any of the National Transport Medical Institution. The institute provide medical services by examining and issuing certificates of physical and mental fitness to drivers of all types of vehicles. Once medical test is completed, a written test consisting of 40 multiple choice questions has to be done. In this test the knowledge on the road signs and traffic rules are assessed. Once the written test is passed, a learners' permit is issued for up to a maximum of 18 months. Holder of learners' permit can practice driving under supervision of licensed driver along with "L" board fitted to the front and rear of the vehicle [10]. A person who completes 18 years of age and a minimum of three months of experience under learners' permit can face the road test [10]. In road test, the general driving ability is checked including fastening the seat belt before starting the vehicle, pulling over at the side of the road, reversing the vehicle, parallel parking at the side of the road. It is compulsory to face the road test and pass it to obtain the driving license. Table 2 gives the number of tests conducted all over Sri Lanka from January 2016 to December 2017.

Table 1: Vehicles under Different Licence Classes

License Class	Description
A1	Light motorcycles of which the engine capacity is less than 100CC
A	Motorcycles of which engine capacity is more than 100CC
B1	Motor tricycle or van of which the tare weight is not more than 500kg and gross vehicle weight is not more than 1000 kg
B	Dual purpose motor vehicle of which the gross vehicle weight is not more than 3500kg and the maximum seating capacity including the driver's seat is 9 seats
C1	Motor lorries of which the gross vehicle weight is more than 3500 kg and less than 17000 kg. Motor vehicles of this class also includes motor hearses and ambulances
C	Motor lorries of which the gross vehicle weight is more than 1700 kg. This class of vehicles can be combined with a trailer which has a maximum tare weight of 750 kg
CE	Heavy motor lorries of which the gross vehicle weight is less than 3500 kg. These vehicles are a combination of a motor lorry and trailers of which the tare weight of a trailer is more than 750 kg
D1	Light Motor Coach- These motor vehicles used for the carriage of people and having a seating capacity more than 9 seats and less than 33 seats including the driver’s seat. This class of motor vehicle can be combined with a trailer having a maximum tare weigh of 750 kg
D	These are motor coaches where the maximum seating capacity is 33 seats including the driver’s seat. This class of motor vehicle can be combined with a trailer having a maximum tare weigh of 750 kg
DE	These are heavy motor coaches having a seating capacity of 33 seats including the driver's seat. This has a combination of two motor coaches or a combination of a motor coach and a trailer having a tare weight more than 750kg
G1	Hand tractors - These are two-wheel tractors with a trailer
G	Land vehicles - These are agricultural land vehicles with or without a trailer
J	These are special purpose vehicles, which are used for construction, loading & unloading and they are equipped with construction equipment and equipment for loading and unloading goods

Table 2: Written and practical test attempts in Sri Lanka from 2016 to 2017

Age (years)	Description	Written Test		Practical test	
		Male	Female	Male	Female
<17	Number	0	0	0	0
17-19	Number	79,197	10,612	98,647	8,160
	Percentage %	23.1	3.1	23	1.9
20-22	Number	35,972	10,749	41,263	11,226
	Percentage %	10.5	3.1	9.6	2.6
23-25	Number	22,863	9,514	27,253	10,106
	Percentage %	6.7	2.8	6.4	2.4
26-28	Number	8,856	4,502	11,384	4,958
	Percentage %	2.6	1.3	2.7	1.2
>28	Number	96,865	63,649	141,267	74,787
	Percentage %	28.3	18.6	33	17.4
Total	Number	243,753	99,026	319,814	109,237
	Percentage %	71.1	28.9	74.5	25.5

Source: Department of Motor Traffic, 2018

Heavy vehicles driving licenses are the extension of the light vehicle driving licences. The person applying for a heavy vehicle driving licence should be a holder of a light vehicle driving licence of class B or B1 at least two years prior to the date of application [10]. To obtain a licence for light motor bus and light motor category the minimum height of the person should be four feet 10 inches. A minimum height of five feet is required to obtain a license for motor bus and motor lorry category [10].

As shown in Table 2, almost 25% of people who attempted the practical test were in 17- 19 years age category while about 50% were aged more than 28 years. The total vehicle population in Sri Lanka in 2010 and 2016 is 3,954,311 and 6,334,992 respectively [11]. There is an increase of 2.3 million vehicles in Sri Lanka within six years. When there is a large increase of vehicle population, attention must be paid to the driving behaviour of people which is a main safety concern for both the drivers and pedestrians. The willingness of the younger age group to obtain driving license highlights the need to focus on driving behaviour of young people. This study is significant as it involves the findings of young drivers and their habitual practices. This is important because finding out the factors that affect a young person’s driving behaviour can help in early intervention and prevention of those factors and reckless driving.

4. METHODOLOGY

4.1 Development of questionnaire and sample size

This research study investigates the habitual practices of the young drivers. Data were collected using a questionnaire form consisting of several questions related to risks involving young drivers. The form also contained questions related to the social economic details of the driver, the type of vehicles they drive, their license categories, the speed at which they drive and some questions related to the habitual practices of the drivers which leads to accidents. The risky aspects and habitual practices were identified by reviewing the previous studies and verified though a pilot survey. The sample size calculation was done according to Equation (1) [12].

$$n = \frac{(Z\alpha/_2 \times \sigma)^2}{e^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where, n = sample size, Z= the critical value at (α/2) % significance level, σ = standard deviation, and e = significance interval.

The minimum sample was obtained by assuming a 95% confidence level (Z = 1.96) and a 5% significance interval (e =0.05). To obtain the minimum sample size a standard deviation of 50% was assumed [6]. This resulted in a minimum sample size of 385. A total of 400 survey forms were printed and distributed. Out of them, 278 were answered by male respondents and 122 were answered by female respondents. The majority of the people who answered the questionnaire was of the age group 19 to 24 which consisted of 83.8% of the total sample size. About 6% respondents were age below 19 years and the rest of 10.2% were age above 24 years. Out of the 400 participants 302 had full license, 28 had just the learner's permit while 70 participants had not taken driving license. All the above people had been exposed to driving at least for 6 months. Only 172 participants out of 400 had driven under someone's supervision who owns a driving license. From the total sample, 230 participants who admitted that their parents has imposed driving limitations, said it was always about speeding where their parents always asked them not to speed. Regarding the involvement in accidents, only 68 participants had been involved in an accident. It was highlighted when it came to traffic offenses committed by them, the highest number for getting pulled over by the police was due to overtaking in restricted areas which was 75 and followed by speeding which was 46. The number of offences for parking in restricted areas was 32, driving without a valid licence 30 and followed by not wearing seatbelt was 16. The least response recorded was for crossing the signal before it turned green which was 12.

4.2 Survey locations

The printed questionnaires were distributed at Diyatha-Uyana in Battaramulla, SLIIT campus in Malabe, Viharamahadevi Park, and in Peradeniya garden. In these locations, young men and women gathered and therefore easily could be found the young and inexperienced drivers. They were seated in these locations and willing to fill the questionnaire forms by themselves. The questionnaire forms were not just given to those who had driving license but also for those who had learner's permit and for those who have driven vehicles without obtaining driving license.

4.3 Cronbach's Alpha Reliability Test

To get this information from the respondents, a 5-unit likert scale from 1 to 5 was used where; 1 = never, 2 = occasionally, 3 = sometimes, 4 = most of the time and 5 = always [5]. This helps in avoiding difficult survey questions like open-ended and fill-in-the-blank questions. Cronbach's Alpha reliability test was used to measure the internal consistency between items in a scale to study the correlation of every item in the likert scale with every other item [13]. This is expressed as a number between 0 and 1. The acceptable values of alpha is from 0.70 to 0.95 and if the value is less than 0.70 considered as questionable [13]. The internal consistency was found before a research to ensure validity. If the items that are subjected to test are well correlated to each other, then the value of alpha is higher. However, if the alpha value is high it does not always mean that it has a higher degree of internal consistency since alpha values can also be affected by the length of the test. The alpha value is also sensitive to the number of tests. The value of alpha can get short if the test length is short. Poor inter-relation between items and inadequate number of questions could also lead to low value of alpha. If the value of alpha is greater than 0.95, it may suggest redundancies and show that the test length needs to be shortened [13].

4.4 Multinomial Logistic Regression

Multinomial Logistic Regression analysis is a predictive analysis and is used for explaining the relationship between a nominal or ordinal dependent variable and one or more independent variables [14]. When the dependent variable is qualitative and if it has more than two possible answers or categories, then multinomial logistic regression could be used to estimate the probability of occurrences for each of the alternatives. The Likert scale used in this study comes under the ordinal variable set which has a 5 point scale namely: never, occasionally, sometimes, most of the time and always.

The model fitting information of multinomial logistic regression contains a likelihood ratio chi- squared test, comparing the full model against a null model. The full model contains all the predictors whereas the null model will not have predictors. The threshold value to consider an overall model as fit or not is the 5% significance level (p- value) [14]. If the significant value is less than 0.05, the null hypothesis (intercept only model) is rejected. This means that the final model is more significant than the null model and the final model is considered as fit.

5. RESULTS

The responses for the all the self-reported negative habitual practices are tabulated in Table 3.

Table 3: Self-reported Driving Habits of Young Drivers

Habitual driving practices	Never (%)	Occasionally (%)	Sometimes (%)	Most of the time (%)	Always (%)	Total Numbers
Over speeding	96.5	1.0	2.0	0.5	0.0	400
Driving after alcohol consumption	95.3	2.3	2.5	0.0	0.0	400
Mobile phone usage	56.5	20.5	18.0	1.0	4.0	400
Taken an illegal U-turn at restricted areas	53.8	27.3	14.3	3.0	1.8	400
Indicate signals when you are changing lanes	4.3	1.5	6.5	23.3	64.5	400
Wearing seat belts even if it was only for a short trip	8.8	4.3	13.0	14.0	60.0	400
Carrying more passengers than that could legally fit in your vehicle	45.3	19.0	23.5	7.5	4.8	400
Taking chance to try to speed and run a yellow light when it is about to change to red	49.0	23.5	21.3	4.8	1.5	400
Overtake vehicles in restricted areas. (ex: double lined road area and curvy roads)	56.5	22.5	19.3	1.8	0.0	400
Overtaking a slow driver from the left side	56.8	16.5	15.0	7.0	4.8	400

5.1 Reliability Statistics

To apply Cronbach's Alpha reliability test for a set of items, all the Likert scaled items were phrased in negative order. Table 4 gives the average correlation among the 10 items that were questioned. The Cronbach's alpha value 0.705 suggests that the average correlation among the ten items, that is in the questionnaire, indicate marginally an acceptable reliability since the value is just greater than 0.70 [15]. This value is a good indication about the average correlation among the Likert scale questions from the questionnaire.

Table 4: Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	Number of Items
0.705	0.705	10

5.2 Inter-Item Correlation

Along with the Cronbach's Alpha values, the internal consistency among items was tested using the inter-item correlation measures which are also part of reliability tests.

Table 5: Inter-Item Correlation Matrix

	Smoking	Driving after alcohol consumption	Mobile phone usage	Taken an illegal U-turn at restricted areas	Indicate signals when you are changing lanes	Wearing seat belts even if it was only for a short trip	Carrying more passengers than legally fit in vehicle	Running yellow light when it is about to change to red	Overtake vehicles in restricted areas	Overtaking a slow driver from the left side
Smoking	1	0.245	0.208	0.047	0.098	0.038	0.018	0.245	0.309	0.248
Driving after alcohol consumption	0.245	1	0.26	0.126	0.246	0.071	0.097	0.094	0.154	0.129
Mobile phone usage	0.208	0.26	1	0.311	0.303	0.321	0.237	0.176	0.213	0.269
Taken an illegal U-turn at restricted areas	0.047	0.126	0.311	1	0.144	0.283	0.131	0.208	0.363	0.177
Indicate signals when you are changing lanes	0.098	0.246	0.303	0.144	1	0.432	0.102	0.042	0.204	0.19
Wearing seat belts even if it was only for a short trip	0.038	0.071	0.321	0.283	0.432	1	0.187	0.104	0.221	0.317
Carrying more passengers than legally fit in vehicle	0.018	0.097	0.237	0.131	0.102	0.187	1	0.16	0.035	0.256
Running yellow light when it is about to change to red	0.245	0.094	0.176	0.208	0.042	0.104	0.16	1	0.467	0.308
Overtake vehicles in restricted areas.	0.309	0.154	0.213	0.363	0.204	0.221	0.035	0.467	1	0.309
Overtaking a slow driver from the left side	0.248	0.129	0.269	0.177	0.190	0.317	0.256	0.308	0.309	1
Note:		*Coloured box indicates the values more than 0.300 (threshold value)*								

Inter-Item Correlation is defined as the correlation with every item considered in the scale with each other time. The larger the value and closer to 1, then the relationship between the response is stronger. Table 5 gives the correlation matrix, in which every value is significant at 95% confidence level. Also, every value above the diagonal 1's and every value below it are the same. The optimal value for the mean inter-item correlation ranges from 0.2 to 0.4 [15].

'Overtaking vehicles in restricted areas' and 'taking chance to speed up and run a yellow light when it is about to change to red' are the two items that had the highest inter- item correlation value of 0.467. This higher value indicated that young drivers who overtake vehicles in restricted areas are also more likely to speed up and running yellow light when it is about to change to red. The second highest inter item correlation value obtained is 0.432 and the third highest inter item correlation value obtained is 0.363. These values indicate how each item is correlated with each other. Out of the 45 available inter- item correlation values, 24 of those inter- item correlation values are greater than 0.2 which suggests that those 24 pair of items have an influence on each other where, when one of the items in a particular pair occurs then there is more chance for the second item of the same pair to occur along with it.

The internal consistency among the Likert scale items from Cronbach's alpha test is 0.705. This value is a good indication about the average correlation among the Likert scale questions from the questionnaire. There are results of 45 available inter- item correlation values. The highest inter-item correlation value 0.467 is obtained for the pair; overtaking vehicles in restricted areas and taking chance to try to speed and run a yellow light when it is about to change to red.

5.3 Likelihood Ratio Tests

For the multinomial logistic regression, the variable 'wearing seat belts even if it is for a short trip' is selected as the dependent variable among the Likert scale set of questions. If young drivers use the seat belt they assume low risk as effectiveness of seat belt reducing crash injuries are well known [16]. However, when the inter-item correlations values are considered, 'overtake vehicles in restricted areas' has four variables above the threshold value (0.300) whereas variable 'wearing seat belts even if it was for a short trip' has three variables. Statistically, it is recommended to select the dependent variable as the variable which has high correlation with many other variables. The other remaining habitual practices among young drivers are selected as the independent variables.

The model was used to analyse how these habitual practices have had an effect on the positive action of a young driver wearing seat belts: in other words, reducing the crash injuries. The significant likelihood ratio values of the habitual practices among the young drivers are shown in Table 6.

Table 6: Likelihood ratio significant values from Multinomial logistic regression

Effect	Chi-Square	df	Sig.
Wearing seat belts even if it was for a short trip (Dependent variable)	-	-	-
Smoking	3.674	4	0.452
Driving after alcohol consumption	9.995	4	0.041
Mobile phone usage	15.250	4	0.004
Taken an illegal U-turn at restricted areas	16.200	4	0.003
Indicate signals when you are changing lanes	47.580	4	0.000
Carrying more passengers than that could legally fit in your vehicle	5.910	4	0.206
Taking chance to try to speed and run a yellow light when it is about to change to red	7.210	4	0.125
Overtake vehicles in restricted areas. (ex: double lined road area and curvy roads)	5.640	4	0.227
Overtaking a slow driver from the left side	22.830	4	0.000

Using the conventional $\alpha = 0.05$, it can be observed that driving after alcohol consumption, mobile phone usage, taking an illegal U-turn at restricted areas, not indicating signals when you are changing lanes, and overtaking a slow driver from the left side are the significant variables. These five independent variables have significant impact on the seat belt not wearing of young drivers indicating high injury risks. A similar study in Australia identified several factors including these four out of five variables were more frequently reported by young novice drivers than provisional drivers [9]. However, overtaking a slow driver from wrong side has not been investigated or reported before. Driving after alcohol consumption is identified as a factor which increases the severity of injury which can be supported with the previous literature [16]. Mobile phone usage is also identified as a primary distraction factor increasing the injury risk of young drivers in several previous studies in different countries [1, 6, 7, 9, 16, and 17].

5.4 Parameter Estimates

The results of parameter estimates provide information about each option in the Likert scale against the reference category option (never) of the dependent variable: wearing seat belts even if it was for a short trip. There are 36 parameter estimates values of which 15 of them have their significant values less than 0.05 as shown in Table 7.

Table 7: Parameter Estimates of wearing seat belts with reference as 'Never'

Wearing seat belts even if it was only for a short trip		β	Std. Error	Sig.	Exp(β)
Occasionally	Taken an illegal U-turn at restricted areas	0.532	0.186	**0.004**	1.703
	Taking chance to try to speed and run a yellow light when it is about to change to red	0.341	0.167	**0.042**	1.406
	Overtaking a slow driver from the left side	0.49	0.148	**0.001**	1.633
Sometimes	Taken an illegal U-turn at restricted areas	0.487	0.187	**0.009**	1.627
	Indicate signals when you are changing lanes	0.872	0.182	**0.000**	2.391
	Overtaking a slow driver from the left side	0.579	0.149	**0.000**	1.785
Most of the time	Mobile phone usage	0.674	0.251	**0.007**	1.961
	Taken an illegal U-turn at restricted areas	0.73	0.266	**0.006**	2.075
	Indicate signals when you are changing lanes	0.954	0.258	**0.000**	2.596
Always	Driving after alcohol consumption	-0.987	0.495	**0.046**	0.373
	Mobile phone usage	0.464	0.193	**0.016**	1.590
	Taken an illegal U-turn at restricted areas	0.495	0.214	**0.021**	1.641
	Indicate signals when you are changing lanes	1.08	0.200	**0.000**	2.946
	Overtake vehicles in restricted areas. (ex: double lined road area and curvy roads)	0.568	0.272	**0.037**	1.764
	Overtaking a slow driver from the left side	0.532	0.179	**0.003**	1.703

From the 15 β coefficients, 14 of these values indicate how the participants who answered any Likert scale question favoured an option from the Likert scale, rather than selecting the reference option of the variable "Wearing seat belts even if it was for a short trip". From the 15 estimates, the same 14 criteria show that, for every unit increase of a participant answering any negative habitual question, the odds of a participant choosing any Likert scale option other than the reference option "never" kept increasing. The first set of results from Table 7 represents comparison between those who chose the option "occasionally" and those who opted "never". From those set of results, three parameters are statistically significant, having a significant value less than 0.05. Those are taking an illegal U-turn at restricted areas (β= 0.532, p= 0.004), taking chance to try to speed and run a yellow light when it is about to change to red (β= 0.341, p= 0.042), and overtaking a slow driver from the left side (β= 0.49, p= 0.001). Table 7 shows only the sets of comparisons which had a significant value less than 0.05. The reference category is 'Never' in each variable.

The β value of taking an illegal U-turn at restricted areas is 0.532 from the "occasionally" category and it is positive. This positive value suggests that those participants who answered the likert scale question "Taken an illegal U-turn at restricted areas" are more likely to select occasionally rather than selecting never of the variable "Wearing seat belts even if it was for a short trip". The odds ratio is given by the values of Exp (β). The odds ratio value of taken an illegal U-turn at restricted areas from the criteria "occasionally" is 1.703. This means that for every one unit increase on a participant taken an illegal U-turn at restricted areas, the odds of a participant opting "occasionally" change by a factor of 1.703. Since this value is greater than 1, it suggests that the odds are increasing. This is a further confirmation that as the participants answer the question on taking an illegal U-turn at restricted areas, they are more likely to answer "occasionally" relative to "never".

6. CONCLUSIONS

This study investigates the young drivers' habitual practices based on data collected through questionnaire forms with Likert scale questions. From this study the negative habitual practices of young drivers while driving are identified and the results proved how these habitual practices have an effect on a positive action of a young driver. The internal consistency among the Likert scaled items from Cronbach's alpha test is 0.705. This value is a good indication about the average correlation among the Likert scaled questions from the questionnaire. There are results of 45 available inter- item correlation values. The highest inter-item correlation value 0.467 was obtained for the pair; overtaking vehicles in restricted areas and taking chance to try to speed and run a yellow light when it is about to change to red.

Overall, the likelihood ratio test values from the multinomial logistic regression show that driving after alcohol consumption, mobile phone usage, taking an illegal U-turn at restricted areas, not indicating signals when you are changing lanes and overtaking a slow driver from the left side are the significant variables for seat belt not use of young drivers. That indicates these factors have an increased injury severity risk. These findings are in line with the previous studies conducted in other countries but overtaking slow vehicle from the illegal side was not identified as a young driver injury risk factor previously at authors' knowledge. This is a novel finding in the young driver safety research. A majority of young driver safety research was conducted in countries with homogenous traffic conditions which have different driver behaviours than Sri Lanka. Even in Sri Lanka, it is not legal to overtake a slow moving vehicle curbside, it can be dangerous and punishable. Under heterogeneous traffic condition in Sri Lanka, overtaking at curbside can be often seen in many urban areas in particular small vehicles like motorcycles and three-wheelers. This study identifies that young drivers overtaking slow moving vehicle from the illegal side as a negative habitual practice among young drivers and proper action should be taken to avoid this practice among young inexperienced drivers. Also, it is better to conduct a research study on this negative behaviour among all drivers because this seems as a critical issue in Sri Lanka. Driving after alcohol consumption, mobile phone usage, taking an illegal U-turn at restricted areas, and not indicating signals when young drivers are changing lanes are critical issues in the country as identified in this study.

Many countermeasures can be recommended to overcome these negative habitual practices. Several studies suggest that policy makers should develop programs targeting risky drivers focusing on education and public awareness [6]. The objectives of these programs are proposed as educating the public about the risk associated with negative habitual practices and reducing the percentage of those habitual practices among these risky drivers [6]. Some studies recommend increase the awareness people by educating them through media [16]. Some studies suggest design of new technologies related to vehicles as well as enforcement efforts. The habitual practices while driving highlight the importance of early intervention for improving road safety. In conclusion, there is always one or more habitual driving practices that has an effect on the other driving habits of a young driver.

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FACTORS IMPROVING BUS TRANSFERABILITY AS THE CHOICE-MODE OF PASSENGERS AT BAMBALAPITIYA RAILWAY STATION

C T Danthanarayana [a]* and W G H A Welarathna [b]

[a b] Department of Economics, University of Colombo, Sri Lanka

* Corresponding author E-mail address: *chamila@econ.cmb.ac.lk*

ABSTRACT

Inadequacy and inefficiency of public bus transport as a mode of transfer at railway stations has led passengers to switch other modes to reach their destinations. This has led to increased traffic congestion on urban roads and heavy economic cost to society.

The main objective of this study is to identify the factors influencing the improvement of bus transferability at the Bambalapitiya Railway station. This study considered sixteen attributes of quality: accessibility, waiting time, cleanliness of the bus stop, facilities of the bus stop, occupancy level, safety of driving, traffic conflict, harassments, courtesy of bus crew, bus route coverage, bus frequency, availability, bus quality, privacy, cleanliness and travel time.

The findings of the descriptive analysis clearly showed overcrowding and increased travel time as crucial factors for not using the existing transfer bus service. As per the results of factor analysis, the six factors which contain the sixteen attributes are network design, convenience, and safety, quality of buses, background factors, and time consumption.

Prioritising the deployment of additional buses during peak hours, introduction of new bus services with integrated scheduling, the assurance of quality, and efficient service are imperative to enhancing bus transferability at the railway station.

Keywords: *Transferability, Quality Attributes, Bus Transit, Factor Analysis, Mode-Choice*

1. INTRODUCTION

Public bus transport is one of the integral transfer modes in an integrated transport system that facilitates an efficient and effective service by increasing economic and social benefits. Public transport probably the most up-to-date answer to the growing need for relieving traffic congestion, associated environmental problems, and continuously increasing cost of transferring passengers [1]. Bus transit provides accessibility to fulfil the daily requirements of people facilitating regional connectivity. A transport journey links different modes as per the choice of passengers. According to Castiglione [2], people consider the choice of travel modes according to their trip purpose that required to be fulfilled. This reveals that mode choice varies according to expectations and satisfaction of passengers on the level of service provision.

In Sri Lanka, the majority of people use public bus transport for their daily movements and this is shown by the mode share of bus transport which accounts for 46.6% including private and SLTB buses [3]. However, the non-availability of proper transport connectivity between different modes has created a long journey time with many discomforts to the passengers. Bus transport is a cost-effective transfer mode that could make proper connectivity between road and rail. The lack of a rail-bus integrating system in Sri Lanka has caused people to choose private vehicles as their transfer mode to reach their destinations. This has led to increased traffic congestion mainly on urban roads whereas creating a heavy economic cost to society. In the Sri Lankan context, many people use rail transport to fulfil their work trips and trains are more crowded during peak periods due to congestion on roads. People attract rail transport as it provides affordable service with shortened travel time compared to buses and other private transport services. Thus, facilitating bus transferability at railway stations to capture transfer passengers is timely imperative as it minimises externalities on roads whereas making passenger access to destinations easier and more affordable.

At present there is no coordinated effort for intermodal transportation and hence there is a breakdown of inter-modalism between trains and buses [4]. Since rail-bus integration and development of public transport services are key aspects of transport policy priorities in Sri Lanka, the study provides guidance to the transport policymakers and planners to improve passenger accessibility by improving transfer bus services. In the global context, many kinds of research have ascertained the factors of mode choice and passenger satisfaction to develop the public transport system. But, in the Sri Lankan context, research conducted to identify the determinants of transfer mode choice for improving bus transferability or rail-bus integration is deficient. Hence, determining the factors of transfer mode choice is imperative to upgrade the prevailing transfer bus services at railway stations as well as introducing new transfer services.

The main objective of this study is to identify the influential factors of improving bus transferability as the choice mode of passengers at the Bambalapitiya Railway Station. Accordingly, the main motivation of this study is to determine which service attributes in public bus service (private/government) make people use them as their transfer mode and identify the user requirements for satisfaction of prevailing transfer bus service. The study focuses on the group of passengers who are currently not using the transfer bus service commencing at the Bambalapitiya Railway Station to ascertain the causality for their non-usage. The study first assesses the causalities of passengers for not choosing bus transit. Second, the study examines the important quality aspects that influence passenger transferability. Finally, the study evaluates the quality attributes identified and ascertains the most influential factors to determine the quality improvement priorities to upgrade the prevailing bus service at the Bambalapitiya Railway Station.

2. LITERATURE REVIEW

A transfer allows the rider of a public transportation vehicle who pays for a single-trip fare to continue the trip on another bus or train [5]. Facilitating transfer service is a key element of an integrated transport system. Previous studies on bus transferability focused on the planning of a proper timetabling system to minimise passenger transfer time while improving the efficiency of rail-bus integration. The determinants of improving transfer bus services depend upon passenger mode choice and passenger satisfaction. According to Mintesnot and Shin [6], travellers' satisfaction is an important performance measure for the transport service providers and a determinant factor affecting the mode choice. The factors of transport mode choice can be classified as characteristics of the trip maker, characteristics of the trip, characteristics of mode as well as many latent factors like comfort and convenience [7]. Cheng et al. [8] analysed factors that affect passenger satisfaction during the bus transfer process at HSR stations based on the passengers' perceptions of convenience, comfort, safety, service, and economy. The results of analysis show that economy and convenience are the critical influential indicators of passenger satisfaction, among which bus fare preferential policy and transfer distance are the most significant factors.

Researchers is generally focused on improving the quality of bus service that connects with the perceived value, and satisfaction of public transport. Nielsen et al [9] mentioned that public transport quality denotes regularity, direct connections, convenient terminal layout, high and fixed frequencies, and short travel times. They further noted these quality aspects are important for the choice of public transport vs private transport. The factors influencing bus transferability can be ascertained through the viewpoint of users on mode choice, exploring the reasons and their level of satisfaction on service quality. Berkley [10] mentioned that customers could supply excellent sources of information and, according to the feedback from customers, governments and companies could improve service quality by distinguishing the areas of services most needed improvement. According to Leonard et al. [11], the only judge of the service quality is the customer. This reveals that identifying customer perspectives on mode choice and satisfaction is very useful for decision making on public transport planning and operation. A person's behavioural intention may also affect transport mode choice [12]-[15].

Customer satisfaction, closely related to perceived service quality and value [16–18], is widely regarded as the main driver of consumer loyalty to public transport and behaviour [19]. Improving service quality could lead to higher passenger satisfaction, which could increase the ridership of public transport [8]. He further mentioned that from the view of service supply, the choice of transfer mode for a passenger at a high-speed railway station is influenced by the service quality of both the transfer process and the target traffic mode. Nor et al [20] forecasted that improvements in bus service quality increase ridership depending on trip purpose.

Factors such as connectivity or reach, accessibility to a specific mode of transportation, information, time satisfaction, user attendance, comfort, security and safety, and environmental impact have been identified to be influential in the choice of a commuter [21]. According to Popuri et al [22], reliability, privacy, comfort, availability, safety, and attitudes towards public transportation were key factors in transportation preference of commuters in the Chicago area in the United States. This reveals passenger preference on transit modes is influenced by service quality and operational performance.

According to the existing studies, from the passengers' perspective, comfort, facilities, reliability, waiting time, journey time, convenience, travel cost, punctuality, and accessibility have been considered as the main factors that affect the quality of service. Shaaban and Khalil [23] stated that individual socioeconomic attributes could affect passenger satisfaction, such as gender, age, occupation, income, and marital status. This shows the personal attributes of passengers are crucial factors affecting travel mode choice behavior. Abdel-Aty and Jovanis [24] found that departure time had a significant impact on the travel behaviour of the elderly. Redman et al [25] pointed out that numerous attributes have been proposed to define public travel quality, which can roughly be classified as physical (reliability, frequency, speed, accessibility, price, etc.) or perception (comfort, safety, convenience, aesthetics, etc.). According to [26] passengers always tend to choose the travel modes meeting their expectations of the service performance to the maximum extent.

Kostakis [27] researched on measuring customer satisfaction in urban buses in Greece and found that route waiting time and frequency are the major determinants directly influencing customer satisfaction. Munzilah et al [28] stated that the choice of public transport as a preferred mode of travel is mainly influenced by the quality of bus operation services. They further mentioned transit users today are more demanding from the bus providers including fast and reliable service, shorter walking distance to stops, low floor buses, cheaper service, and friendly safe drivers. The performance of the bus transferability at stations depends on service quality and efficiency expected by passengers. Madhuwanthi et al [29] conducted research on factors influencing travel behaviour on transport mode choice and identified that vehicle ownership, safety and comfort become the most crucial factors.

Research studies of Mazzulla and Eboli [30] analysed public transport non-use reasons why passengers did not use public transport. According to the analysis, the main reasons for not using public transport are low service frequency followed by vehicle overcrowding, slowness of the vehicles, and long waits at the stop. The Land Transport Authority of Singapore [31] conducted a survey on transport customer satisfaction to determine passenger expectations and identified service attributes for improvement. The survey determined the three most important service attributes: waiting time, travel time, and reliability which provide guidance to enhance the public transport service level for commuter benefit. According to Taylor and Fink [32] service reliability, particularly service coverage and service frequency are the most crucial factors influencing public transport ridership.

The literature review clearly shows that people tend to choose transfer mode with concerning the comfort, security, vehicle in time, trip distance, time reliability, cost of the travel mode, availability, and frequency of services, etc. since people have various opportunities to choose the mode in the present context. Mode choice analysis is vital to organise transportation and adjust operation plan effectively [33]. Hence, determining the factors of transport passenger mode choice and passenger satisfaction, travellers' behaviour and ridership patterns are important aspects of improving transfer bus services.

3. METHODOLOGY

Bambalapitiya Railway Station is located on the Coastline between Kollupitiya and Wellawatte Railway Stations in the Colombo district of Sri Lanka. It is the fourth Railway station located 5.22 km away from Colombo Fort. Bambalapitiya Station is a major transfer point to many suburban areas and main cities in the Colombo District. The station is accessed by many commuters with a high loading level during morning and evening peaks. At present, three bus services: Bambalapitiya-Dematagoda (154), Bambalapitiya-Kadawatha (177), and Bambalapitiya- Sethsiripaya (154) are operated from Bambalapitiya railway station. The services operate during morning peak hours (From 6.00 am to 10.00 am) to target the working population arriving at Bambalapitiya Railway Station.

Since heavy road traffic congestion occurs during this time period and passengers are facing inconveniences to reach their destinations, improving the transferability of prevailing bus services and introducing new transfer bus services are a paramount solution to enhance passenger mobility and accessibility. The passengers who transfer from the Bambalapitiya Railway Station mainly use state and private buses, para transits, or office transport services as their egress modes. The study is based on the quantitative research method and collected primary data from passengers who are currently not using public bus transport as their transfer mode at the Bambalapitiya Station. Further, the study focused on passengers who make mode choice as their egress mode. A structured questionnaire with five-point Likert scale was used to ascertain passenger experience and opinions of different mode choices. The study was conducted during the morning peak which could be identified many transfers. Among the total population of the survey which consists of total transfer passengers from the Bambalapitiya station from 6.00 am to 10.00 am, 150 passengers were randomly selected as the sample. The survey is based on the identified factors of service quality attributes and the factors were tested on passengers' perspectives. Sixteen key quality attributes (accessibility, waiting time, cleanliness of the bus stop, facilities of the bus stop, occupancy level, safety of driving, traffic conflict, harassments, curtsey of bus crew, bus route coverage, bus frequency, availability, bus quality, privacy, cleanliness and travel time) that influence passengers' transfer mode choice were used in this study and the selection of the quality attributes was based on the literature survey and brainstorming.

Data analysis is based on the evaluation of passengers' level of agreeability on service quality. A five-point Likert scale with "Highly Agree (HA)" equalling 5, "Agree (A)" equalling 4, "Neutral (N)" equalling 3, "Disagree (D)" equalling 2, and "Highly Disagree (HD)" equalling 1, was used in the rating of the questions for the assessment of passengers' mode choice. A descriptive analysis and factor analysis were used to examine the underlying constructs. First, correlation analysis was undertaken to measure the linear correlation between quality attributes, and factor analysis was performed to cluster them using SPSS software.

4. RESULTS AND DISCUSSION

4.1 Analysis of Descriptive Statistics

According to the analysis of socio-economic data, the sample consisted of 57% female and 43% male passengers in different age groups. The highest age group categories who are not using bus transport as their transfer mode are 20-30 years (32%) and 30-40 years (23%) which represent almost half of the total sample. As per the analysis of employment status, the majority of people who are not using bus transfer service are employed as office workers and businesspeople (51%). As per the frequency of usage, 55% of passengers used transfer services 'mostly' and 18% of passengers used 'on average' to reach their destination. This shows the majority of rail transport users regularly choose different services as their egress mode. Further, the majority of the sample has a wide experience of existing transfer modes and their quality as regular passengers.

Table 1 depicts descriptive statistics for quality attributes under investigation. The descriptive analysis shows passengers agreed that considerations related to accessibility, waiting time, occupancy level, harassments, courtesy of bus crew, bus frequency, privacy, and travel time (Mean >3.0) for not using bus transfer service. The quality attributes passengers are most concerned with are high occupancy level (Mean= 4.3) and travel time taken to complete their journey (Mean = 4.6) that reflects the most crucial factors on transfer mode choice.

Table 1: Descriptive Statistics

Component (Quality Attribute)	N	Minimum	Maximum	Mean	Std. Deviation
Accessibility	150	1.0	5.0	3.213	1.5910
Waiting Time	150	1.0	5.0	3.033	1.3581
Cleanliness of Bus stop	150	1.0	5.0	2.053	.6833
Facilities of Bus stop	150	1.0	5.0	2.567	1.1138
Occupancy Level	150	1.0	5.0	4.353	.9772
Safety of Driving	150	1.0	5.0	2.767	1.0832
Traffic Conflict	150	1.0	5.0	2.033	.9005
Harassments	150	1.0	5.0	3.033	1.4536
Curtsey of Bus Crew	150	1.0	5.0	3.533	.9530
Bus Route Coverage	150	1.0	5.0	2.933	1.2674
Bus Frequency	150	1.0	5.0	3.167	1.3532
Availability	150	1.0	5.0	2.820	1.7573
Bus Quality	150	1.0	5.0	2.527	.9603
Privacy	150	1.0	5.0	3.900	.9814
Cleanliness	150	1.0	5.0	2.300	.8956
Travel Time	150	2.0	5.0	4.593	.6564
Valid N (listwise)	150				

Source: Author

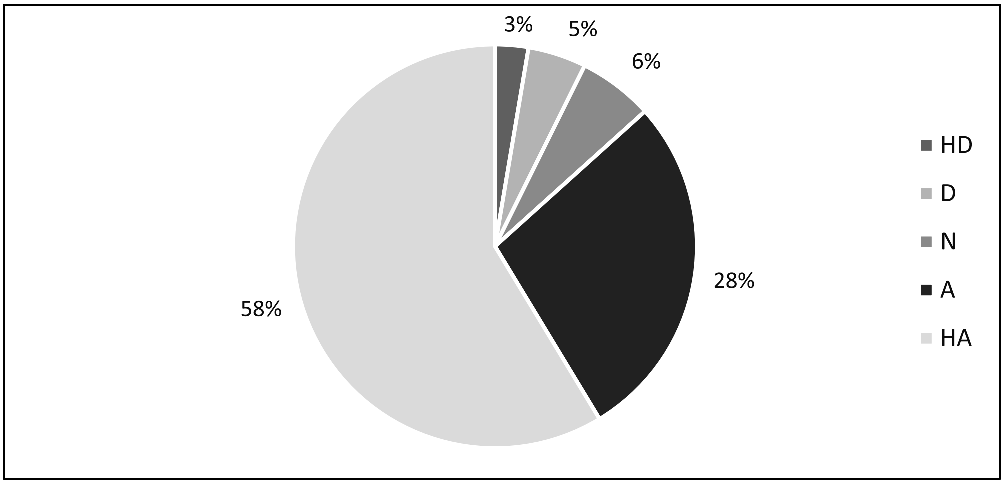

Figure 1: Passengers Perspective about Occupancy Level of Transfer Bus Service

Statistics shows that 86% of passengers considered the high passenger occupancy level (Figure 1), and 95% passengers considered the high travel time associated with the prevailing transfer bus service as the reasons for not using buses as their egress mode (Figure 2).

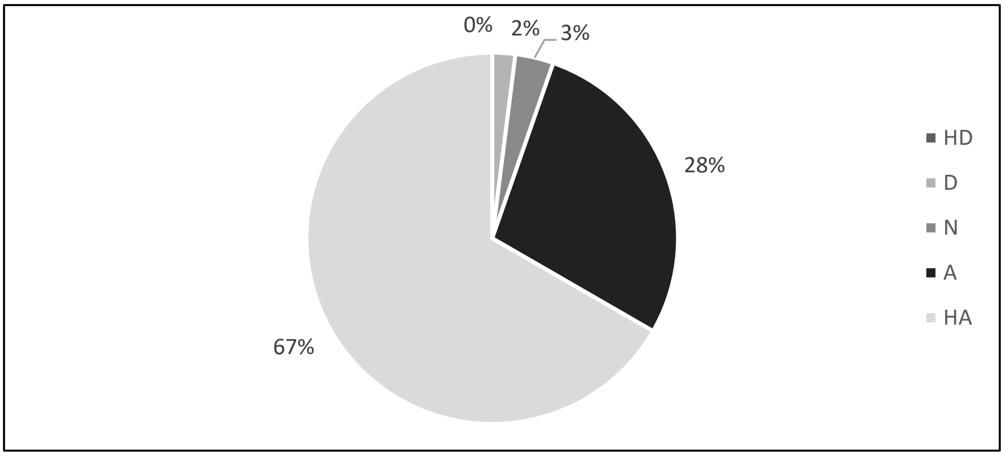

Figure 2: Passenger Perspective about Travel Time of Transfer Bus Service

4.2 Factor Analysis

The factor analysis produces a small number of factors from a large number of variables which is capable of explaining the observed variance in the larger number of variables. The Exploratory Factor Analysis (EFA) was carried out in the study for the selected 16 quality attributes that contribute to the transfer mode choice at Bambalapitiya Station.

The test for the validity of the dataset was examined according to Kaiser- Meyer-Ohlin (KMO) measure of sample adequacy and Barlett's test of sphericity (Table 2). According to Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, the study shows KMO value of 0.613, confirming acceptance of the model for factor analysis to proceed. KMO value more than 0.5 score implies the analysis could be continued further for all given factors in the study. The Bartlett's significant score (Sig. = 0.000) indicates that the variables are relevant and suitable for structure detection. The test result shows the strength of the relationship among variables indicating that the correlation matrix is not an identity matrix.

Table 2: Results of Kaiser-Meyer-Ohlin [KMO] Measure and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.613
Bartlett's Test of Sphericity	Approx. Chi-Square	508.518
	df	120
	Sig.	.000

Source: Author

Table 3: Total Variance Explained

Component (Quality Attribute)	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.673	16.708	16.708	2.673	16.708	16.708	2.159	13.494	13.494
2	2.476	15.477	32.185	2.476	15.477	32.185	2.123	13.267	26.762
3	1.836	11.476	43.661	1.836	11.476	43.661	1.789	11.181	37.942
4	1.250	7.812	51.473	1.250	7.812	51.473	1.735	10.844	48.786
5	1.149	7.181	58.654	1.149	7.181	58.654	1.399	8.744	57.531
6	1.028	6.428	65.082	1.028	6.428	65.082	1.208	7.551	65.082
7	.862	5.390	70.472						
8	.770	4.814	75.286						
9	.727	4.544	79.829						
10	.615	3.842	83.671						
11	.568	3.548	87.219						
12	.541	3.382	90.601						
13	.493	3.080	93.681						
14	.446	2.787	96.468						
15	.311	1.942	98.410						
16	.254	1.590	100.000						

Source: Author Extraction Method: Principal Component Analysis.

Table 3 above shows all the factors extractable from the analysis along with their eigenvalues that met with the cut-off criterion (extraction method). As per the percentage of variance attributable to each factor after extraction (Extraction Sums of Squared Loadings % of variance), six factors were identified which would contribute to improving bus transfer service.

Figure 3 shows the scree plot of eigenvalues against all the factors. The graph clearly shows that the curve begins to flatten after the factors 6 and it is noticeable that factor 7 onwards have an eigenvalue of less than 1, so only six factors have been retained as per the analysis.

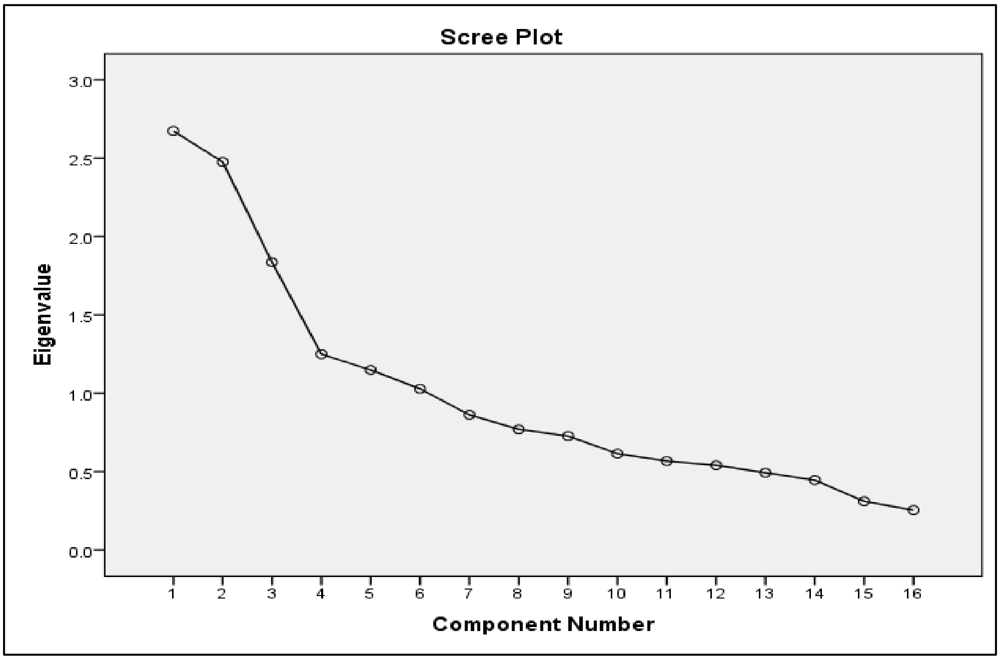

Figure 3: Factor Scree Plot

The idea of factor rotation is to reduce the number of factors on which the variables under investigation have high loadings. As per Table 4, three variables named bus route coverage, bus frequency, and availability are loaded on factor one named 'Network Design.' The next three variables named privacy, curtsey of bus crew, and occupancy level are in the second factor named 'Convenience'. The third factor named 'Safety' contains variables of harassments, safety of driving, and Traffic Conflict. The fourth factor named 'Quality of Buses' contains two variables of bus quality and cleanliness. The fifth factor named 'Background Factors' contains variables facilities of the bus stop, cleanliness of bus stop, and accessibility. The sixth factor named 'Time Consumption' contains variable waiting time and travel time of buses.

Table 4: Rotated Component Matrix

Component (Quality Attribute)	Factor					
	Network design	Convenience	Safety	Quality of Buses	Background Factors	Time Consumption
Bus Route Coverage	.869	.016	.006	.096	.002	-.137
Bus Frequency	.843	.021	-.058	-.031	.107	.155
Availability	.632	-.267	.133	-.146	.163	.242
Privacy	-.029	.769	.017	.173	-.064	-.081
Curtsey of Bus Crew	-.105	.659	.335	.110	.110	-.048
Occupancy Level	-.011	.627	.245	-.243	.005	.246
Harassments	-.153	.136	.769	-.039	-.056	.046
Safety of Driving	.084	.305	.663	.131	.128	-.067
Traffic Conflict	.196	-.098	.658	.347	-.026	.035
Bus Quality	.023	.040	.178	.847	-.050	-.035
Cleanliness of Buses	-.056	.035	.068	.803	.142	.137
Facilities of Bus stop	.082	-.044	-.005	.065	.801	-.200
Accessibility	.222	.407	-.067	-.045	.579	.183
Cleanliness of Bus stop	-.035	-.351	.265	.143	.563	.477
Waiting Time	.370	.014	.034	.234	-.083	.679
Travel Time	-.118	.465	-.136	-.141	-.033	.498

Source: Author

Cronbach's Alpha reliability test is conducted to measure the internal consistency i.e. reliability of the measuring instrument (Questionnaire). According to Table 5, Cronbach's Alpha value, 0.64 which is greater than 0.5 shows the results of the analysis are reliable.

Table 5: Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardised Items	N of Items
.637	.647	16

Source: Author

5. CONCLUSIONS

The study investigates factors of improving bus transferability as the choice mode of passengers at the Bambalapitiya railway station. The contribution of this study is the assessment of the passenger perspective on transfer mode choice and ascertain the service quality attributes for improving bus transferability. The study mainly considered sixteen quality attributes: accessibility, waiting time, cleanliness of the bus stop, facilities of the bus stop, occupancy level, safety of driving, traffic conflict, harassments, courtesy of bus crew, bus route coverage, bus frequency, availability, bus quality, privacy, cleanliness, and travel time that affect transfer mode choice.

The study focused on the perspectives of passengers who are currently not choosing bus transport as their transfer mode and the findings of the study reflect the factors of passenger mode choice which are useful to improve bus transferability at the Bambalapitiya Railway Station. The results of the descriptive analysis clearly show overcrowding and increased travel time are the most crucial factors for not choosing bus services as the transfer mode. The study provides a direction to transport policy decision-makers, regulators, and service providers to improve bus service quality and frequency while introducing new bus services during peak hours to minimise the overcrowding of buses and increase the efficiency of service.

The results of factor analysis show six groups of variables with similar characteristics. The six factors containing the sixteen quality attributes are network design, convenience, safety, quality of buses, background factors, and time consumption that could be used as variables for further analyses. According to the factor extraction, passengers are more concerned about network design. It represents bus route coverage avoiding further transfers, availability of service to their destination, and level of frequency which connects with the arrival time of trains. The study provides a guide to the government to nominate policy priorities for introducing new transfer bus services by both state and private sectors according to passenger demand for destination centres. Imposing and enforcing time schedules for bus dispatching is imperative to reduce waiting time for buses and travel time delays. The study gives a reasonable path ahead to the configuration of policies that will ensure more effective bus transferability to the existing bus users as well as attracting new passengers through an efficient rail-bus integration system.

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TRIPS-IN-MOTION TIME MATRIX TO IDENTIFY TIME WINDOWS AS AN INPUT FOR TIME-OF-DAY MODELLING

S Chandrasena [a]**** and T Sivakumar*** [b]

[a, b] Department of Transport & Logistics Management, Faculty of Engineering, University of Moratuwa, Katubedda, Sri Lanka

* Corresponding author E-mail address: sampathsure@gmail.com

ABSTRACT

Time-of-day modelling is an additional step to the conventional four-step Travel Demand Models (TDMs). Here, the target is to obtain more detailed outputs over the temporal dimension. With this additional step, daily (24-hour) travel demand is distributed into a discrete number of time-windows.

This paper aims to identify the most precise time windows that maximise the trips that fall within a given time-window and minimise the trip-tailing associated with it. The trips-in-motion method follows a more logical approach to capturing the entire trip duration. The Colombo Metropolitan Region Transport Masterplan database, developed in 2013, is analysed using Bentley Cube Voyager transport demand modelling software. The most precise starting timestamps of two-hour time windows were selected for the morning, mid-day, and evening peaks at 6:30 AM, 01:30 PM and 05:00 PM.

This study has developed a systematic approach to identify time-windows as input for time-of-day based modelling. This attempt is an initial step to simulate the third-dimension of a trip, which is called the temporal dimension of TDMs.

Finally, it is recommended to study the shift in peak periods with the change in time of demand, which would be the behavioural change most expected to occur post-COVID-19.

Keywords: *Time of Day, Travel Demand Model, Time Window, Peak-Time*

1. INTRODUCTION

A trip is a movement between two geographic points of the spatial dimension and also a movement between two timestamps of the temporal dimension. Transport systems connect many such spatial points and facilitate trips to move forward along the temporal dimension. Traffic observed in the road transport network is an aggregation of many such trips that are moving within a particular time-window. Time-specific demand estimation is a significant concern in metropolitan Travel Demand Models (TDMs) [1]. The temporal resolution of static TDMs is usually into a few discrete time-periods [2]. The dynamic TDMs simulate shorter time intervals, typically 15 minutes each [3].

The microscopic and mesoscopic simulation models focus more on the temporal distribution of trips or tours than macroscopic simulation models [3]. However, due to various limitations, including computational capability, the study is limited to several square kilometres. Due to that limitation and many other reasons, the state (national) and metropolitan level TDMs are macroscopic models that generally adopt static assignment where the finer time resolution was not focusing as microsimulation models. Getting time-specific outcomes was difficult under such limitations of the static assignment.

Time-of-Day modelling is an addition to the conventional four-step travel demand models to enhance the forecasting capability over the temporal dimension. Time-of-day modelling disaggregates the nature of temporal aggregation in four-step TDMs and estimates temporally varying model outputs related to some discrete number of time periods. Temporal variation in traffic congestion, transit demand, and carbon emission are some of the output measures varying according to time-of-day.

There are two methods used for the time-of-day application, namely the 'pre-defined fixed factors' (fraction of the total trip) method or 'the discrete choice models'. For both these methods, it requires to split the day (24 hours) into a few discrete numbers of time-windows. However, one of the most critical aspects of the time-of-day application is distinguishing the peak vs off-peak model outputs. Hence, the peak characteristics should be represented in the peak time-windows. Therefore, the logic behind deriving such time windows is significant and got focused in this study.

Usually, there is an error associated with the trips assigning process into time windows. Even though a trip is allocating to a time window, either one or both trip-ends may fall into the adjacent time windows (preceding window or following window). Therefore, the time-window must be defined in a manner in which the above error will be minimum.

There was no satisfactory evidence of an experimental approach to derive time-of-day time-window. Even though the 'Trips-in-Motion' concept shows greater precision, we could not find proper evidence for its application. When using the trips-in-motion, it is crucial to measure the errors associated with the trip-timing tails that have fallen into the adjacent time-windows. Minimising the percentage of error related to trip tails were not studied in past applications. The paper aims to identify the most precise peak period time-window which (1) maximise the trips fall within the window and (2) minimise the error due to trip tails fall into adjacent time-window.

2. LITERATURE REVIEW

Importance of studying the temporal resolution of urban TDMs emerged when analytics started to seek temporally varying outcomes [2] than the primary concerns of evaluating highway and transit capacity expansions [1]. It was required to measure the degrees of the variations in congestion speed and the transit availability between the peak and off-peaks of a day in order to evaluate the various strategic solutions proposed for the urban areas. Also, congestion speeds of TDMs were required for emission modelling as inputs for their model development [2]. Such demands were not able to cater by the traditional daily (24 hours) based macroscopic TDMs. Therefore, the conventional four-step in TDM needs an improvement that reflects the variations over the temporal dimension. Table 1 below summarises some of the significant advantages found in several past studies.

Table 1: Advantages of Time-of-day Applications

No	Advantage	Sources
01	Measuring the impacts of peak tolling strategy	[4], [5]
02	Distinguish the peak vs off-peak travel demand for emission modelling and air quality analysis	[6], [7]
03	Identifying peak bottlenecks for traffic management	[8]
04	Accurate representation of timely varying transit availability	[9], [10]
05	Reflection of the proper directional distribution of traffic network capacity analysis	[10]

In order to overcome the limitations of daily basis TDMs, a concept called time-of-day came into practice. Pendyala [10] and Smith [11] have mentioned the time-of-day application as an additional model step into four-step TDM processes TRB [1] reveals that 75% of the large (over 1 million population) Metropolitan Organisations (MPOs) in the USA have applied time-of-day for their TDMs. Moving from metropolitans to the larger state level, Donnelly and Moeckel [12] reveals that the time-of-day has enhanced the conventional four-step into a five-step modelling process of passenger TDMs. Further, they indicate that, out of the 34 state-wide TDMs in the USA, 35% applied time-of-day as a separate model step. However, there was no evidence found for applying time-of-day into four-step TDMs in the other parts of the world. Even though did not use in a four-step TDM, time-of-day choice modelling has been incorporated for various model developments in countries like the United Kingdom and Netherland [13], [9].

In the Sri Lankan Context, models developed for traffic demand estimations attempted to follow at least a few steps of the four-step modelling process. Intercity Passenger Travel in Sri Lanka; Demand Estimation and Forecasting for Bus and Rail [14] focused on public transport demand estimation and modal split. Another attempt was made in the study called Inter-City Demand Estimation for Auto Travel developed from road link traffic counts in 1986, which targeted inter-city movements of private vehicles. TransPlan had its three versions as V1 (1995), V2 (1997) and V3 (2001) which were developed for Colombo Municipal Council Area (CMC), Western Province (Kumarage, Bandara, & Wijerathne, TRANSPLAN V2: A Regional Traffic Estimation Model, 1999) and entire island respectively. There was no time-of-day application found in any of the above models, and all of them have estimated the daily demand. Time-of-day would be an innovative attempt to model some of the Sri Lankan transport system characteristics, mostly the metropolitan.

CoMTrans was the next step, and the comprehensive model development of the above TDM efforts in Sri Lanka developed for the Colombo Metropolitan Region (CMR). This study was based on their Household Visit Survey (HVS) [16]. The HVS covered more than 3% of the households in the CMR. Here, the daily trip tables were used for entire four-step, and there was no time-of-day application. However, CoMTrans, in their report, presented the peak hours volumes and speeds. Apparently, those outputs were not incorporated into the final assignments. We observed CoMTrans approach is quite similar to TDM of San Francisco in the 1990s [3]. Later, San Francisco model was developed as an activity-based TDM, which included the time-of-day based trip assignment. However, CoMTrans [16] has reported the 52% of modal share (among motorised modes) for public transport. Application of time-of-day modelling is mostly essential in analysing transit trips [17] in such a transport system.

The time-of-day modelling is commonly applied either using ‘pre-defined fixed factors’ (fraction of the total trip) method or ‘the discrete choice models’. National Cooperative Highway Research Program [2] and Martin & McGuckin [18] reveal that historical fixed factors are the commonly accepted method. USDOT [17] mentions insensitivity of the fixed factors to the transportation level of service is one of the significant shortcomings. However, Smith et al. [19] published a set of tables for hours trip ratios of different trip purposes related to USA urban areas. Furthermore, TRB [1] has emphasised the need for a more advanced application for TDMs. Discrete choice modelling has been proposed as an advanced application that develops relationships to select time-periods for travelling based on socio-economic, traffic, toll and many other factors [13], [20].

NCHRP [2] mentioned three aspects that need attention in the definition of time-windows, which are (1) analysis needs of the region (2) characteristics of congestion (3) difference in transport services; the definition should also be based on the available data [3]. However, data availability is one of the factors that decides the positioning within four-step modelling. Here, the trip-based approach is applied in pre-assignment steps of the four-step, and the link-based approach is used in the post-assignment stage [10].

Apart from that, capturing most directional commuting trips [11] is another aspect that needs to be considered. One of the primary targets of time-of-day application is to separate the peak vs off-peak outputs of a transport system from the daily assignment [19]. The congestion on transport networks usually associates with the peak-periods of the day. The diurnal distribution of the traffic shows peaks and off-peaks. Therefore, the diurnal distribution pattern of trips provides the basic ideology for deriving time windows [19], [17].

There is no exact number for the time windows, but many metropolitan and state-level models apply –four to five time windows [2], [17]. There are two or three peak periods and subsequent off-peak periods are in use. Some of state-wide TDMs such as Colorado, Ohio & Oregon have finer increments in time windows of 19 - 24 [12]. However, all these time-of-day windows are not assigned to the network due to the runtime limitations. Smith [11] reveals that a temporal window is needed more than the longest trip length in the network. But there was no evidence found to prove meeting such a condition in above three TDMs.

On the other hand, the length of the time window and the number of discrete-time windows have an inverse relationship. To obtain the maximum number of time-windows, the time window length must be smaller as much as possible. There are several questions: (1) maximum length of a time window, (2) requirement of unique length for all windows, (3) way of treating the trips which have either one or both ends outside the respective time-window, remain unanswered.

In order to determine the fixed-factors for each time-window, all trips must be allocated into one of the pre-defined discrete time-windows. As the basis for assigning trips into a time-window, departure time, arrival time, temporal midpoint are the available options [2], [17]. Among them, the temporal midpoint has been introduced as the preferred option. However, all of these return single timestamps that cannot represent the trip movement's entire time duration within the transport system. Therefore, a trip cannot be limited only to a timestamp since it exists within the transport network for a particular time duration. A much more realistic concept called ‘trips-in-motion’ considers the entire trip time and measures the actual number of trips within a specific time-window. Therefore, that can be introduced as the best alternative to defining the peak-periods because of its greater precision [20].

Eash [7] reveals that the Chicago Area Transport Study (CATS) in 1990 used trips-in-motion diurnal distribution for deriving into eight time-windows; however, the trips are allocated by using departure and arrival times of trips. In addition to that, the four-step model developed in the South California region for their six countries has applied trips-in-motion diurnal factors to divide daily trip tables into five time-windows [21].

Various TDMs have divided the day into time-windows in order to archive their modelling requirements. The time-of-day model developed for Louisville-Southern Indiana Metropolitan Area [11] divided a day into four time-windows (AM peak, midday, PM peak and overnight) and split AM & PM peaks into one hour. Here, capturing commuting trips and capturing trip purposes were the primary concerns in defining time windows. Usually, model developers use HVS data and its diurnal distribution for time-of-day application. The Mid-Ohio region's TDM is an activity-based model which has a temporal resolution of one hour. The model produced the departure & arrival hour as output, and the tours were allocated for seven time-windows [22]. In Tampa Bay's time-of-day Choice model, trips were categorised into four time-windows based on each trip's temporal midpoint [10]. However, the distinction of the peak was found as a common objective of all the above cases.

3. METHODOLOGY

In order to derive precise time-windows for time-of-day application, the methodology followed five steps.

3.1 Building the Trip Timing Matrix

In the initial step, the trip's start (departure) and the end time (arrival) obtained from HVS data were assigned into pre-defined discrete timestamps. Timestamp was a day sliced by the gap. The time difference between Start Timestamp (S_s) and End Timestamp (S_e) was the travel time of the relevant trip. A gap (interval) between two successive timestamps was defined from HVS respondents' sensitivity to the timing. The possible values for the gap (G) could be 1 min, 5 min, 10 min, 15 min, 30 min etc. Once the G is defined from the HVS database, the number of timestamps (N) for a day (24 Hours) can be defined as follows:

$$\text{Number of timestamps for a day (N)} = \frac{(24*60)}{G} \quad \text{.......................(1)}$$

In traditional TDMs, the OD-matrix defines the origin and destination with spatial labelling called TAZs, whereas, in time-of-day based TDMs, the trip-timing matrix defines the start time and end time with its timestamps. A time matrix dimension will be N x N. The temporal movement of trips is coded with starts timestamp (S_s) and end timestamp (S_e).

Accordingly, (S_{ij}) is the total number of trips moving from the respective i^{th} timestamp to the j^{th} timestamp (where i & j ≤ N). The shaded cell of figure 1a below represent, as an example, trips of $S_{ij}= S_{45}$ (Trips starting from 4^{th} timestamp and ends in 5^{th} timestamp). The intra-zonal cells represent the number of trips which are not passing at least one successive gap (G).

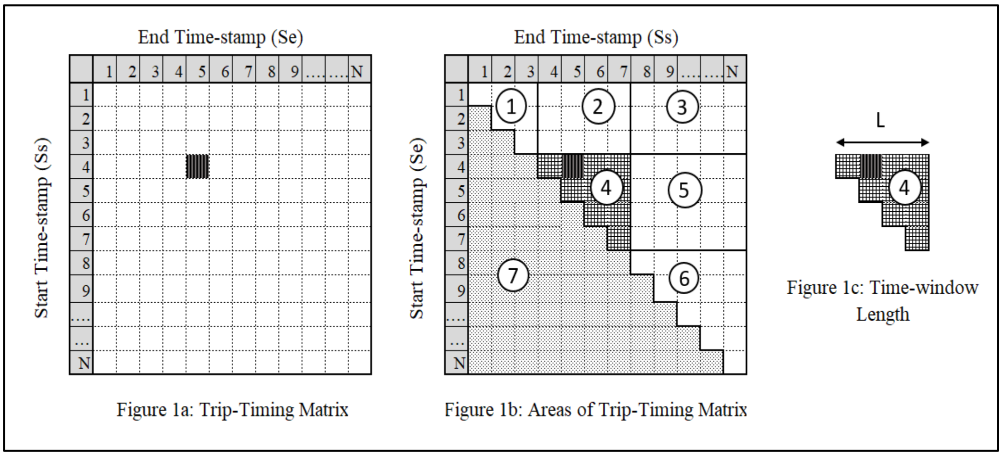

Figure 1: Trip Timing Matrix

3.2 Defining the Length of a Time-window

In most time-of-day applications, length (L) of a time-window was not defined with equal periods among all the time-windows. Focusing better simulation during peak period, the L was set into relatively shorter periods such as 1, 2 or 3 hours [10], [12], [21]. Usually, the off-peak was comparatively longer than peak time. However, this study follows equal periods for all 24 hours as the length (L) of a time-window for the analysis purpose.

3.3 Defining Matrix Areas

Once the L, S_s and S_e are defined, the time matrix cells were further categorised into seven areas relative to the respective time-window. Figure 1b above illustrates those areas relative to the time window from fourth to seventh timestamp. The areas were interpreted as,

- Area 1 - Trips start and end before the time-window
- Area 2 - Trips start before and end within the time-window
- Area 3 - Trips start before and ends after the time-window
- Area 4 - Trips start and end within the time-window
- Area 5 - Trips start within and end after the time-window
- Area 6 - Trips start and end after the time-window
- Area 7 - Trips move through the midnight

Then, the numbers of trips belonging to each of the above areas were determined. Under the defined L, all possible time windows (W_L) were interpreted as $(N - L)/G$ until midnight.

$$W_{L(\max)} = \frac{N-L}{G} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

3.4. Identifying the Best Time Windows

Here, the objective of this study was represented by three criteria. Maximising the number of trip's end was described under criteria 1 & 2 in Table 2 below. Minimising the error due to trip tails was represented under criteria 3-1 & 3-2.

Table 2: Criteria for Selecting Best Time Windows

No	Criteria	Matrix Area	Best W_L
1	Maximum trips travel only within the W_L	Area 4	Maximum Trips
2	Maximum trips that touch the W_L	Area 2, 3, 4 and 5	Maximum Trips
3-1	Minimum trip ends (starts or ends) in adjacent windows	Area 2, 3 and 5	Minimum Trips
3-2	Minimum trip-minutes of the trips that their end (starts or ends) in adjacent windows	Total trip-minutes laid before or after the time window	Minimum Trip-minutes

Criteria 1 and 2 in the above Table 2 were set to find the time window, which has a maximum number of trips. The best time window under Criteria 1 had the highest number of trips travels only within the window. Criteria 2 gave the highest values related to trips-in-motion. Criteria 3-1 & 3-2 set to determine the error percentage of the time-windows occurred from the trip movements to adjacent time-windows. Criteria 3-2 determined the number of trip-minutes of the criteria 3-1 to check whether the longest part of the trip is in other time windows.

3.5. Selecting the Most Precise Time Window for Time-of-day Application

The possible number of time-windows *[N – (L/G)]* were considered against the criteria, as mentioned in Table 2 to select the precise time window by comparing the least absolute difference.

4. DATA ANALYSIS

The methodology of this study was tested with the database developed by the CoMTrans in 2013. Departure and arrival trip-timing of over 175,000 sample trips were used. As estimated by CoMTrans, more than ten million trips occurred within a day in the CMR. Among them, 78% of trips uses at least one motorised transport mode during their door-to-door journey. Therefore, a separate analysis was done for all door-to-door trips and motorised trips to identify the best time windows.

Observing the pattern of the HVS respondents' answers for trip arrival and departure times (how they rounded the answer), the gap (G) was defined as 15 minutes. Even though there were shorter alternatives for G (5 or 10 minutes), 15 minutes was chosen to reduce the number of time windows subjected to analysis. If G was increased further (e.g.: 30 min) impacted on the accuracy since the temporal movement of the considerable number of trips would have fallen into the same timestamp of the time-matrix. Smith [11] stated that the time span of time window must be similar to the longest trip in the study area. In the CMR, trip timing of the 96.9% of the door-to-door trips was less than two hours. Therefore, two hours was considered the length of all time-windows (L= 120 min). When G=15, the number of timestamps became 96 (N=96) for 24 hours.

Figure 2 below plotted the total number of door-to-door trips for two-hour (120 minute) time windows (W_{120}), where the time window starts at each timestamp of a 15-minute gap. The graph clearly shows that the trips-in-motion (triangular mark) always represent the higher value than the other two bases since it captures all trips at each timestamp. Based on above distribution, three time-periods (1) 5:00 AM – 8:00 AM, (2) 11:00 AM – 2:00 PM and (3) 3:00 PM to 7:00 PM were selected as the morning, mid-day and evening peak-periods respectively. The graph further shows that the rising slopes of the trips-in-motion points almost align with the departure time basis point in the respective time stamps. In the same manner, falling slope aligns with the arrival time points. These patterns prove almost all the trips at the timestamps in rising slopes are closer to their origin zones, and at the falling slopes trips are closer to the destination zones.

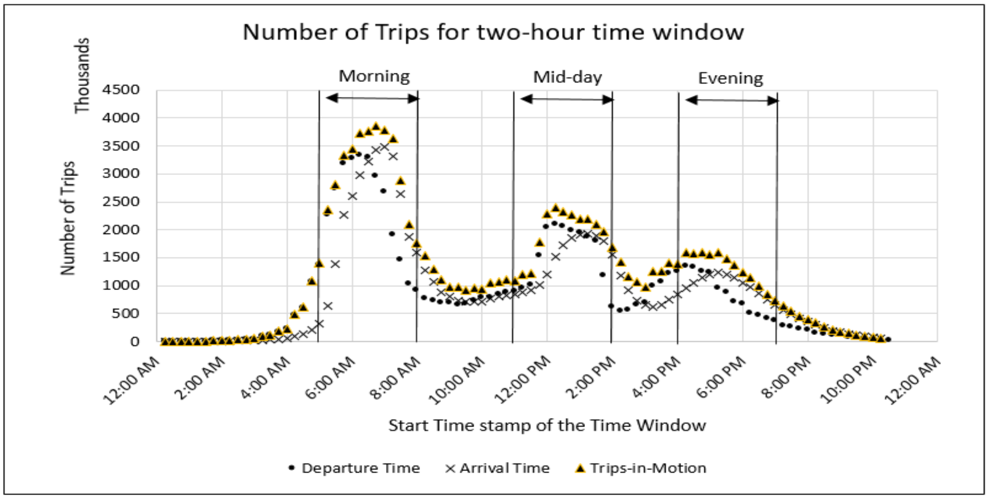

Figure 2: Total Door-to-door Trips for Two-hour *(W_{120})* Time-Window

The time matrix for 96 timestamps was developed using Citilabs Cube Voyager Traffic Demand Modelling Package. The number of trips belonging to Areas 1 through 6 of Figure 1b were determined for all 88 time-windows based on the developed matrix. Area 7 was not considered in the analysis since trips travel over the midnight was a neglectable value. To derive the precise time windows for the three peak periods, we analysed each peak period separately. Table 3 below shows the number of trips for W_{120} at each timestamp of the morning peak period (5:00 AM – 8:00 AM).

Table 3: Number of Trips for W_{120}

Start Timestamp (S_S)	Trips only within the window		Trips under trips-in-motion		Tail Trips		Trip-Hours outside the window (x 1000)
	Trips (x 1000)	% from Daily Trips	Trips (x 1000)	% from Daily Trips	Trips (x 1000)	% from Daily Trips	
Criteria	Criteria 1		Criteria 2		Criteria 3		Criteria 4
5:00	296	3%	1,405	14%	1,109	11%	782
5:15	570	6%	2,354	23%	1,784	18%	1,042
5:30	1,337	13%	2,811	28%	1,474	15%	812
5:45	2,153	21%	3,325	33%	1,172	12%	752
6:00	2,467	24%	3,445	34%	978	10%	583
6:15	2,611	26%	3,733	37%	1,122	11%	644
6:30	2,767	27%	3,772	37%	1,005	10%	596
6:45	2,577	26%	3,854	38%	1,276	13%	730
7:00	2,424	24%	3,774	37%	1,349	13%	860
7:15	1,607	16%	3,637	36%	2,030	20%	1,156
7:30	1,249	12%	2,885	29%	1,636	16%	1,079
7:45	824	8%	2,092	21%	1,268	13%	871
8:00	767	8%	1,756	17%	988	10%	822

The analysis reveals that the W_{120} starts at 6:30 AM has the highest value (27% of daily door-to-door trips) for the trips only moving within the W_{120}. The 6:45 AM was the highest value for trips-in-motion under criteria-2 (38%). However, both selections showed only 1% - 3% difference to all others. W_{120} starts within 6:00 AM and 7:00 AM. Both minimum tail trips and a minimum of trip-hours moving outside the W_{120} were observed in the W_{120} beginning at 6.00 AM.

We determined the absolute difference to other W_{120} under each criterion to select the most precise W_{120} compliance with all of the above criteria. As shown in Table 4 below, the first objective; maximising the trips for W_{120} comply more with S_S= 6:30 AM. This W_{120} showed only a 2% absolute difference to the best S_S selected under criteria 2. If S_S= 6:45 AM had been chosen, it showed 7% difference to the 6:30 AM under criteria 1. Therefore, 6:30 AM became as the most precise S_S in terms of maximising the trips. Following the same process, S_S= 6:00 AM was selected as the best S_S that complied with both Criteria 3-1 & 3-2 under the objective of minimising errors. However, 6:30 AM was the next best S_S, which had only 2% absolute difference. From all different S_S obtained for each criterion, we chose S_S = 6.30 AM for W_{120} in the morning peak-period.

Table 4: Absolute difference from the selected S_S

Starting Timestamp (S_s)	Objective 1 (Max Number of Trips)			Objective 2 (Max Number of Trips/ Trip-hrs)		
	Criteria 1	Criteria 2	Avg.	Criteria 3-1	Criteria 3-2	Avg.
5:00	89%	64%	76.4%	13%	34%	24%
5:15	79%	39%	59.2%	82%	79%	81%
5:30	52%	27%	39.4%	51%	39%	45%
5:45	22%	14%	18.0%	20%	29%	24%
6:00	11%	11%	10.7%	0%	0%	0%
6:15	6%	3%	4.4%	15%	10%	12%
6:30	0%	2%	1.1%	3%	2%	2%
6:45	7%	0%	3.4%	30%	25%	28%
7:00	12%	2%	7.2%	38%	47%	43%
7:15	42%	6%	23.8%	107%	98%	103%
7:30	55%	25%	40.0%	67%	85%	76%
7:45	70%	46%	58.0%	30%	49%	40%
8:00	72%	54%	63.4%	1%	41%	21%

We applied the same calculation process for mid-day and evening peak periods to derive the best S_S compliance with this study's objective. Table 5 shows the selected S_S under each criterion for door-to-door trips.

Table 5: Selected S_S for Door-to-door Trips

Peak Period	**Objective 1 (Max Number of Trips)**			**Objective 2 (Max No. of Trips/ Trip-hrs)**			**Final S_S for W_{120}**
Criteria	**Criteria 1**	**Criteria 2**	**Best S_S**	**Criteria 3-1**	**Criteria 3-2**	**Best S_S**	
Morning Peak 5:00 - 8:00	6:30 (27%)	6:45 (38%)	6:30	6:00	6:00	6:00	**6:30**
Mid-day Peak 11:00 - 14:00	13:00 (17%)	12:15 (24%)	13:00	11:00	11:00	11:00	**13:30**
Evening Peak 15:00 - 18:00	17:00 (9%)	16:45 (16%)	17:00	15:00	17:00	17:00	**17:00**

To determine the peak W_{120} for motorised trips, the same analysis process was conducted for the motorised trip transfers. Here, 22% of the door-to-door trips in CMR area were dropped since no motorised mode was used for transfers. Some of the trips contained with both motorised and non-motorised modes with transfers especially in transit trips. Therefore, the second phase of the analysis included only the motorised transfers of such trips. Also, waiting times captured in HVS data were filtered and dropped during the CUBE voyager scripting for the matrix manipulation. Table 6 below shows the resulted **S_S** at W_{120} for all three peak periods of a day.

Table 6: Selected S_S for Motorised Trip Transfers

Peak Period	**Objective 1 (Maximum Trips)**			**Objective 2 (Minimum Trips/ Trip-hours)**			**Final S_S for W_{120}**
Criteria	**Criteria 1**	**Criteria 2**	**Best S_S**	**Criteria 3**	**Criteria 4**	**Best S_S**	
Morning Peak	6:30	6:45	6:45	6:15	8:00	8:00	6:30
Mid-day Peak	13:15	12:30	13:15	11:00	11:00	11:00	13:30
Evening Peak	17:00	17:00	17:00	03:00	18:00	18:00	17:00

5. DISCUSSION

Analysis of the study reveals that around one-fourth (27%) of daily demand remains only within the W_{120} from 6.30 AM to 8.30 AM. The same time window contains more than one-third (37%) of daily demand under trips-in-motion. By considering all together, the three W_{120} derived in this study consist of 52% of trips. Also, 78% of door-to-door trips are trips in motion. Therefore, this suggests that improving the TDM with the time-of-day application will provide more accurate results in temporal variations.

In the second phase of the study conducted for motorised trips, 55% of the total motorised transfers were located only within the derived three W_{120}. Above value was distributed as 29%, 15% and 11% for the morning, mid-day and evening peak periods respectively. Further, 74% of the motorised trip-transfers touched or laid within the derived three W_{120}. An interesting finding was that door-to-door trips show almost similar distribution to motorised transfers in term of temporal distribution. Finally, that was proven by obtaining the same periods for W_{120} under both door-to-door and motorised mode transfers. This study's derived result show many similar patterns to peak-periods reported by CoMTran, reported as 7 - 8 AM, 1 - 3 PM and 5 - 7 PM and containing 55% of the daily trips [16].

Compared to the morning peak, the mid-day and evening peaks W_{120} did not comply with all criteria. This was shown in Figure 2, by flattening in the curve during mid-day and more flattening in the evening peak period. Instead of limiting to two-hour intervals (W_{120}), we recommend covering mid-day and evening peak periods with longer time windows. Table 7 compares this study's results against the time windows in departure time and arrival time basis determined for the same length. Similar to Figure 3, the derived peak time windows always lay between the departure time and arrival time basis.

Table 7: W_{120} for Three Approaches

Peak Period	Four criteria including trips-in-motion	Departure time	Arrival time
Morning	06:30 AM	06:15 AM	07:00 AM
Mid-day	01:30 PM	12:15 PM	04:15 PM
Evening	05:00 PM	05:00 PM	05:15 PM

However, industrial zones, administrative zones, educational zones might have trip scheduling that does not align with the time-windows derived in this study. A key effort in this study was to derive the time-windows precise to the entire study area. But passengers’ travel modes which influence trip-timing have not been considered.

6. CONCLUSION

The timestamp matrix is an aggregate representation of travellers' trip-timing in a macroscopic TDM. Deriving time windows using time matrix is suggested as an initial step to time-of-day model development. Since there are obvious three peak periods in CMR, the validity of daily trip tables is questionable in obtaining timely varying model outputs. Therefore, we recommend enhancing the four-step TDM in CMR with the time-of-day application. Advantage of the trips-in-motion concept is to determine the trips moving through a time window. This study's attempt is an initial step to simulate the third-dimension of a trip, which is called the temporal dimension of a TDM.

The method used in this study provides reasonable justification for derived time-windows with the portion on daily trips laying within the derived time-windows. In the research, the first phase was for the door-to-door trips and then repeated for filtered motorised trip transfers. Further, this study could be extended to many other aspects, such as mode, sub-regional, or purpose-specific analysis. The results of this study showing more rational values compared to the departure time and arrival time basis. Peak periods mentioned in the original TDM developed with the same database are almost similar to this study's results but not the same. CUBE Voyager Travel Demand Modelling Software was used for matrix manipulation is recommended as an excellent tool to formulate and develop the timestamp matrices.

Under the prevailing COVID-19 situation in the country, discussions on reducing crowding in public transport are underway. This paper reveals that 74% of the daily motorised trips move across peak periods totalling six hours. This study can be extended further to drive time windows longer than two hours. That congestion is moving towards the Central Business Districts (CBD) in the morning and outwards in the evening is another critical feature in CMR which could also be incorporated as a future study.

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NETWORK CENTRALITY ASSESSMENT (NCA): ASSESSING THE TRANSPORT NETWORK RESILIENCE TO URBAN FLOODING

L.D.C.H.N. Kalpana [a], A B Jayasinghe [b]*, C C Abenayake [c] and P N P Wijayawardana [d]

[a,b,c,d] Urban Simulation Lab, Department of Town and Country Planning, University of Moratuwa, Sri Lanka

* Corresponding author E-mail address: amilabj@uom.lk

ABSTRACT

This study presents a methodology to assess transport network resilience to urban flooding. The proposed methodology is developed based on the centrality measures and graph theory. The study utilises Open-Source GIS tools to compute betweenness and closeness centrality values. The case study was carried out in Greater Colombo - Sri Lanka, with reference to three significant urban flooding events in 2010, 2016, and 2017. The study assessed the resilience of road network in terms of topological impacts and accessibility changes.

The results revealed three key findings. First, over 60% of road network revealed a significant change in its topological structural coherence during each flooding event. This was particularly pronounced in vehicular movements relative to pedestrian movements. Second, the study revealed a redundant depreciation of the transport accessibility as it shifted from city centre to peripheral areas creating temporary accessibility hotpots in the periphery. Third, a significant drawback of the resilience of road network was identified in terms of the deviation from the shortest path, increasing the travel time and trip length. In overall, the study concluded that the proposed methodology can be utilised as a planning and designing tool to assess road network`s resilience devising precautionary measures to mitigate disaster risk.

Keywords: *Urban Flood, Transport Planning, Network Centrality Assessment, Open-Source GIS, Transport Network.*

1. INTRODUCTION

Flooding is considered one of the most destructive natural hazards in both local and global contexts which impacts urban livelihood in multiple ways [1]; [2]. According to the World Meteorological Organisation (WMO), 47% of flood and storm-related events have affected 2.3 billion people in the world during the decade from 1995 to 2015 [3]. Therefore, mitigating flooding impact and making cities safe and resilient has been a widely discussed subject in major global agendas, particularly when examining how to make cities more inclusive, safe, resilient, and sustainable, notably under Sendai Framework for Disaster Risk Reduction 2015-2030, the Sustainable Development Goals (SDG) for 2030 and the World Humanitarian Summit Commitments to Action and the New Urban Agenda [4].

In the urban context, flooding impacts built environment, land, properties, and population; thus defined as urban flooding [5], [6]. It severely impacts the transport system, disrupts the flow of essential services and weakens the accessibility of the residential population in urban areas [7]. Extreme rainfall or uncertainties, an agglomeration of population, unplanned urban development, increasing imperviousness and poorly maintained drainage systems lead to frequent flooding causing damage to surface infrastructure and disruption to transport networks in urban areas [8], [9]. However, in the contemporary urban development process, evaluation of flooding impact on transport system is usually a micro-scale in-situ impact assessment. This severely underestimates and misrepresents the actual flooding impact and causes the failure of disaster-resilient measures [10], [9]. An alternative framework, therefore, becomes necessary to access transport network resilience in a holistic and reliable manner.

Transport networks feel the immediate impact of flooding because roadways become the preferred path for storm water to flow. leading to fast inundation. Thus, it may cause accessibility breakdowns within the urban system. However, considering past urban flooding events in the Western Province in Sri Lanka (refer to Table 1), the impact on the transport system appears considerably low (impacted on less than 5% from the entire transport network of the Western Province). As the transport system is an interconnected network, a failure in one road segment may impact the transport flow of the entire network. This is an aspect that may not have been adequately quantified in recent studies [9], [11]. Further, knowledge regarding the behaviour of transport systems under flood conditions provides deep insights into the development of disaster resilience measures for cities.

Hence, this study attempted to consider the transport network as a holistic interconnected system, and to apply the Network Centrality Assessment (NCA) method to estimate the transport system's resilience in coping impacts from urban flooding.

Table 1: The impact of major flooding events on the transport System in the Selected Area.

The year of Flooding Event	Inundated Road Length by Type			Inundated Road Length as a % of total Road Length		
	A Class	B Class	Other Roads	A Class	B Class	Other Roads
2017	4,823m	4,125m	64,097m	1%	0%	1%
2016	6,814m	4,761m	86,074m	2%	1%	1%
2010	8,493m	6,958m	117,821m	3%	1%	1%

A number of recent studies have been examining the impact of flooding on the vulnerability of road networks with reference to traffic speed, travel time, inundation area, flood depth, and level of accessibility. The existing flood impact assessment methods can be categorised into four approaches: scenario-based, strategy-based, simulation-based, and mathematical model-based [12], [13]. Additionally, some studies have developed vulnerability indices for anticipated flooding events [8], [14]. This paper has focused on simulation-based approaches. Under simulation-based approaches, existing studies have employed several simulation tools including GIS-based applications, SWMM, City CAT, Spatial Importance Measure (SIM), Macroscopic Fundamental Diagram (MFD) etc. [15], [16]. A few of the recent studies have utilised advanced computational assessment methods based on Machine learning algorithms [17], [18].

Road networks perform a crucial role during emergency flood situations, ensuring accessibility to amenities, and providing alternative pathways avoiding inundation areas (flood preventive route options). But lack of studies about the resilience of transport networks in real case studies with extreme flooding events. In the era of Anthropocene, where climate change and environmental degradation have become a reality, planning for infrastructure resilience, particularly for transport networks, has become a national and worldwide imperative in recent years [19]. In order to fill this gap, this research developed a methodology to assess the transport network's resilience for urban flooding utilising the Network Centrality Assessment (NCA) tool [20], [21], [22]. The case study was carried out in Colombo, Sri Lanka. The analysis was primarily based on free and open-source geospatial software. The study conceptualised the impacts of urban flooding on the transport system as a three-dimensional concept as depicted in Figure 1.

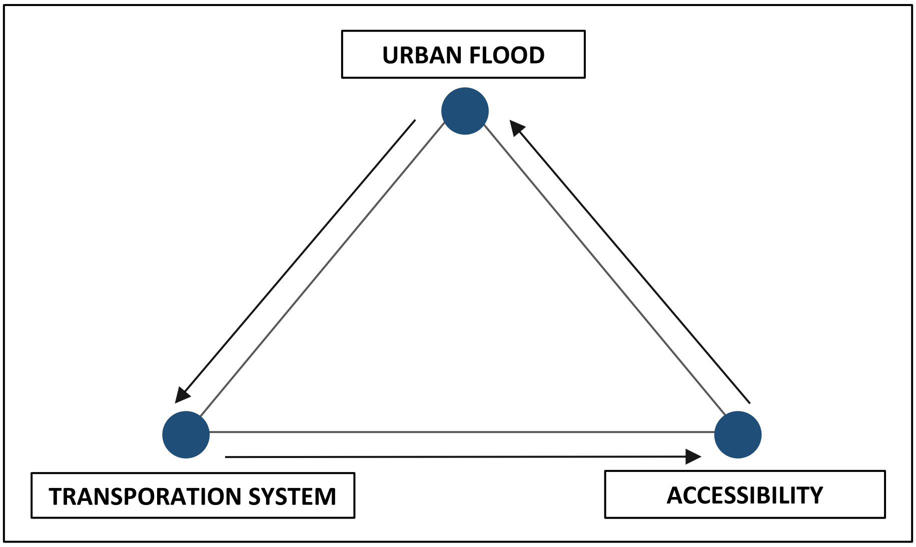


Figure 1: Conceptual framework of the study

The main objective of the research is to develop a methodology to assess the transport network's resilience to urban flooding. The study first investigates the changes in topological characteristics of road networks due to flooding, then investigates the changes to the relative importance of road segments under flood-inundated situations, and finally, proposes a framework to assess the transport networks' resilience for urban flooding.

1.1 Network Centrality Assessment

The concept of 'Centrality' originated in the 19th century as a concept explaining the interactions and interrelations of systems [23]. Network Centrality was developed based on graph theory and frequently applied to assess the transport system's accessibility [21], [24], [22]. In classic urban geography, network centrality was applied to measure the attraction and interaction of each node in a road network based on topological and geometric properties [25]. Currently, the concept has been extremely successful and permeated the methodologies employed for a myriad of urban models for measuring accessibility [26]; [27]. Therefore, this study utilised the network centrality to assess the transport network's resilience to the urban flooding.

In order to assess the transport network's resilience for the urban flooding, this study utilised two NCA parameters, which can measure centrality in terms of topological characteristics of the transport system.

First, this study utilised closeness centrality (CC) [23] parameter to measure the relative impact on each road segment in terms of accessibility (i.e., the attraction to trip destinations) during the flood-inundated situation compared to the baseline situation.

$$CC_{i_{[r]}} = \frac{(N-1)}{\sum j \in N, j \neq i d_{ij}} \qquad (1)$$

Wherein,

CC_i : Closeness centrality of the road segment 'i'

N : The total number of segments in the road network

d_{ij} : The shortest path distance between road segments 'i' and 'j'

r : The radius of influence of the road network

Secondly, the study utilised the betweenness centrality (BC) [23] parameter to measure the relative impact upon each road segment in terms of the attraction of pass-by trips during the flood-inundated situation compares to the baseline situation.

$$BC_i = \frac{1}{(N-1)\,(N-2)} \sum_{j,k \in N; j \neq k; k \neq i} \frac{P_{jk_{(i)}}}{p_{jk}} \qquad (2)$$

Wherein,

BC_i : Betweenness centrality of the road segment 'i'

N : The total number of segments in the road network

P_{jk} : The number of geodesics between road segments 'j' and 'k'

$P_{jk\,(i)}$: The number of geodesics between road segment 'j' and 'k' that passing through road segment 'i'

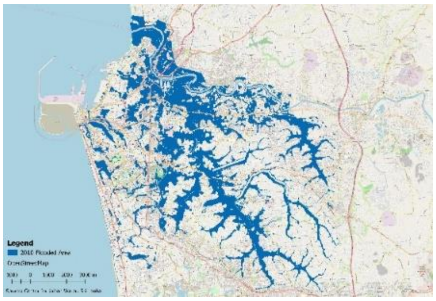
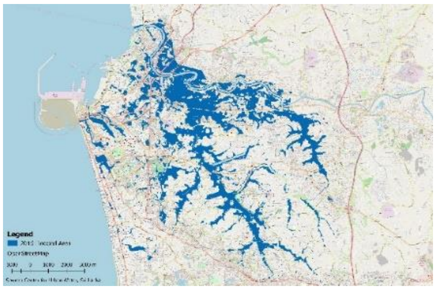
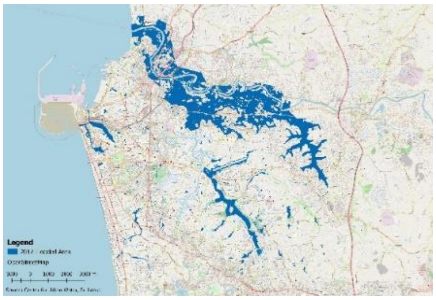
In order to compute the above-discussed network centrality parameter, the study utilised the transport data extracted from the Open Street Map (OSM). Further, the study utilised sDNA toolkit [28] to carry-out the network centrality assessment under the Qgis (Quantum Geographic Information System) environment. The detailed steps are discussed under the methodology section of this paper.

2. METHODOLOGY

2.1 Study Area

In order to assess the transport network's resilience for urban flooding, the study area was selected as the 40km buffer zone of the Colombo Core Area, which is severely affected by urban flooding incidents. The selected area consists of a highly-urbanised zone and covers 2260 sq km of land area with an approximate population of 4.7 million [29]. The selected area consists of two major rivers (i.e., Kalani Ganga and Kalu Ganga), and a stream (i.e., Aththanagalu Oya). Those water bodies caused heavy flooding every rainy season. The study only included three significant flooding events considering the spatial data availability. Table 2 depicts the characteristics of the selected flooding events.

Table 2: The characteristics of the Selected Flooding Events.

Flooding Event	Impacted Area	Affected Population in the study area	Flood Inundation Area
17th May, 2010	41 Sq.km	91,000	
15th May, 2016	32 Sq.km	228,871	
25th May 2017	22 Sq.km	21,000	

Source: Author compilation based on Center for Urban Water (CUrW) Database.

2.2 Description of Data

The data used for the study is summarised in the Table 3. The study completely utilised open-data as it is financially affordable in developing countries.

Table 3: Data Description

Data Type	Year	Source	Description
Road Network	2020	Open Street Map, (OSM)	GIS File (Polyline)
Flood Maps	2010, 2016 & 2017	Center for Urban Water, Sri Lanka, (CUrW)	Image Files (JPEG)

2.3 Study Framework

The study utilised the above-mentioned transport network to calculate the network centrality. The study assessed the transport network centrality considering two scenarios as (i) road network at the baseline situation, and (ii) road network under the flood-inundated situation. The overall method of study is depicted in the Figure 2.

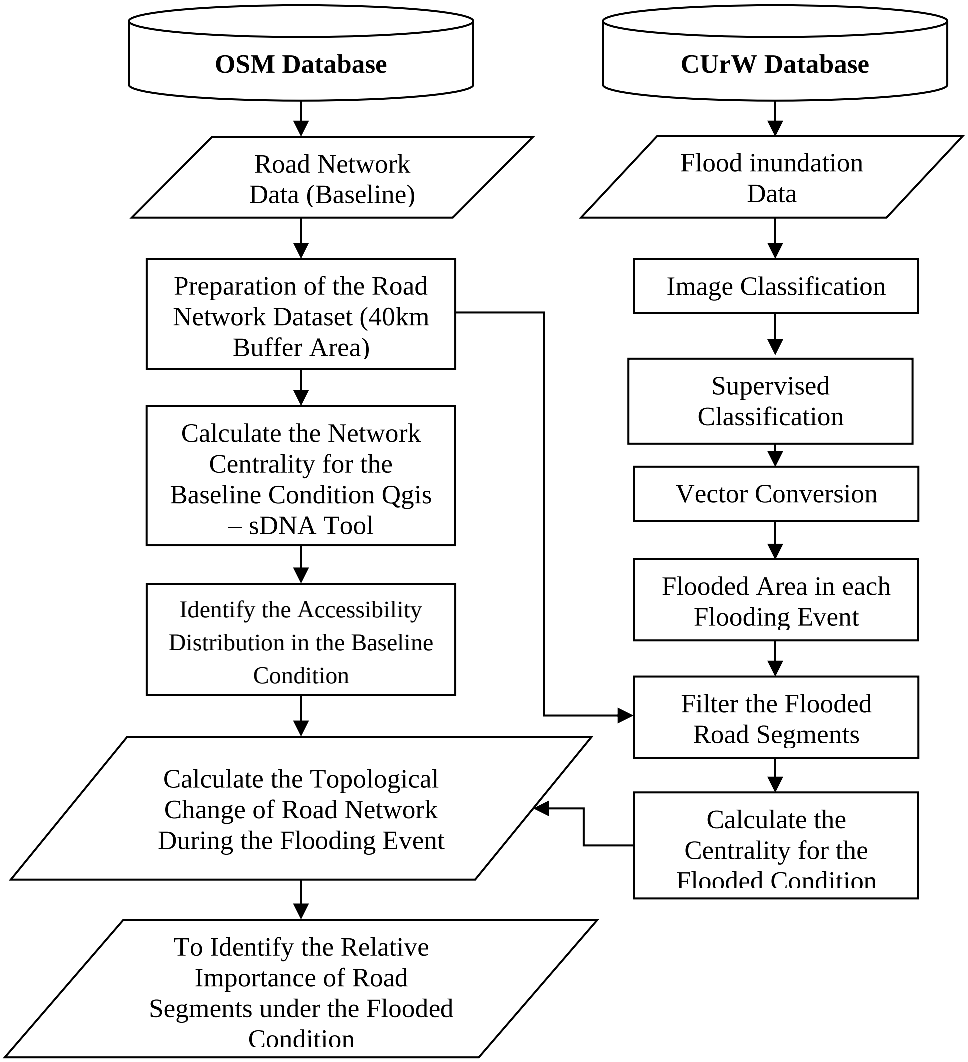


Figure 02: Study Framework

2.4 Computation of Network Centrality

The study utilised the Spatial Design Network Analysis (sDNA) tool [30] in Qgis environment to compute BC and CC. This study utilised 'road-segments' graph method [31] to convert the real road network into the network graph. In the road-segments graph method, the road segments are termed as 'links' and the road intersections are termed as 'nodes'. In preparation of the graph, the study utilised 'road centerlines' (i.e., vector line data that represent the geographic centre of the rights-of-way of a given road segment). In the graph, segments represent the physical locations of trip origins and destinations. The study considered two influence areas as r=1km and r=10km to capture pedestrian movements and vehicular movements respectively.

3. ANALYSIS AND RESULTS

After obtaining the network centrality results, the study analysed the topographical change of the road network and accessibility change of the road network during each flooding events.

3.1 Topographical Change of the Transport System

In order to study the topographical change of the transport network due to the flood, the study computes the change of road centrality under each flood event and compared it with the baseline situation. The study utilised Python programming language to calculate the change between the flooded condition and the baseline condition. It helps to process large size databases efficiently compares to the Microsoft Excel or GIS applications.

When considering the pedestrian movement (refer to Table 4 below), flooding directly impacts only 3% - 7% of the road segments from total road length. However, more than 40% of road segments recorded changes in closeness centrality values due to the flood. Therefore, results indicate that, even though the direct physical impact to the road network is less, the flooding event has significantly decreased the road centrality by disconnecting the shortest paths which are connected origin and destination, (i.e., O-D) trips of pedestrian movement in the network. Hence, it severely impacts to decrease the level of accessibility of the entire transport network by more than 25%. Further, it caused to reduction in the BC by more than 23% of the road network. It made a significant impact on the pass-by road segments that are utilised by the pedestrians.

When considering vehicular movement (refer to Table 4 below), more than 90% of road segments have recorded centrality changes due to flood. It is mainly caused in the long-distance travel failures due to the decline of CC and BC values. In general conditions, a majority of trips are generating in the suburban and peri-urban areas and then move towards to the CBD. Hence, failures of shortest paths in the daily transport routes may impact on the entire transport system significantly. This clearly indicates by the findings that even though the direct physical impact to the road network is less than 7%, it caused to reduce around 60% of betweenness and closeness centrality from the transport network. Moreover, this decline of CC values impacted on the O-D trips in the transport network. Further, the decline of BC values impacted on the pass-by trips in the transport system.

Table 4: The Network Centrality Change by Flooding Event.

Type	Measure	Flood Event	Increase Centrality	Decrease Centrality	Total Change	No Change	Flooded Road Segments in terms of length
Pedestrian Movement (1Km)	CC	2010	2810 (16%)	4658 (26%)	7468 (41%)	9377 (52%)	1204 (7%)
		2016	2818 (16%)	4896 (27%)	7714 (43%)	9385 (52%)	950 (5%)
		2017	2816 (16%)	5081 (28%)	7897 (44%)	9543 (53%)	609 (3%)
	BC	2010	2587 (14%)	4195 (23%)	6782 (38%)	10063 (56%)	1204 (7%)
		2016	2600 (14%)	4426 (25%)	7026 (39%)	10073 (56%)	950 (5%)
		2017	2636 (15%)	4569 (25%)	7205 (40%)	10235 (57%)	609 (3%)
Vehicular Movement (10km)	CC	2010	6801 (38%)	10044 (56%)	16845 (93%)	0	1204 (7%)
		2016	6884 (38%)	10215 (57%)	17099 (95%)	0	950 (5%)
		2017	6799 (38%)	10641 (59%)	17440 (97%)	0	609 (3%)
	BC	2010	5908 (33%)	10562 (59%)	16470 (91%)	375 (2%)	1204 (7%)
		2016	6114 (34%)	10603 (59%)	16717 (93%)	382 (2%)	950 (5%)
		2017	6241 (35%)	10829 (60%)	17070 (95%)	370 (2%)	609 (3%)

In addition to the statistical analysis, the study also measured flood impact to the transport system as a spatial representation as depicted in Figure 3 below.

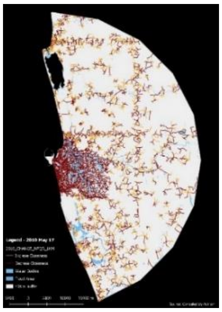
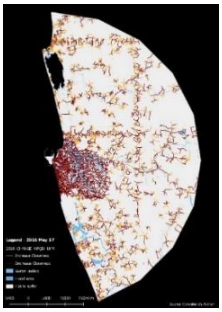
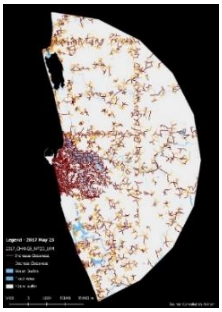
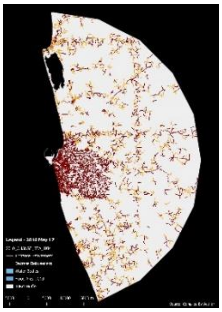
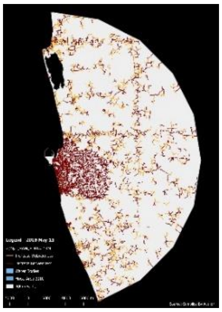
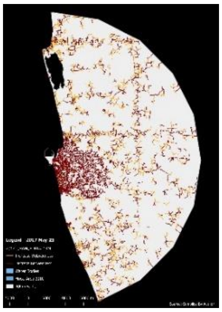
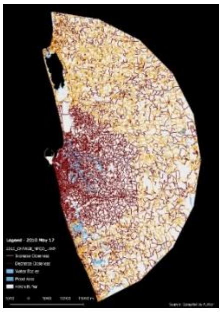
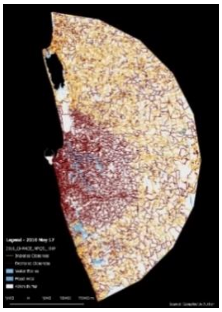
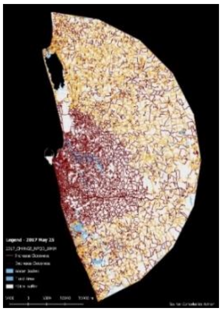
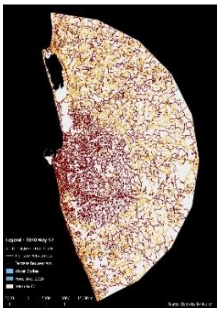
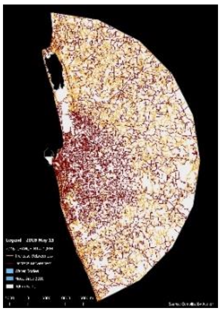
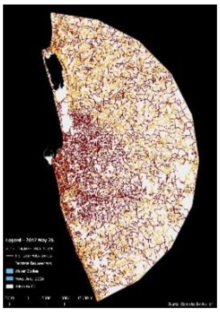
	Spatial Change of Closeness and Betweenness Centrality			
		2010 May 17	2016 May 15	2017 May 25
Network Centrality Change of Pedestrian Movement (1Km)	Closeness Centrality			
	Betweenness Centrality			
Network Centrality Change of Vehicular Movement (10Km)	Closeness Centrality			
	Betweenness Centrality			
Legend	Increase CC & BC	Decrease CC & BC	Water Bodies	40Km Buffer

Figure 3: Topographical Change of Closeness and Betweenness Centrality Measures in Pedestrian & Vehicular Movement

As depicted in Figure 3, in the vehicular movement failure of road segments significantly impacts to the entire transport system because in the long-range entire transport system function as an interconnected system. Therefore, it clearly proved that the impact of the urban flood affects the entire transport system in a significant manner.

3.2 Accessibility Change of the Transport System

The study further evaluates the accessibility changes of the transport system due to urban flooding events.

It is important to notice that, in the baseline condition accessibility is predominantly concentrated in CBD area and then gradually trickles down towards the suburban areas through major arteries (Figure 4 – Left). But, with flood temporal accessibility hotpots have emerged in the outer areas, (i.e., suburban and peri-urban areas) of C where have relatively good accessibility during the flooding condition (Figure 4 – Right). Thus, these potential locations can be identified as potential areas for the disaster resilience. Also, these locations are ideal for enhancing facilities and infrastructure to provide adequate service during the flooding events in the future scenarios. However, validating this argument requires further studies regarding the socio-economic, transport and other infrastructure capacities of those temporal accessibility hotspots to understand the functional capability because, this study only focused on the accessibility change of the transport system.

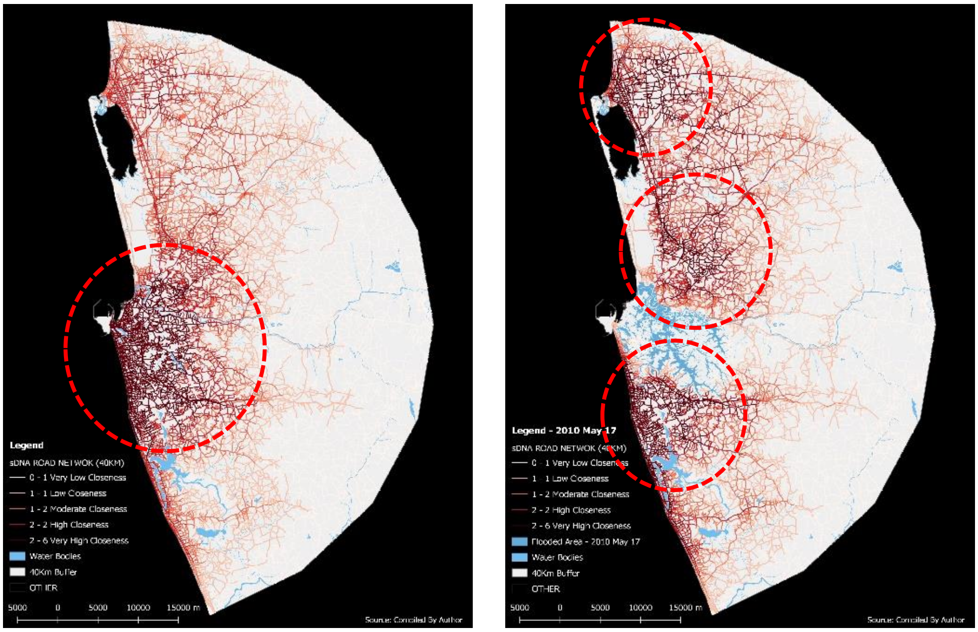
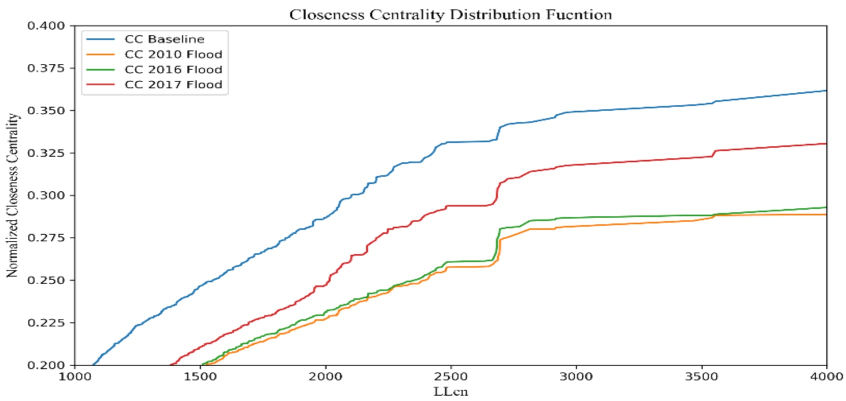


Figure 4: Accessibility concentrated of In Regular Situation (Left side). Emerging temporal accessibility hotpots due to the flood (Right side)

Further, the study considered the statistical distribution of network centrality parameters in the baseline and the flooding events. The study normalised the centrality values of each flood event and distribute them according to the length of the individual road segment (LLen) as depicts in the figure 5. It denotes that in the baseline condition both centrality parameters are significantly higher. However, when it comes to the flooding situations CC value declines from 0.350 (Normalised CC value) to 0.325. Also, the figure denotes, extensive impact on road accessibility in the year 2010 as it covers the 41sq km and declined accessibility up to 0.275. The most significant identification of the graph can be noticed in the tail of the distribution because in the lower scale all the lines are growing in a similar manner and when it comes to the tail it shows a very dynamic distribution. This mainly caused the flooding impact to the larger road segments are significantly impacted on the decrease of road centrality. Further, this considerably higher in the betweenness centrality as the loss of shortest path roads segments significantly impact to the pass-by movements of the transport system (refer Figure 5).



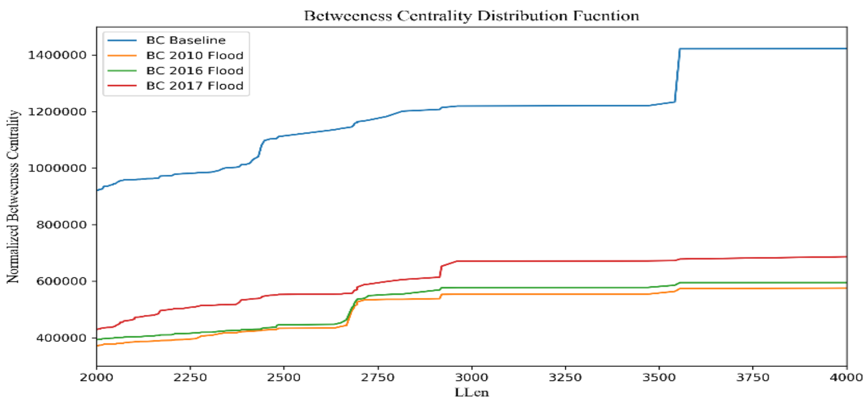


Figure 5: Closeness Centrality (Above) and Betweenness Centrality (Below) Distribution Function (Display Only the Tail of the Distribution)

4. DISCUSSION AND CONCLUSION

The study was intended to assess the transport network's resilience to the urban flooding by utilising an NCA-based approach. The study utilised two centrality parameters: (i) Closeness and (ii) Betweenness centrality to measure network the centrality of a given road network under two different scenarios as the baseline scenario and flood-inundated scenario.

The study discussed the impact of flooding on pedestrian movements and vehicle movements respectively. It was revealed that the impact of flooding is more significant over the vehicle movement as it affects the entire transport network. As revealed through the closeness centrality variations, urban flooding caused a temporal shift of the accessibility, particularly from central business districts (CBD) towards the periphery due to the inundation of road segments. As the peripheral road segments found to be more redundant, the study suggests that improving the infrastructure facilities and services of peripheral areas may help to provide adequate services during the future flooding events. Under the betweenness centrality, it was measured the transport network's resilience, particularly referring to the pass-by (intermediate) trips over road segments. Thus, it was identified a significant drawback of the resilience of road network in terms of the deviation from the shortest path, increasing the travel time and trip length. Therefore, the study emphasised the requirement of a holistic approach in order to enhance the flood resilience of road networks focused on the failure of critical road segments which may affect the entire network.

Future research on this domain may focus on testing the applicability of the proposed method for the other localised natural hazards such as landslides and tsunami in assessing the transport network's resilience. Further, it would be interesting to customise the assessment incorporating the relative importance of road segments in terms of access to other critical infrastructure and evacuation shelters (i.e., hospitals, stations, schools, etc.).

the proposed methodology can be employed to enhancing disaster resilience of road networks, particularly in planning and designing road networks, capacity improvements, and retrofitting of structures.

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REVIEWS

REVIEW

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COLOMBO SUBURBAN RAILWAY PROJECT: REVIEW OF THE FEASIBILITY STUDY AND PROPOSAL FOR THE WAY FORWARD

Tilak Siyambalapitiya

Managing Director, Resource Management Associates (Pvt) Ltd, and
Former Chief Engineer (Planning), Ceylon Electricity Board, Sri Lanka

1. INTRODUCTION

Upgrading the railway network for faster travel, modern rolling stock and passenger facilities is a long-felt need. The Government made a policy decision in 2015 to upgrade and electrify the network serving the suburbs of Colombo, and a project by the name "Colombo Suburban Railway Project (CSRP)" was established in 2016 under the Ministry of Transport. By way of the existing network, the logical nodes of CSRP may be identified as Colombo-Polgahawela (main line), Colombo-Kalutara South (coastal line), Colombo-Avissawella (Kelani valley line) and Ragama-Airport-Negombo (Puttalam line). The distant nodes approximately reflect the boundaries of the Western Province.

CSRP published feasibility study reports in 2019 (for Kelani Valley line [1]) and in 2020, for main, coastal and Puttalam lines [2]. The reports are available in the public domain, and CSRP from time to time, invited public comments on their contents. However, there are no reports of any public comments being accommodated or revisions being made to CSRP designs.

Figure 1 shows the layout of the Colombo Suburban Railway Project as it is conceptualised at present (2021) by the Ministry of Transport. CSRP defines Rambukkana (on the Main Line), Kalutara south (on the Coastal Line), Negombo (on the Puttalam Line) and Avissawella (on the KV Line) as the end nodes of the suburban railway network of Colombo.

Figure 1: Colombo Suburban Railway Network Proposed to be Upgraded and Electrified

Source: www.csrp.lk

The Light Rail Transit (LRT) project, widely in discussion since 2015 plans to build four lines, mostly elevated, exclusively for passenger transport, serving the immediate suburbs of Colombo. In contrast, CSRP specifically addresses the long-felt need to improve the efficiency of the *existing* railway network, using - to a large extent - the *existing* right of way. The LRT requires a passenger market to be developed, whereas CSRP already has no less than 200,000 passenger trips per day within the CSRP zone and offers added benefits to longer distance passengers passing through the suburban sectors.

Railway investments are typically not financially viable: there cannot be a viable business that makes profits by building railway infrastructure, purchasing rolling stock and operating a passenger service. However, just as any other public investment, they should be economically viable: for example, building CSRP may not make Sri Lanka Railways a profitable entity but CSRP should bring in adequate economic value to the country by way of fuel saved (diesel replaced with electricity, and overall technical and commercial efficiency), avoided investments on roads and vehicles, and faster travel times. If economic benefits too are uncertain or inadequate, then such a project should be redesigned to make it economically viable or should otherwise be abandoned.

This paper reviews the coverage, content, basic accuracy and conclusions of the four feasibility study reports of four sectors of CSRP. The publication of the feasibility study reports was preceded by several other related studies: A Proposal for Railway Electrification, 2008, by the Institution of Engineers, Sri Lanka [3]; KV line alternatives study, 2017[4] by CSRP, and Panadura-Veyangoda Initial Feasibility Report, 2018 [5] by CSRP. The paper also summarises the design features as proposed by the consultants to the Ministry of Transport as of end 2020. It explains the required improvements to the design, costing and economic evaluation, to ensure the planned investments yield the expected economic benefits, without becoming yet another liability on the already-constrained national economy. Design features are discussed for each of the four lines, whereas costing and economic evaluation are discussed in overall consideration for all lines. Finally, the paper presents a feasible action plan for more rigorous study and costing to ensure the project makes economic sense.

2. WHICH LINE FIRST?

The preliminary study in 2008 by IESL [4], identified the Panadura-Colombo-Veyangoda as the sectors to be electrified first. This was on the basis that 43% of all trips on the entire railway network originated and terminated between Panadura and Veyangoda. Resumption of services to Kankesanthurai and Thalaimannar in 2012 may have slightly lowered this ratio. Using a simplified scoring system, the study compared Panadura-Veyangoda, Kalutara South-Veyangoda and Colombo Fort-Polgahawela in terms of their relative merits and recommended that Panadura-Veyangoda be prioritised. The study therefore focused on serving *existing* passengers to be the highest priority. This strategy involves the least uncertainty in terms of forecast passenger numbers and financial/economic benefits. Considering that railway electrification is a relatively new concept in Sri Lanka (although widely and successfully used all over the world), the study recommended a sector of shorter length, proven passenger patronage, a higher passenger share and a higher passenger density, to be electrified first. This was to demonstrate the feasibility of the technological improvements and to gather public support, which is essential for an infrastructure project to serve a large number of people, using public funds.

Table 1: Ranking of Possible Sectors to be Electrified

	Sector Starts	Sector Ends	Sector length (km)	% of psgrs served	Psgrs per month per km	Rank in Distance	Rank in Passenger share	Rank in Passenger density	Sum
1	Panadura	Veyangoda	63.4	43%	58,233	3	2	3	8
2	Kalutara South	Veyangoda	79.0	48%	52,430	1	3	2	6
6	Fort	Polgahawela	73.8	39%	45,462	2	1	1	4

Source: A Proposal for Railway Electrification, The Institution of Engineers, Sri Lanka, June 2008 [4]

Table 1 above summarises the perception at that time. Equal weighting factors were given for the three criteria (a) distance (longest =1, shortest =3), (b) share of passengers served (lowest=1, highest=3) and (c) passenger density (lowest=1, highest=3)

EGIS, the consultants to the Ministry of Transport, in the pre-feasibility study on the development of Panadura-Veyangoda [5], confirmed the following:

(i) the internal passenger trips within the section is 50% of the total passenger trips in Sri Lanka Railway,

(ii) the total passengers using the Panadura-Veyangoda corridor (including long distance passengers and transfers from other lines) amounted to 309,400 per day in 2016, representing 89% of the total railway passenger trip count of 371,800.

These two features present a strong case to suggest that the Panadura-Veyangoda sector should be the first to be upgraded and electrified, subject to financial and economic justification.

In contrast, the Final Feasibility Reports of main, coastal, KV and Puttalam lines have worked out forecast passengers for each line. Forecasts were reported for milestone years 2025 and 2035.

Table 2 shows the passenger data for 2016 (ie at the time feasibility studies commenced) and the forecasts presented in the feasibility studies conducted by consultants to the Ministry of Transport.

Analysis of actual and forecast information reveals the following important features:

(a) **Line with highest passenger density**: Colombo-Veyangoda (or Colombo-Rambukkana) sector has the highest number of passengers using the peak section.

(b) **Number of trains required to serve the peak**: This depends on the number of passengers in the peak hour in the peak direction. The feasibility study states that this grows by more than 10 times on the KV line (compared with 2016), once the proposed upgrades and electrification is completed. For the other three lines, the baseline figures in 2016 have not been reported.

(c) **Share of population in the catchment area taking a daily train ride**: Studies report that in 2016, about 5% of the population in the Divisional Secretariat (DS) divisions served by CSRP take a daily train ride. CSRP studies forecast that this ratio will increase to 21% by 2025, once CSRP is implemented.

Considering that the population in the catchment is about 50% of the population in the Western province, the forecasts imply that about 10.5% of the entire population of the Western province will take a CSRP train ride every day.

Table 2: Actual and forecast passengers after implementation of CSRP

Line	Sector	Sector length (km)	CSRP: Forecast passengers per day in both directions in the peak section			CSRP: Forecast passengers at peak hour in peak direction			Source
			2016 (actual)	2025	2035	Actual (2016)	2025	2035	
Main	FOT-VGD	37.5	175,400[a]	539,000	589,000	Not stated	Not stated	Not stated	E
	FOT-RBK	83.0		419,405	501,603		43,618	52,167	D20
Coastal	FOT-KTS	41.8	106,000[a]	364,200	439,198		37,877	45,677	D20
PTM	RGM-NGB	23.2	Not stated	175,744	213,436		18,278	22,197	D20
KV	MDA-HMA	26.5	23,000[a]	224,508	371,318	1,638[a]	15,985	26,438	E
	MDA-AVS	61.1		176,969	201,662		18,405	20,973	D20

Line	Sector	Sector length (km)	CSRP: Forecast passenger trips per day			Source
			2016 (actual)	2025	2035	
Main	FOT-RBK	83.0	Not stated	500,516	566,839	D20
Coastal	FOT-KTS	41.8	Not stated	504,587	597,074	D20
PTM	RGM-NGB	23.2	Not stated	203,023	248,311	D20
KV	MDA-AVS	61.1	Not stated	273,566	365,731	D19
Total passenger trips		209.1	330,902	1,481,692	1,777,955	D19
Population in the DS divisions served by the network			3,067,346[b]	3,456,362[c]	4,302,189[c]	
Assuming all passengers make return trips, individuals forecast to be using CSRP as a share of population in DS divisions			5%	21%	21%	

[a] Reported by EGIS only, [b] for 2014, [c] Forecast at a growth rate of 1% per year. indicatively this population is about 50% of the entire population in the Western Province.

Source Abbreviations:
E: EGIS, 2018 D19: DHOWA, 2019 D20: DHOWA, 2020

Station Abbreviations:
FOT: Colombo Fort VGD: Veyangoda RBK: Rambukkana KTS: Kalutara South
RGM: Ragama NGB: Negombo MDA: Maradana HMA: Homagama
PTM: Puttalam AVS: Avissawella

In summary, the sector with the highest number of passengers is Colombo-Veyangoda, and the second highest is Colombo-Kalutara South. Assuming passenger growth forecasts in the feasibility studies reflect the reality, the passenger trips in CSRP will increase from 330,902 per day in 2016 to 1,777,955 per day in 2035, a five-fold increase.

By way of a target to be achieved through a major investment in the railway network and rolling stock, a five-fold increase to 1.7 million passenger trips per day appears to present a reasonable target. However, the following aspects require careful consideration to determine the investments which would bring best value for money invested:

(i) severe limitations in capital spending and borrowing,

(ii) uncertainties of government policies that may not facilitate growth in passenger trips, and

(iii) capital intensive nature of railway projects.

Therefore, prioritisation has to be within the framework of constraints.

The KV line admittedly has inadequate capacity which in turn causes a poor passenger turnout. Making the first major investment on Sri Lanka railways after nearly a century, based on assumptions (of passenger numbers on KV line increasing tenfold) when a ready complement of passengers is already available, using the Panadura-Veyangoda sectors leaving little room for imagination, carries an unwanted risk with public funds.

Therefore, it becomes evident that the move by the Ministry of Transport to prioritise the Colombo-Avissawella line (KV line) has no basis, other than, may be, the fact that the feasibility study on KV line was concluded one year before those of the other lines.

3. PROJECT OUTLINE

The CSRP plans to achieve much-delayed upgrading and modernisation of the suburban railway network, in the Western Province. It does not plan to open new rights of way or include major deviations of existing rights of way or tracks. Beyond minimal land acquisition to straighten curves or extend the lengths of station platforms, parking spaces for trains, passenger vehicles and workshops, CSRP will not acquire land to expand or extend the network.

In other words, CSRP aims to provide a more efficient service, using existing rights of way and assets to the best possible extent, investing only on essential upgrades necessary to achieve overall efficiency in terms of energy usage and service provision.

CSRP, as it is structured now, aims to:

(i) Upgrade and electrify the service in the double tracked sections of the suburban network i.e., Colombo-Rambukkana[1], Colombo-Kalutara-South[2] and Ragama-Negombo (inclusive of the airport branch)[3]

(ii) Upgrade and electrify the KV line; Colombo-Avissawella[4]

There are a few fundamental features that need to be understood about the existing railways and the upgraded network.

(a) **Sharing tracks**: Long distance trains (diesel) and electrified trains (suburban) will operate on the same tracks. In a few sections where there will be 4 or more tracks, the suburban service may have two dedicated tracks usually used, but all tracks will be enabled for both electric and diesel services.

(b) **Electrification**: In electrified sections, power will be supplied by an overhead catenary, a wire suspended above each track. All other operations, including signalling / communications, will be the same for both diesel and electric trains.

(c) **Electricity supply**: Trains will be supplied with electricity from the national transmission network, but not the local distribution network. When trains brake, part of the energy lost in braking will be converted to electricity and sent back to the grid. A suburban train typically recovers 30% of the electrical energy used for forward drive, by such “regenerative braking”.

(d) **Stations**: All station platforms will be standardised to 230 m and to the required height, to accommodate the standard electric multiple unit[5], enabling swift boarding and alighting.

Accordingly, the feasibility studies have been conducted by DHOWA Consultants, and completed in 2019 for the KV line, and in 2020 for main, coastal and Puttalam lines. The costs, benefits and economic viability, as reported in the feasibility studies are summarised in Table 3.

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[1] Present plans of CSRP do not include electrification of Veyangoda-Rambukkana section but specifies EMU services to Rambukkana. This requires correction.

[2] Present plans of CSRP are inconsistent about electrification, with some sections stating electrification being limited to Panadura, others stating up to Kalutara South, but EMU services planned up to Kalutara South. This requires correction.

[3] CSRP has not included the station at the airport terminal into the project. A new terminal commenced construction in 2020.

[4] Present CSRP plans propose passengers to Avissawella change to a diesel train at Padukka.

[5] an electric multiple unit or EMU consists of up to 12 cars, with two drive cars and 10 trailer cars. Depending on track curvature specifications, in the context of Sri Lanka, each car will be 15 m (KV line) or 20 m long (other lines within CSRP). Passenger information system, centralized door control and air conditioning are expected to be standard features of Sri Lanka’s future EMU fleet.

Table 3: Costs and benefits, as assessed in the published feasibility reports

Line	Sector	Sector length (km)	Investment (USD mn)	Investment (USD mn/km of route)	Economic benefits in 2025 (USD mn per year)	Economic simple payback period (years)	Benefit: cost at a discount rate of 9%
Main	FOT-RBK	83.0	1,319.7	15.9	202.6	6.5	2.09
Coastal	FOT-KTS	41.8	948.0	22.7	151.3	6.3	1.63
PTM	RGM-NGB	23.2	317.4	13.7	74.5	4.3	1.40
KV	MDA-AVS	61.1	1,424.3	23.3	577.4	2.5[a]	3.50[a]
Total		209.1	4,009.4	19.2			

Sources: Feasibility reports for main, coastal, Puttalam lines (2020) [2] and KV line (2019) [1]

[a] corrected to account for an arithmetic error in the report

4. PROJECT ECONOMIC AND FINANCIAL PERFORMANCE

Table 3 reveals that the KV line design by CSRP displays exceptional economic benefits, causing the economic simple payback period to be extremely attractive and the benefit to cost ratio at a discount rate of 9% to be 3.5, again a highly attractive index. Projects with such high economic benefits may also be viable for financing by the private sector, especially because the largest share of savings are stated to be in savings in vehicle operating costs. Therefore, the passenger forecast and economic benefits of KV line require more detailed analysis.

Table 4 shows the share of economic benefits for each line from each "type" of economic benefit.

Table 4: Types of economic benefits of each line in CSRP for year 2025

Line	Sector	Psgr trips per day[a] in 2025	Economic benefits in 2025 (USD million)					Economic benefit[a] in 2025 per pasgr trip (USD)
			Vehicle operating costs	Vehicle operating time	Accidents avoided	Emissions avoided	Total	
Main	FOT-RBK	500,516	190.0	11.2	0.5	1.0	202.6	1.1
Coastal	FOT-KTS	504,587	143.3	7.0	0.3	0.7	151.3	0.8
PTM	RGM-NGB	203,023	51.17	17.9	2.0	3.4	74.5	1.0
KV	MDA-AVS	273,566	420.0	110.4	17.4	29.6	577.4	5.8

Sources: Feasibility reports for main, coastal and Puttalam lines (2020) and KV line (2019)

[a] economic benefit owing to all passengers. Usually, the incremental benefit should be used

The forecast economic benefits of reduced vehicle operating costs are exceptionally large in the KV line, indicating that the number of passengers and the type of passengers moving from road to rail, to make-up the forecast 10-fold increase in passenger trips by 2025, are of exceptionally higher economic value. However, the essential requirements such as good and accessible parking facilities near stations, have not been specifically designated or included in project costs of KV line or any other line, but have only been stated as requirements.

Therefore, the passenger forecast and the economic value of cost and time savings, require a deeper evaluation for all lines, especially for the KV line. In case of the financial analysis, the feasibility study for each line concludes, as expected, that the project is not financially viable, meaning that the government should subsidise the project to facilitate its financial sustainability. For example, the government requires to subsidize the KV line to a level of about USD 55 million per year, to enable the KV line project to be financially viable, and that too, to achieve a poor financial internal rate of return (IRR) of 3%. Table 5 shows the government subsidy proposed to be paid to the CSRP in 2025 and 2035, continuing in increasing quantities throughout its life.

Table 5: Government Subsidy Required to meet CSRP's financial commitments

Line	Sector	Passenger trips per day in 2025		Government subsidy required (USD Mn/year)		Subsidy per passenger trip (USD)	
		2025	2035	2025	2035	2025	2035
Main	FOT-RBK	500,516	566,839	38.75	40.54	0.21	0.20
Coastal	FOT-KTS	504,587	597,074	32.43	33.73	0.18	0.15
PTM	RGM-NGB	203,023	248,311	12.66	13.5	0.17	0.15
KV	MDA-AVS	273,566	365,731	53.04	58.24	0.53	0.44
All		1,481,692	1,777,955	136.88	146.01	0.25	0.22

Sources: Feasibility reports for main, coastal and Puttalam lines (2020) [2] and for the KV line (2019) [1]

Here too, the KV line stands out, indicating that even with a forecast ten-fold increase in passengers, the KV line requires the highest continuing subsidy from the government per passenger trip.

5. RE-ASSESSMENT REQUIRED

The foregoing summaries of (i) investments and passenger forecasts, (ii) project economic benefits and (iii) subsidy requirements to make the project financially viable (though marginally), point to the need for a deeper review of the project, specifically on it costs and benefits. CSRP, as designed by the Ministry of Transport, concluding with feasibility study reports dated 2019 and 2020:

(a) plans to invest USD 4009 million, on the upgrade and electrification of all the four lines.

(b) forecasts that the ridership will increase from 330,000 (2016) to 1.5 million (2025) passenger trips per day.

(c) on the basis of forecast ridership in the peak hour in the peak direction, determined the number of train sets and the number of services required in the peak hour, and the structure of the line (at-grade or elevated)

As such, CSRP or any of its components will be the largest infrastructure investments ever proposed to be built in Sri Lanka. While increasing the ridership to 1.5 million trips per day is a remarkable target, it would be good to re-examine the project investments.

The project, if implemented as planned at present, will add USD 4000 million to Sri Lanka’s national debt. Therefore, project design, unit costs, scope of work and investments require to be investigated deeply and thoroughly by costing specialists, to ensure the project finally provides good value for money in public perception.

This paper therefore, examines only two out of many features of the CSRP that require even deeper analysis:

(i) Number of passengers per hour in the peak direction on KV line

(ii) Cost estimates, considering costs of station construction as an example

5.1 Number of passengers per hour in the peak direction on KV line

CSRP design assumes that by 2025, there will be 15,985 passengers per hour in the peak direction [5]. Subsequently, this has been increased 18,405 (DHOWA, 2019). Considering a ten-car configuration, each car 15 m long (to enable negotiating sharp curves on KV line; elsewhere in the network, the car length will be 20 m), each train can carry 1988 passengers. Accordingly, to serve the forecast peak, the feasibility study has calculated the highest frequency required would be 18,405/1988 = 10 services per hour or a six-minute headway between trains at peak.

Considering the lower growth scenario used in [5], the more prudent assessment would be 15,985/1988 = 8 services per peak hour, with the option of using longer train sets of 12 cars each. A twelve-car EMU on KV line would be 12 x 15 = 180 m long, and hence can be accommodated on the 230 m platforms specified for all stations. Thus, using a lower, more conservative estimate of 15,985 passengers served in the peak hour in the peak direction using 12 car train sets, the number of services required will reduce to seven, or most likely six, if time-of-use pricing (or similar demand management measure) is implemented. That means a headway of 10 minutes between trains in the peak hour.

CSRP has proposed that since a six-minute headway to provide 10 services in the peak hour will cause congestion at level crossings, the railway line from Colombo to Malapalla (a few km before Homagama) should be fully elevated. The assumption has been that all level crossings require to be closed for three minutes for a train to pass. The 3-minutes closure duration has been derived through observations of closure durations at a specific railway crossing in the UK [1]. However, such conditions cannot be generalised. With careful management of level crossings assisted by modern equipment, safety systems, smoother road surface and improved signalling, it is possible to limit the closure duration (ringing of warning bell to complete gate opening) to a maximum of 70 seconds. This duration is less than the present closure duration of traffic signals at many road crossings, whereas the remaining 8 minutes and 50 seconds until the next warning bell rings, is at least four times the opening duration of any existing road crossing. Therefore, the physical disturbance to traffic flow will not exceed the disturbance at any existing road crossing managed with traffic signals.

An additional concern of CSRP has been the potential conflict at level crossings near stations. Safety guidelines of Sri Lanka railways require a crossing immediately downstream of a station to be closed before a train approaches a station. With the planned stopping of thirty seconds at a station plus deceleration and acceleration duration, even the most efficient level crossing management near a station is likely to cause a total closure of two minutes and thirty seconds, thus making it longer than the closure duration of many existing traffic signals at road crossings. Sri Lanka Railways have historically used split platforms to overcome this problem, by stopping a train downstream of a level crossing. In this arrangement, up and down platforms will be split, each platform being located after the road crossing. In all stations, all platforms will anyway be interconnected with a passenger underpass, which in this case, can provide exits to road as well as allow roadway pedestrians too, to use the station underpass to safely cross the railway line, as a regular feature. Ramps for wheelchairs too can be arranged within the same underpass. It is obvious that the cost of extending the passenger underpass toward the split platform required at a station with an adjacent road crossing, would only be a fraction of the cost of USD 20 million for a road flyover. Cumulatively, the costs of such underpasses will be a fraction of the cost of elevating the entire KV railway line at a cost of USD 420 million and elevating 14 stations at a cost of USD 70 million.

However, CSRP has not considered these options, and to overcome the perceived congestion at level crossings, CSRP has proposed line elevation between Colombo and Malapalla, at an additional cost of USD 420 million plus USD 70 million for elevated stations, which is included in the cost estimate stated in Table 3. A closer examination of passenger forecasts and options to relieve congestion at level crossings, would significantly reduce this investment on elevating the lines and stations. The requirement is to provide a unique, cost-efficient solution to each road crossing. Solutions that should have been selectively considered are: (i) closure of the crossing, (ii) combining several crossings together, (iii) split platforms, (iv) shorter railway flyover, (v) road fly-over, (vi) cut and fill for railway, minor road fly-over. However, none of these lower cost options have been evaluated in the CSRP.

Another related concern is the approximately 1.8 km traverse through the Colombo golf links. Instead of proposing underpasses for golfers to move from the main golf course to the practice links across the railway line, the CSRP design considers it to be an added advantage to elevate the line across the golf course.

5.2 Excessive cost estimates

The costs for station construction estimated by CSRP was examined and cross-checked against recent station construction work done in Sri Lanka. While this paper does not attempt to make a detailed BOQ for a station (platforms, buildings and over or underpasses), it is clear that the use of typical costs of Sri Lanka indicate that all the stations can be built for about USD 38 million against USD 190 million estimated by CSRP. Detailed costing or a quantity surveyor's reports have not been provided in CSRP documentation.

Table 6: Potential savings of costs estimated for station construction

Line	Number of stations		Station construction: CSRP estimate (USD mn)	Typical Sri Lanka costs			
				LKR million			USD million
	Main	small		Main stations	Small stations	Total	Total
Main	14	24	57.1	1,400	1,200	2,600	13.7
Coastal	9	11	48.0	900	550	1,450	7.6
PTM	5	8	21.5	500	400	900	4.7
KV	12	23	64.4	1,200	1,150	2,350	12.4
Total	40	66	190.9	4,000	3,300	7,300	38.4

Basis: Main station: 100 Mn LKR; Small station: 50 Mn LKR. Exchange Rate: 190 LKR/USD

Therefore, large disparities are observed in CSRP cost estimates. Station construction costs were taken as an example to illustrate the potential disparities. A project of this nature and magnitude, would therefore require a more rigorous evaluation by cost estimators and quantity surveyors, as well as cost engineers, to evaluate options and present estimates with justification. The correct approach would be to use unit costs, based on Sri Lanka standard unit costs (for civil works) and internationally published unit costs for others.

6. A PROPOSED 10-YEAR DEVELOPMENT PLAN FOR EVALUATION

It is evident that the CSRP, as presently planned, requires numerous improvements. Only a handful of improvements so required, were explained in this paper. While Sri Lanka urgently needs a modern suburban railway network to provide a comfortable ride to existing passengers and to attract more passengers to train, the project requires to be designed with a cost minimisation objective as well. An excessive investment cost estimate is most likely to be rejected by the government or the financiers, including multilateral lending agencies.

A higher cost estimate, coupled with a high passenger demand forecast, can still make a project to appear to be economically viable. Banking large investments on high forecasts that so far do not indicate any trend is dangerous. Cautious assessment and taking small steps at a time, is the usual practice worldwide, when decisions require to be made amidst uncertainty.

Therefore, the present estimate of USD 4000 million investment to raise the daily passenger trips from the present 330,000 to 1.5 million by 2025, is unlikely to proceed, without major downward revisions to cost estimates. Such downward revisions should be preceded by similar downward revisions to estimates of passenger counts, which in turn would reduce cost estimates by requiring a smaller fleet of trains, avoiding unwanted track elevation to overcome perceived congestion at crossings, and reducing investments on maintenance infrastructure. In other words, the per cent reduction in estimated investments on CSRP will be higher than the per cent reduction in CSRP passenger forecast.

Using international cost databases and costs provided by SLR sources, a “prudent” cost estimate was prepared for the entire CSRP. Table 7 shows the key features of a ten-year plan, along with sequencing of the project, and Table 8 shows these revised cost estimates. The plan reflects a change of priorities presently pursued by CSRP. The first sector to be upgraded and electrified will be Colombo-Veyangoda, closely followed by Colombo-Panadura, especially considering that the maintenance depots to serve all sectors are most likely to be located in Ratmalana.

Table 7: Indicative Sequence of CSRP Implementation

Stage	Sector	Details	Upgrade existing tracks, build loops for stabling	Build new tracks proposed	Upgrade/rebuild stations to final plan, passenger information	Electrification	Signalling, communication	Light maintenance depot (LMD)	Comments
Stage 1	Sector 1	FOT-VGD	Y	Y	Y	Y	Y	Y	Sector 1or 2 to be done first, to depend on the location of the LMD at Daraluwa or Ratmalana, respectively.
	Sector 2	FOT-PND	Y	No #	Y	Y	Y	NA	
Stage 2	Sector 1	RGM-NGB	Y	NA	Y	Y	Y	NA	
	Sector 2	Extension t airport	Y	Y	Y	Y	Y	NA	
Stage 3	-	MMD	NA	NA	NA	NA	NA	NA	Be alongside the LMD at Daraluwa or Ratmalana
Stage 4	Sector 1	PND-KTS	Y	NA	Y	Y	Y	NA	
Stage 5	Sector 1	MDA-PDK	Y+	Y	Y	Y	Y	NA	
	Sector 2	PDK-AVS	NST	Y	Y	Y	Y	NA	
Stage 6	Sector :	VGD-RBK	Yes	NA	Yes	No	Yes	NA	

Third track will require beach reclaiming project to be completed.

Y: Yes Y+: Yes and straighten curves NA: not applicable NST: New Single Track

LMD: light maintenance depot MMD: Major Maintenance Depot

Station Abbreviations:

FOT: Colombo Fort VGD: Veyangoda RBK: Rambukkana KTS: Kalutara South
PND: Panadura RGM: Ragama NGB: Negombo MDA: Maradana
PDK: Padukka AVS: Avissawella

Table 8: CSRP Implementation: Indicative Parameters and Investment Estimates

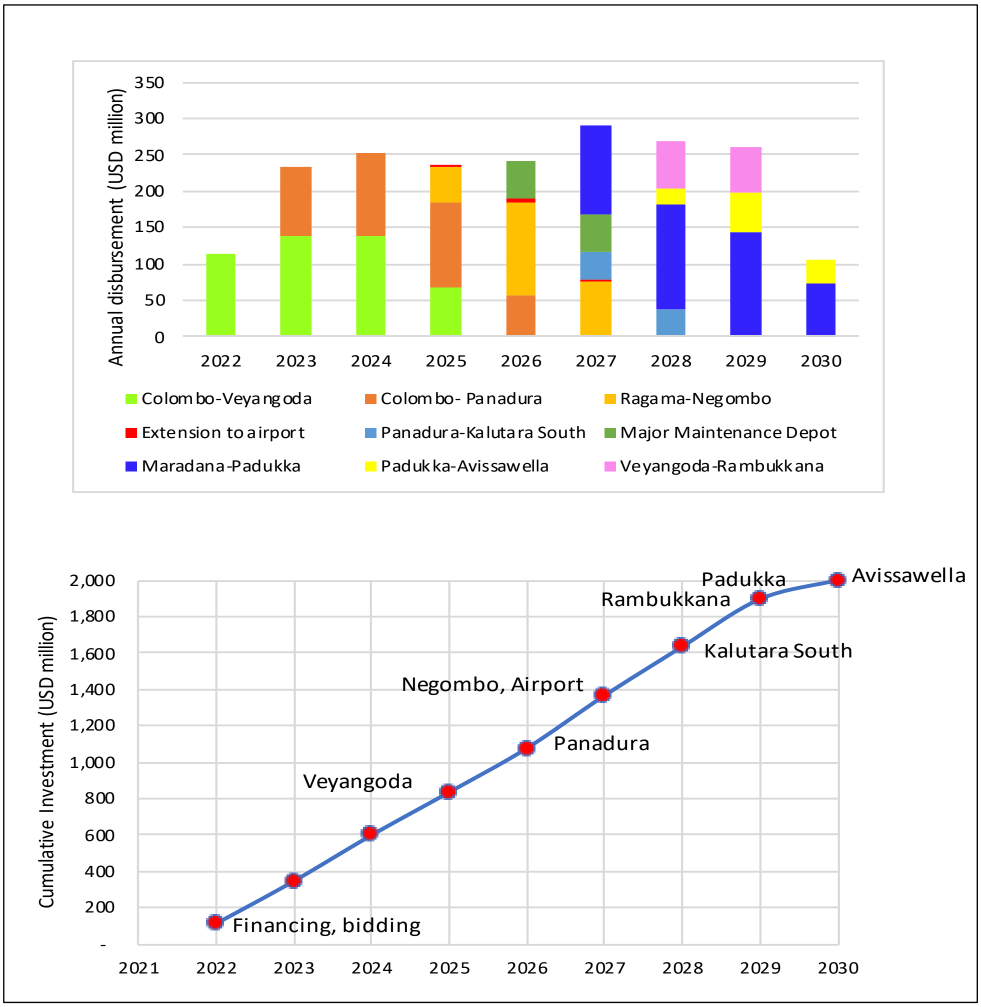
Stage	Sector	Pre-construction	Construction		End station or asset	Distance (km)	Stations	EMUs	Target investment (USD Mn)
			begins	ends					
Stage 1	Sector 1	2020-2021	2022	2025	VGD, LMD	36	18	15	460
	Sector 2	2021-2022	2023	2026	PND	29	15	15	380
Stage 2	Sector 1	2023-2024	2025	2027	NGB	24	14	10	250
	Sector 2	2023-2024	2025	2027	Airport	2	1	-	10
Stage 3	Sector 1	2024-2026	2027	2028	KTS	15	5	-	80
Stage 4	-	2024-2025	2026	2027	MMD	-	-	-	105
Stage 5	Sector 1	2021-2026	2027	2030	PDK	35	22	10	480
	Sector 2	2024-2026	2028	2030	AVS	24	12	4	110
Stage 6	Sector 1	2027-2028	2028	2029	RBK	47	18	-	125
Total CSRP						**212**	**105**	**54**	**2,000**

Abbreviations:
LMD: Light Maintenance Depot, MMD: Major Maintenance Depot;
EMU: Electric Multiple Unit

Station Abbreviations:
FOT: Colombo Fort VGD: Veyangoda RBK: Rambukkana KTS: Kalutara South
PND: Panadura RGM: Ragama NGB: Negombo MDA: Maradana
PDK: Padukka AVS: Avissawella

Pre-construction: Environmental and other approvals, due diligence by government and financiers, bidding procedure. Long pre-construction durations have been allowed for lines that have substantial relocation and land acquisition, including straightening of curves.

Figure 2: Indicative Annual Disbursement Schedule for CSRP and Cumulative Investments



Note:
Sequence of development proposed is on the basis that annual investments would be between USD 110 million and USD 300 million (LKR 20 to 55 billion).

7. CONCLUSIONS

The Colombo Suburban Railway Project (CSRP) is presently designed as a USD 4,000 million investment, expecting up to a ten-fold increase in passenger counts. While excessive passenger forecast itself has caused the project costs to increase to such high levels, all subprojects of CSRP require government subsidies. The CSRP, as presently planned, has several issues: incorrect prioritisation of lines to be upgraded, commencing with KV line (with an expectational 10-fold increase in passengers to 273,000) has to be changed to Panadura-Colombo-Veyangoda, which already have 330,000 passengers per day. The elevation of KV line, proposed at an additional investment of USD 420 million plus USD 70 million for elevated stations can be reduced by providing a unique solution to each road crossing, along with a realistic passenger forecast, coupled with longer trainsets.

All cost estimates of CSRP require downward revisions and professional assessments by costing specialists, considering transparently applied unit costs, using published information available locally and internationally.

What is presented in this paper is an alternative investment plan and a development sequence, prioritising the sectors with lower investment and higher benefits, eventually upgrading and electrifying all sectors of CSRP by year 2030. This plan too, requires more rigorous re-assessment. However, the present designs and costing of CSRP, if implemented, are most likely to cause a net drain on the national economy rather than providing true economic benefits.

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34, M J C Fernando Mawatha,
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