ISSN 2783-8897
eISSN 2783-8676

Journal of South Asian Logistics and Transport

Volume 1 Issue 2
September 2021

Sri Lanka Society of
Transport and Logistics

JSALT

Journal of South Asian Logistics and Transport

ISSN 2783-8897 eISSN 2783-8676

Volume 1 Issue 2
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Sri Lanka Society of
Transport and Logistics

International Journal of the
SRI LANKA SOCIETY OF TRANSPORT AND LOGISTICS

Moratuwa, Sri Lanka

JOURNAL OF SOUTH ASIAN LOGISTICS AND TRANSPORT
International Journal of the Sri Lanka Society of Transport and Logistics
Bi-annually published

ISSN 2783-8897 eISSN 2783-8676

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Volume 1 Issue 2, September 2021

Editor-in-Chief: T Lalithasiri Gunaruwan

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Printed by:

Cybergate Services (Private) Limited

57A, Soratha Mawatha, Gangodawila, Nugegoda 10250, Sri Lanka
Telephone: +94 78 378 3783 Email: info@cybergate.lk

Sri Lanka Society of
Transport and Logistics

ISSN 2783-8897 eISSN 2783-8676

JSALT

Journal of South Asian Logistics and Transport

Volume 1	Issue 2	September 2021

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ISSN 2783-8897 eISSN 2783-8676

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Journal of South Asian Logistics and Transport

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Sri Lanka Society of Transport and Logistics

ISSN 2783-8897 eISSN 2783-8676

Journal of South Asian Logistics and Transport

International Journal of the Sri Lanka Society of Transport and Logistics

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 ‘Strategic Perspectives’ which articulates alternative strategic thoughts and policy approaches.

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

ISSN 2783-8897 eISSN 2783-8676

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DOI: http://doi.org/10.4038/jsalt.v1i2.31

RISK FACTORS OF CRASHES INVOLVING MOTORCYCLES IN SRI LANKA

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ABSTRACT

Motorcycle is among the most popular and important modes of land transportation in tropical developing countries like Sri Lanka. Yet, research on the effect of motorcycles on traffic safety in Sri Lanka is limited.

Investigation of the risk factors and contributory causes of motorcycle crashes using data sourced from Police records was the objective of this research. Police-reported crash data in Sri Lanka contain details of crashes at all severity levels that got reported, together with their corresponding different conditions, including environment, roadway, rider, and vehicle characteristics, throughout the country. Investigating the odds-ratios, the risk factors for motorcycle crashes could be identified in developing the potential counter-measures to improve traffic safety.

In Sri Lanka, during 2009-2013, more than 200,000 of motorcycle crashes have been reported. The predominant crash conditions associated with motorcycles were driving on rural roadways, during weekdays, and riding newer motorcycles. The odds-ratios indicated that riding a motorcycle on dry surface conditions, on urban roads, and using safety helmets would be much safer.

The results of the study add new insights to the traffic safety literature in regard to improving road safety in Sri Lanka.

Keywords: *Motorcycle Crashes, Injury Severity Model, Motorcycle Safety*

1. INTRODUCTION

According to the Global Status Report on Road Safety published in 2018, road traffic crashes, which could be prevented, was the eighth most influential cause of fatalities in the world [1]. The total number of road traffic fatalities in the world is 1.35 million per year while approximately 50 million injuries annually are reported due to traffic crashes [1]. The average road traffic fatality rate in 2018 was 18 per 100,000 population, which is comparable with that in the Eastern Mediterranean and Western Pacific countries. The fatality rates were 23.6, 29.3, and 5.1 per 100,000 population in the middle-income countries, low-income countries and in high-income countries respectively. When investigating Police-reported crashes in Sri Lanka, it was found that fatality rate in 2013 was approximately 11 per 100,000 whereas in middle-income countries that was 20.1 per 100,000 in the same year [2]. Figure 1 shows the fatal, grievous injury, and non-grievous injury trends due to traffic crashes in Sri Lanka from 2004 to 2013. Sri Lanka had an increasing trend in the total traffic injury rates during 2004 to 2012; however, the rates in 2013 were slightly lower than that of 2012.

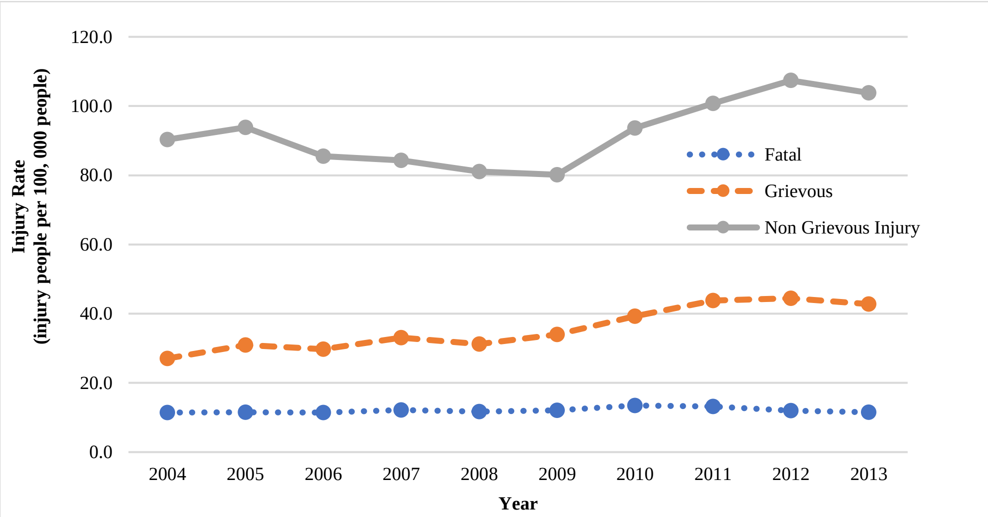

Figure 1: Traffic Injury Rate in Sri Lanka from Year 2004-2013 [2]

Middle-income countries showed no reduction in the fatality rates from 2013 to 2016 [1]. In South-East Asian countries about 43% of traffic fatalities were due to motorised two-wheelers or three-wheelers involved crashes, 16% were due to non-motorised two-wheeler crashes, and 14% due to pedestrian crashes. Motorcycle has become an essential vehicle among the people in those countries for commuting or transporting goods because it is an economical and easy mode to be used for short distances. In South-East Asian countries, relative use and ownership of motorcycles or non-motorised two-wheelers are high - for example, in Thailand 86% of households own at least one motorcycle, which is comparatively higher than that in high-income countries [3].

Motorcycles in Sri Lanka usually share the lane with fast-moving vehicles such as cars, buses, and trucks. Motorcycle users are more vulnerable compared to travellers in fast-moving traffic, because motorcycles are less visible owing to their smaller size, and because they lack protection during a crash. As a result, motorcycle crashes are often reported with severe injuries caused to its users. However, even though the higher risks faced by motorised two-wheeler riders is often documented, the knowledge pertaining to the measures that should be taken to reduce or prevent this high crash risk is incomplete.

Several scientific studies have attempted to explore the factors that cause increasing crash severity associated with motorcycles, including different environmental, road, vehicle, and human factors. However, results of those studies appear inconclusive as they have yielded different priorities pertaining to those factors [4]. The conjunctural and circumstantial differences at different study areas associated with driver-, traffic-, vehicle-, road-, and environmental-related factors could possibly have been behind such mixed results. Also, the techniques used in data collection and statistical methods of analysis could also have given rise to different results. Thus, it becomes necessary to undertake further studies using country-specific data and appropriate statistical methods so that the outcomes would possibly yield a clearer and complete picture pertaining to road safety characteristics attributable to that particular country.

This study focused on investigating the risk factors and contributory causes of crashes involving motorcycles using reported data pertaining to accidents obtained from the Sri Lanka Police. It has been identified that the safety helmets were effective in reducing the injury severity in the case of motorcycle crash specially by preventing head injuries. In this study, the effect of safety helmets in reducing the injuries in the case of motorcycle crashes of Sri Lanka was also investigated.

All Sri Lankan regulations for motor vehicles are applicable to motorcycles [5]. The owners are required to register their vehicles at the Department of Motor Traffic and riders have to obtain a driving license to operate motorcycles. Every year thereafter, they are required to obtain annual revenue licenses. Motorcycle is a popular vehicle among middle-income and low-income people in Sri Lanka and mainly used to commute to work, to transport goods, as well as for recreational purposes as a family vehicle.

The distribution of registered number of vehicles in Sri Lankan during 2016 is shown in Figure 2 [6].

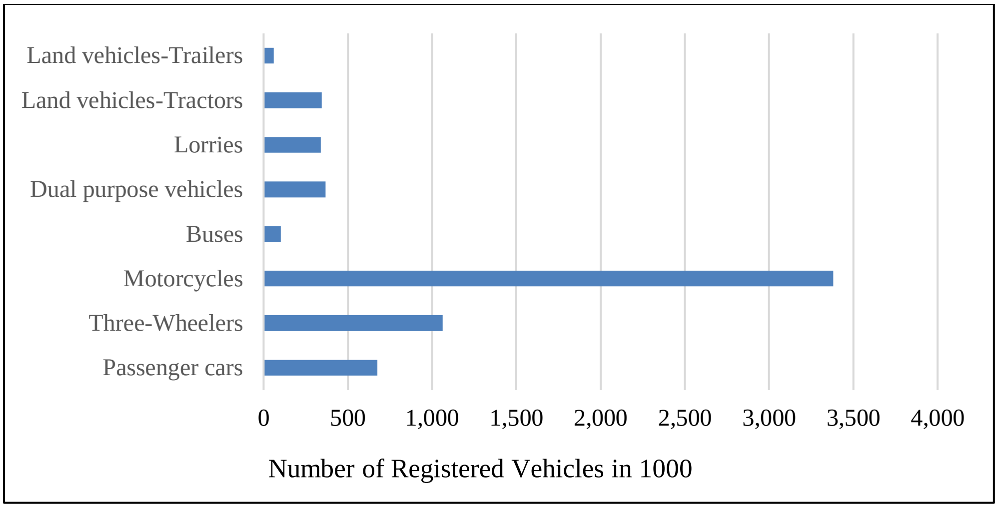

Figure 2: Type of Registered Sri Lankan Vehicle in 2016 [5]

The most common vehicle on Sri Lankan roads is the motorcycle and the number of motorcycles is three times that of the second most common vehicle, the three-wheeler. For instance, in 2016, a total of 3,381,726 motorcycles was registered in Sri Lanka, which was 53.4% of the total registered vehicles in the same year, as shown in Figure 3 [6].

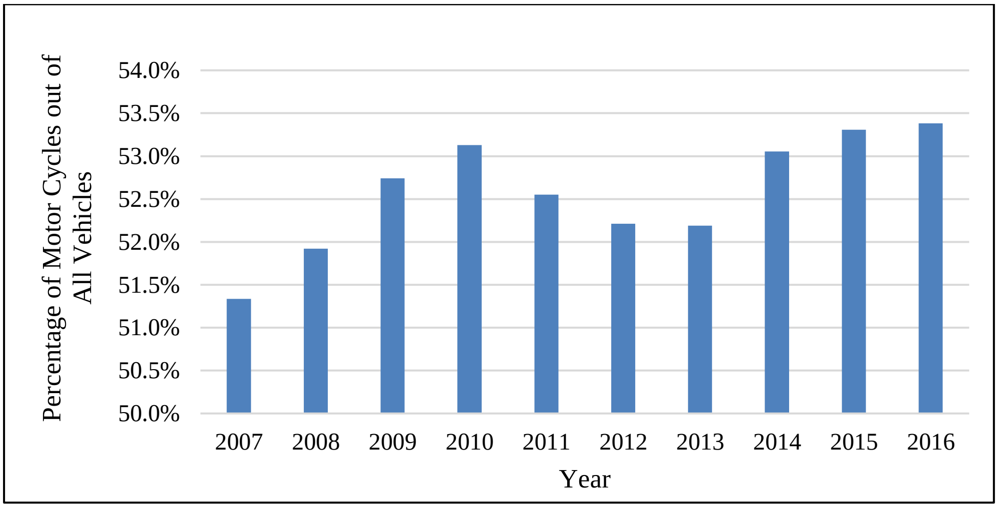

Figure 3: Percentage of Registered Motorcycles in Sri Lanka out of all Registered Vehicles [5]

The ownership and use of motorcycles and other two-wheelers in middle-income and low-income countries is usually higher than that in high-income countries. Registration of motorcycles in Sri Lanka has increased by 210% between 2007 and

2016, resulting in a 2.8% increase in the corresponding modal share. This reflects the trend of motorcycles gaining popularity, both in ownership and ridership. The probability of motorcycle crashes increases with this increasing number of motorcycles and modal share, and therefore, much more intensive effort is needed to improve their safety on roads.

Table 1: Injury Rates and Numbers of Motorcycle Crashes in Sri Lanka during 2009-2013 [2]

Year	Fatal Injury		Grievous Injury		Non-grievous Injury		Total	
	No.	Rates per 1000 MC	No.	Rates per 1000 MC	No.	Rates per 1000 MC	No.	Rates per 1000 MC
2009	4,240	2.24	10,503	5.54	21,081	11.12	35,824	18.89
2010	4,782	2.28	12,003	5.71	24,258	11.55	41,043	19.54
2011	4,665	1.98	13,474	5.72	25,159	10.69	43,298	18.39
2012	4,262	1.67	13,980	5.49	27,888	10.95	46,130	18.12
2013	4,047	1.53	13,268	5.02	25,771	9.75	43,086	16.31

The numbers and rates of motorcycle crashes on Sri Lankan roadways between year 2009 and 2013 are shown in Table 1. These crash rates were estimated using the crash data provided by Sri Lankan Police [2]. During year 2013, around 43,086 motorcycle crashes occurred on Sri Lankan roadways, out of which 4,047 were fatal crashes [2]. The highest motorcycle crash rate and the highest number of fatal motorcycle-crashes recorded in 2010. From year 2009 to 2012, the annual number of motorcycle crashes has increased. There has been a slight decline in those injury rates of motorcycle crashes over the last three years, but safety of motorcycle riders has remained a major concern.

Before 2011, wearing safety helmet was not mandatory in Sri Lanka for some types of motorcycles with low engine capacity, such as moped motorcycles [7]. The law was revised requiring safety helmets when riding any type of motorcycles with effect from 2011. If a motorcycle is involved in a crash, wearing a safety helmet would reduce the risk of head injury. Many studies have been conducted to investigate the effects of a motorcycle helmet in preventing head injuries in case of a crash. Results pertaining to the safety of helmet use differed depending on the study type, population, situation etc. Therefore, the effectiveness of safety helmet in reducing crash injuries in the Sri Lankan context needs to be further investigated.

Not only the number of motorcycles on Sri Lankan roads increased over the years, but also, a significant change in the types of motorcycles used has been observed. Due to these changes in motorcycle types and their use, in driver characteristics, and in evolving motorcycle crash rates, it becomes important to examine whether there would be any relationship between road-, vehicle-, rider-, and environmental-related factors that could be associated with motorcycle crashes and the corresponding safety effects of helmet use.

The present study was therefore conceived with the objective of analysing motorcycle crashes of all severity levels that occurred in Sri Lanka during the period of five-years from 2009 to 2013. It attempted to identify the injury risk factors of motorcycle crashes. Understanding the contributory causes of motorcycle crashes, and those contributing towards increasing their severity, and also the effect of safety helmets on motorcycle crashes was specifically intended. The findings of the study could be used in formulating countermeasures to reduce motorcycle crashes and their severity as well as to improve the overall safety in heterogenous mixed traffic.

2. LITERATURE REVIEW

Covering different countries including Sri Lanka, several studies have been done on different aspects of safety helmet use, and motorcycle safety. Numerous studies have investigated the factors affecting the occurrence and severity of motorcycle crashes. The factors that contribute to increase the occurrence or severity of motorcycle crashes were similar in many studies. Some of those similar factors identified as causing head-on crashes, run-off the road, night and weekend crashes include drunk drivers, inexperienced drivers, older drivers, speeding, and inattention [8].

Motorcycle crash data were extracted from state crash databases in New South Wales, during the 5-year period from 2004 to 2008 by Rome and Senserrick to investigate the high-risk factors for severity of motorcycle crashes [9]. Also, crash-related factors, and rider behavioural factors, and crash rates by demographics were studied. Over the 5-year study period, both numbers of motorcycle registrations and crashes increased, but a decrease was observed when considered the crash rates and fatality crash rates per 10,000 registered vehicles. Unlicensed motorcycle riders were overrepresented in fatal motorcycle crashes, and young motorcycle riders also were frequently found involved in crashes than that of other motorcycle riders. About 41% of unlicensed motorcycle riders involved in crashes did not wear safety helmets and 26% of all motorcyclists were with high blood alcohol concentration. A larger proportion of motorcycle crashes occurred on roadways having the speed limit 60 km/h or less. The results showed that crash risk patterns could provide important details to be highlighted in driver education and intervention programs.

In order to identify motorcyclist subgroups having high crash risk and to investigate the risk factors at work, Bjørnskau et al. [10] conducted a study in Norway, using data on motorcycle rider characteristics, their behaviour, and accident risk, collected through a questionnaire survey and also from four years of fatal motorcycle crash records in Norway during 2005 and 2008. The results showed that drivers of sport bikes, and drivers whose age was less than 19 years were the high crash risk subgroups among Norwegian motorcyclists. Excessive speed was the cause for almost all fatal crashes with sport bikes. Other high-risk factors included combinations of younger age, less experience, “unsafe” attitudes, and risky driving behaviour. The age of the rider as an important factor for occurrence and severity of motorcycle crashes was confirmed by both crash data and questionnaire data.

By developing a binary logistic regression model, Haque et al. [11] investigated the occurrence of crashes owing to faults of motorcycle riders. The dependent variable used was a binary variable which indicated whether the motorcycle rider was at-fault or not-at-fault. The independent variables considered were roadway-, environmental-, motorcycle-, and rider-related factors to investigate their association on crash occurrence. Non-intersections, intersections, and expressway locations were considered in investigating motorcycle riders’ faults. The results showed that these locations had different effects as contributory factors to motorcycle crashes. Motorcycle riders were found vulnerable at both intersections and expressways during night-times more than during daytimes. Further, it showed that number of motorcycle riders who were not-at-fault, but involved in crashes, increased over the years.

To investigate the factors which would increase the injury severity of motorcycle riders when they involved in crashes, multinomial logistic models were developed by Geedipally et al. [12] using Police-reported crash data from Texas, United States of America. Separate probabilistic analyses were conducted developing injury severity models to study urban and rural motorcycle crashes. According to its results, alcohol consumption, gender of the rider, lighting condition at the time of crash, and presence of horizontal and vertical curves, have emerged as significant factors which increase the severity of both urban and rural motorcycle crashes. In addition, the injury severity of rural motorcycle crashes was found further accentuated by angular crashes, single-vehicle crashes, divided highways, and older motorcycle riders.

Motorcycle crashes are frequently related to combinations of risk factors such as riding without wearing safety helmets, under the influence of alcohol, and without valid licence. Therefore, Schneider et al. [13] studied the *at-fault status* of motorcycle riders in associated with different combinations of crash- and rider-related factors and also the effect of these factors to other high-risk behaviours. Police-reported crash data in Ohio years from 2006 to 2010 were used to develop a multivariate probit model. Results revealed that the younger motorcycle riders would be more likely to be at-fault in crashes. The commonly found faults were riding without wearing safety helmets, and under the influence of alcohol. When examining other vehicle-related factors, it was found that the new motorcycle riders would be more likely to be at fault compared to rider of old motorcycles. In two-vehicle crashes, motorcycle riders tended be at fault in rear-end crashes while other vehicle drivers would be more likely to be at fault at crashes at intersections and driveways; situations which limit the distance seen.

3. METHODOLOGY AND DATA

Data for this study were obtained from Sri Lanka Traffic Police crash database which contains characteristics of Police-reported crashes in Sri Lanka at all severity levels from year 2009 and 2013 [2]. Not all crashes get reported to the Police [14, 15]. Some crashes, particularly those having caused property damage only, may go unreported. According to research done in Kandy district, the estimated underreporting rate was in between 33.0% and 56.3% [16]. Such under-reporting of data and inadequate quality of crash data are among main constraints when undertaking traffic safety research. The Police-reported crash data in Sri Lanka contain information related to different driver-, occupant-, environment-, vehicle-, crash-, and road-related characteristics of all vehicles involved in crashes and their contributory causes. Depending on the highest level of injury sustained by vehicle occupants, the crashes are reported in three crash severity categories: non-grievous injury, grievous injury, and fatal injury. In this study, crash severity of motorcycle accidents, as recorded in the crash database, was selected as the dependant variable to investigate the influential factors for severity of motorcycle crashes.

Data pertaining to motorcycles crashes in Sri Lanka between 2009 and 2013 were used in this study. When investigating crash data, it was observed that the number of annual crashes during this period was nearly equal. Therefore, without considering the increase or decrease of number of crashes in consecutive years, the data were aggregated for this analysis. The research was conducted using the most recent data that could be sourced, as it was impossible to obtain access to Police-reported crash database after year 2013. When multiple number of motorcycles that were involved in a single crash, information pertaining all motorcycles were considered in the analysis to perceive different vehicle-related and rider-related factors. In this study, the vehicle, namely the motorcycle, was considered the unit of analysis. There could be more than one injured occupant at a motorcycle crash as, in addition to the rider. Therefore, it might be possible to have a greater number of casualties than number of motorcycle crashes. The terminology adopted in this paper to define occupants of motorcycle include “riders” for motorcycle operators (drivers) only, and “motorcyclists” for both motorcycle riders and other occupants.

As the first step in analysing the data, the study calculated the frequencies and percentages of motorcycle crashes. Next, a *crash severity model* was developed to investigate the severity of the motorcycle crashes. The crash data contains the injury severity in three-point scale: non-grievous injury, grievous injury, and fatal injury. As the number of motorcycle crashes associated with non-grievous injuries was much higher than that resulted in fatal or grievous injuries, the latter two categories were grouped together in order to develop a better model adopting the binary logistic regression methodology. Both economic and social lost due to a fatal injury or a grievous injury very high; therefore, combining these two categories would be helpful to understand risk factors for sever injuries with compared to non-grievous injuries.

3.1. Logistic Regression Analysis

Crash data were used to formulate a binary logistic regression model for motorcycle crashes to investigate variables that could increase the crash severity. The coefficient of the independent variables could be used to identify whether those factors would increase the severity of crashes or not [17] [18]. The dependent variable, y, in the developed model was crash severity, a binary variable which explains whether crash was involved with a fatal/grievous injury or not. When severity of traffic crash is considered as the dependent variable, y, when the i^{th} crash is severe, $y=1$, otherwise $y=0$. Assuming there are p influence factors that are related to dependent variable y, and are denoted as $X= (x_1, x_2, \dots x_p)$, the probability of a fatal crash can be derived as follows.

$$\Pi(x) = p_i = \frac{e^{\beta_0+\beta_1 x_1+\cdots+\beta_p x_p}}{1+e^{\beta_0+\beta_1 x_1+\cdots+\beta_p x_p}} \tag{1}$$

where: $\Pi(x)$: the probability of fatal/ grievous injury crashes under the influence of p number of independent variables,

x_i : the influencing independent variables for crash severity, and

β_i : regression coefficients [19].

Considering the severity of the crash to be a dichotomous dependent variable, $x_1, x_2, \dots x_p$ are its corresponding independent variables, logit model may be established as;

$$logit\ (y) = x_i^t \beta \tag{2}$$

in which, $p_i = p\left(y_i = \frac{1}{x_i}\right) = e^{x_i^t\beta}/(1 + e^{x_i^t\beta})$,

$x_i = (1, x_{i1}, \dots x_{ip})^t\ and\ \beta = (\beta_0, \beta_1, \dots \beta_p)^t$ [20].

The model could be estimated using maximum likelihood estimator which aims at deriving values for the coefficients in such a way that maximize the joint probability of observed sample. In that respect, the dependent variable is the log of odd ratio, and the estimated coefficients cannot be directly interpreted, except the direction of the relationship; that is, whether the given factor increases or decreases the probability of occurring a fatal accident. Marginal coefficients or probability at given level of independent variables could be derived using the estimated coefficient. The coefficients of logistic regression model could be estimated using the maximum likelihood method, which is an iterative numerical analysis involving successive approximations.

Therefore, using statistical software by applying a numerical method, the best estimates of coefficients β_i could be obtained. In this study, Fisher scoring method in SAS software was used for the model development.

Odds-Ratios (ORs) could be estimated through binary logistic analysis [14]. Those ORs could be used to measure the relationship between crash severity and characteristics of motorcycle crashes. OR statistic could be used in crash analyses, to compare whether the probability of an event would be similar among two groups [17, 18]. The probability of the event occurring divided by the probability of that event not occurring could be defined as the "odds" of an event as shown in Equation 3 [14].

$$Odds = \frac{P(y = 1 / x_1, x_2, \ldots\ldots, x_p)}{P(y = 0 / x_1, x_2, \ldots\ldots, x_p)} \tag{3}$$

Odds Ratio (OR) is the ratio of odds of one variable as a ratio of that of another variable, as depicted in the Equation 4.

$$odds\ ratio = \frac{odds_1}{odds_0} \tag{4}$$

It indicates the relative effect of one independent variable ($odds_0$) on an odds dependent variable ($odds_1$); when the value of the independent variable is increased by 1.0 unit, the effect on odds dependant variable would be indicated as an increase (OR > 1.0) or decrease (OR < 1.0) by the Odds Ratio.

The dependent variable used in this study was the “crash severity”, a binary-variable reflecting whether the motorcycle crash was fatal/ grievous or not. Univariate and multivariate analyses were two approaches used in this study, depending on the number of independent variables considered at a time. The difference between univariate analysis and multivariate analysis was that the dependent variable would be affected by only one independent variable when other independent variables were kept unchanged in the univariate analysis, while the multivariate analysis would assume the dependent variable as influenced by all different independent variables.

The independent variables used in this analysis were road-, driver-, vehicle-, and environmental-related characteristics of motorcycle crashes.

4. RESULTS

In Sri Lanka, a total number of 209,381 motorcycle crashes had been reported to the Police between 2009 and 2013 which included 124,157 accidents with non-grievous injuries, 63,228 with grievous injuries, and 21,996 involving fatalities. Nearly 97 percent operators involved in these crashes were males as shown in Table 2.

Table 2: Parameter definitions of independent variables and their frequencies

Characteristics	Parameter Definition	*Number of crashes*	%
Driver-Related Characteristics			
Male	If driver is male=1, otherwise 0	66,294	96.8
Young drivers	If driver is young (<20 years) =1, otherwise 0	8,102	11.8
Middle-aged Drivers	If driver age is 21-40 years =1, otherwise 0	44,882	65.6
Novice driver	If driver experience is <5 years=1, otherwise 0	54,314	79.4
Alcohol related	If alcohol or drug related=1, otherwise 0	2,957	4.3
Valid licensed	If driver had a valid license=1, otherwise 0	39,648	58.8
Safety helmet used	If driver used helmet=1, otherwise 0	42,785	62.5
Environmental-Related Characteristics			
Dark (No daylight)	If dark =1, otherwise 0	24,371	35.6
Clear weather	If clear weather=1, otherwise=0	63,580	92.9
Weekdays	If weekday=1, otherwise 0	47,878	70.0
Road-Related Characteristics			
Urban roads	If urban area=1, otherwise 0	24,507	35.8
Intersections	If intersection related=1, otherwise 0	19,493	28.5
Dry road surface	If road surface is dry=1, otherwise 0	65,300	95.4
Light vehicle speed limit	If light-vehicle posted speed limit > 70 kmph =1, otherwise 0	31,575	46.1
Vehicle-Related Characteristics			
Vehicle Age	If vehicle age <5 years=1, otherwise 0	45,979	67.2
Two Vehicle Crashes	If two vehicle crashes=1, otherwise 0	60,543	88.5
Contributory Causes			
Speeding	If speeding=1, otherwise 0	9,053	13.2
Aggressive driving	If aggressive or negligent driving=1, otherwise 0	32,561	47.6
Other driver contributory causes	If other driver contributory cause=1, otherwise 0	3,657	5.3
Vehicle-related	If crash due to vehicle factors=1, otherwise 0	3,404	5.0
Road-related	If crash due to road factors=1, otherwise 0	2,720	4.0

Age of the motorcycle driver appeared to be one of the factors useful for understanding the characteristics of crashes involving motorcycles. While there were some young and older riders, 65.6 percent of motorcycle riders involved in crashes were between 20 and 40 years old.

About 41.2 percent of the motorcycle crashes involved riders holding no valid licence. Riders of motorcycles involved in 37.5 percent of crashes were found not wearing safety helmets. More frequent conditions associated with motorcycle crashes appeared to be driving on rural roadways, driving during weekdays, and driving newer motorcycles.

The different characteristic factors which were considered as independent variables explaining motorcycle accidents are presented in the Table 2. Among those, several were possible to be defined as continuous or discreate variables; however, in this study, better model was obtained considering independent variables as dummy variables.

To analyse the severity of motorcycle crashes in Sri Lanka occurred during the period of study, a binary-logistic regression model was adopted. The dependent variable of the model, the "injury severity", was assigned the value of 1 for a grievous or fatal injury while the value of 0 was assigned for crashes with non-grievous injuries.

The variables deployed were checked for multi-collinearity using Pearson's correlation matrix to identify the significantly independent candidate variables. Among the independent variables, a total of two correlated pairs achieved a significance level of $p \leq 0.5$, which was the cut-off criteria selected for the current analysis. One variable from each pair was discarded, so that the variable providing the strongest model, i.e. the variable with the higher-magnitude of Pearson's statistic, was retained.

The model finally retained had 21 independent variables which are depicted in the Table 3. The model diagnostics showed a Likelihood Ratio Chi-Square statistic of 68.88 with a p-value < 0.001.

The estimated ORs corresponding to such crash characteristics from the year 2009 to the year 2013 are tabulated in the Table 4. Variables such as novice drivers, clear weather condition, day of week, vehicle age, aggressive driving, road-related contributory causes were not significant at 1% level of significance in multivariate analysis. Variables such as young drivers, day of week, vehicle age, aggressive driving, other-driver contributory factors were not significant at 1% level of significance in univariate analysis as shown in Table 4. Variables such as light-vehicle speed limit of the road, speeding, road-related contributory causes were significant in both analyses; yet, indicated different results.

Table 3: Determinants of Severity of motorcycle crashes in Sri Lanka

Dependent variable: *severity of traffic crash, y=1 if crash is severe, otherwise y=0.*			
Variable	**Parameter Definition**	**Estimated coefficient**	**p-value**
Intercept		3.651	0.006
Driver-Related Characteristics			
Male	If driver is male=1, otherwise 0	0.727***	0.000
Young drivers	If driver is young (<20 years) =1, otherwise 0	-0.507***	0.000
Middle-aged Drivers	If driver age is 21-40 years =1, otherwise 0	-0.276***	0.000
Novice driver	If driver experience is <5 years=1, otherwise 0	0.043	0.185
Alcohol related	If alcohol or drug related=1, otherwise 0	0.324***	0.000
Valid licensed	If driver had a valid license=1, otherwise 0	-0.711***	0.000
Safety helmet used	If driver used helmet=1, otherwise 0	-0.494***	0.000
Environmental-Related Characteristics			
Dark (No daylight)	If dark =1, otherwise 0	0.324***	0.000
Clear weather	If clear weather=1, otherwise=0	-0.113	0.562
Weekdays	If weekday=1, otherwise 0	0.004	0.455
Road-Related Characteristics			
Urban roads	If urban area=1, otherwise 0	-0.311***	0.000
Intersections	If intersection related=1, otherwise 0	-0.099***	0.002
Dry road surface	If road surface is dry=1, otherwise 0	-0.219***	0.000
Light vehicle speed limit	If light-vehicle posted speed limit > 70 kmph =1, otherwise 0	0.510***	0.000
Vehicle-Related Characteristics			
Vehicle Age	If vehicle age <5 years=1, otherwise 0	-0.015	0.376
Two Vehicle Crashes	If two vehicle crashes=1, otherwise 0	-1.058***	0.000
Contributory Causes			
Speeding	If speeding=1, otherwise 0	0.510***	0.000
Aggressive driving	If aggressive or negligent driving=1, otherwise 0	0.036	0.456
Other driver contributory causes	If other driver contributory cause=1, otherwise 0	-0.208***	0.000
Vehicle-related	If crash due to vehicle factors=1, otherwise 0	0.178***	0.000
Road-related	If crash due to road factors=1, otherwise 0	0.070	0.567

Note: ***-Variable significant at 1% level of significance.

Table 4: Odds Ratios for Motorcycle Crashes in Sri Lanka from 2009-2013

Characteristics	Parameter Definition	***Multivariate Analysis***		***Univariate Analysis***	
		OR	p-value	***OR***	p-value
Driver-Related Characteristics					
Male#	If driver is male=1, otherwise 0	**2.069*** **	0.000	**2.197*** **	0.000
Young drivers	If driver is young (<20 years) =1, otherwise 0	**0.602*** **	0.000	**1.024**	0.122
Middle-aged Drivers#	If driver age is 21-40 years =1, otherwise 0	**0.759*** **	0.000	**1.093*** **	0.000
Novice driver	If driver experience is <5 years=1, otherwise 0	**1.044**	0.185	**0.642*** **	0.000
Alcohol related#	If alcohol or drug related=1, otherwise 0	**1.382*** **	0.000	**1.576*** **	0.000
Valid licensed#	If driver had a valid license=1, otherwise 0	**0.491*** **	0.000	**0.448*** **	0.000
Safety helmet used#	If driver used helmet=1, otherwise 0	**0.610*** **	0.000	**0.635*** **	0.000
Environmental-Related Characteristics					
Dark (No daylight)#	If dark =1, otherwise 0	**1.383*** **	0.000	**1.604*** **	0.000
Clear weather	If clear weather=1, otherwise=0	**0.893**	0.562	**0.609*** **	0.000
Weekdays	If weekday=1, otherwise 0	**1.004**	0.455	**0.975**	0.234
Road-Related Characteristics					
Urban roads#	If urban area=1, otherwise 0	**0.733*** **	0.000	**0.633*** **	0.000
Intersections#	If intersection related=1, otherwise 0	**0.906*** **	0.002	**0.771*** **	0.000
Dry road surface#	If road surface is dry=1, otherwise 0	**0.803*** **	0.000	**0.599*** **	0.000
Light vehicle speed limit#	If light-vehicle posted speed limit > 70 kmph =1, otherwise 0	**1.665*** **	0.000	**0.757*** **	0.000
Vehicle-Related Characteristics					
Vehicle Age	If vehicle age <5 years=1, otherwise 0	**0.985**	0.376	**0.983**	0.231
Two Vehicle Crashes#	If two vehicle crashes=1, otherwise 0	**0.347*** **	0.000	**0.308*** **	0.000
Contributory Causes					
Speeding	If speeding=1, otherwise 0	**1.665*** **	0.000	**0.500*** **	0.000
Aggressive driving	If aggressive or negligent driving=1, otherwise 0	**1.037**	0.456	**0.029**	0.234
Other driver related causes	If other driver contributory cause=1, otherwise 0	**0.812*** **	0.000	**0.908**	0.345
Vehicle-related	If crash due to vehicle factors=1, otherwise 0	**1.195*** **	0.000	**0.587*** **	0.000
Road-related	If crash due to road factors=1, otherwise 0	**1.073**	0.567	**0.649*** **	0.000

Note: ***- Significant at 1% level

#: Variable significant at 1% level of significance in both multivariant and univariate analyses.

The variables emerged significant variables at a 1% level of significance, both in multivariate and univariate analyses were used in arriving at inferences. An OR value lesser than 1 implied the variable under consideration would lead to a lesser risk, and vice versa. Lesser risk in this regard would mean that a motorcycle would be more likely to be involved in a crash resulting in a non- grievous injury than a fatal/ grievous injury.

Accordingly, riding on roads with dry surfaces or riding by wearing safety helmets, with their ORs less than 1, were found associated with non-grievous injury crashes compared to fatal/ grievous injury crashes at 1% level of significance. The variable ‘male’, having the highest magnitude of Odds Ratio among variables in both multivariate and univariate analyses, showed that motorcycle-involved crashes would be more likely to be causing fatal/grievous injuries when ridden by men than by women. The Odds Ratio of alcohol-impaired riders was higher than 1 indicating its significant association with crashes causing fatal/grievous injuries. On the other hand, motorcycle riders holding valid driving license were found less likely to be involved in such accidents inflicting fatal/grievous injuries. Similarly, the use of safety helmets while travelling on motorcycles would significantly lower the risk of facing severe injuries at crashes, the corresponding OR revealed.

The Odds Ratios of environment-related variables showed motorcycle crashes would be severe when occurred in ‘dark’ light conditions. Motorcycle crash severity on urban roads would be milder compared that on rural roads. Also, at intersections and dry road surface conditions independently would be associated with lower injury severity risk. Two vehicle crashes showed lower odds ratio, indicating lesser association with severe injuries compared to crashes involving single vehicle or multiple vehicles. Both multivariate and univariate analyses enabled identification of factors contributing to increasing severities of crashes involving motorcycles.

Many factors combine to produce circumstances that could lead to a traffic crash; there is rarely a single cause of such an event. Aggressive/negligent driving and speeding were the most frequent rider factors associated with motorcycle crashes. It was interesting to note that when the contributory cause was one of those, the helmet use has been comparatively low. Road conditions and surrounding conditions also become relevant because the possibility of the rider having to face unexpected events when travelling cannot be excluded. Defective road surfaces or defective road signs were found the main roadway-related contributory causes of motorcycle accidents; safety helmet use was found the lowest when crashes were associated with such defective road signs or speeding. The most frequent contributing causes related to motorcycle crashes and the corresponding safety helmet usage ratios are comparatively depicted in Table 5.

Table 5: Contributory Causes and Helmet Use Involving Motorcycle Crashes

Contributory Causes	Number of Motorcycle Crashes	Safety helmet used	
		Frequencies	%
Driver Factors			
Aggressive/negligent driving	32561	17445	54%
Speeding	9053	4783	53%
Influenced by alcohol/drug	1699	1028	61%
Error of Judgment	1127	689	61%
Distracted	157	95	61%
Fatigue/Fall asleep	98	84	86%
Road Factors			
Defective road surface	733	443	60%
Defective road signs	531	284	53%
Vehicle Factors			
Brakes	727	448	62%
Tyres/wheels	172	115	67%
Other crash factors			
Avoiding manoeuvre	893	512	57%
Hit and run	2075	458	22%

Crashes due to failure in the breaks were most frequent between the two vehicle-related causes considered. Presence of one or more of these contributory factors would not by itself cause motorcyclists facing an accident but could indicate that they are at risk.

5. CONCLUSIONS

This study investigated the factors associated with motorcycle crashes reported in the records of Sri Lanka Police. While riding on rural roadways, riding during weekdays, and riding newer motorcycles were found as more predominant crash conditions for motorcycle crashes in Sri Lanka. The Odds Ratios indicated that traveling on dry surface conditions, traveling on urban roads, using safety helmets would be much safer. Further, riding the motorcycles during weekends would be more prone to accidents. Rider being a male, alcohol-impaired, or travelling in dark conditions would increase severity of crashes. The results of this study could be used for developing future intervention programs aimed at reducing motorcycle crashes and reducing their severity. Incorporating these findings into existing training and education programs for both motorcyclists and drivers of other vehicles could improve awareness of the public regarding risks and help them reduce the frequency of crash occurrence.

ACKNOWLEDGEMENTS

The author acknowledges the Sri Lanka Police for providing crash data.

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Sri Lanka Society of
Transport and Logistics

Journal of South Asian Logistics and Transport
Volume 1 Issue 2 September 2021
JSALT 1.2.2: pp. 19-33
DOI: http://doi.org/10.4038/jsalt.v1i2.32

PSYCHOLOGICAL RESPONSES OF MOTORCAR DRIVERS TO FLASHING AMBER LIGHTS AT SIGNALISED T-INTERSECTIONS

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ABSTRACT

The accurate and timely decision making of drivers is vital to ensuring public safety and reaching the destination in time. This paper presents a detailed comparison of the expectation of regulatory bodies in implementing flashing amber lights and explores the actual driver responses to flashing amber lights at a signalised T-intersection by taking speed variation as a proxy for their decision making.

A survey was conducted at a signalised T-intersection during the operation of flashing amber lights to measure the speed variation. Time-distance and speed gun techniques were used to collect speed data of motor cars.

Results reflect those drivers show only a marginal response to flashing amber lights. Therefore, the intention of regulatory bodies that vehicles maintaining lower speed at a T-intersection with flashing amber lights was not satisfactorily fulfilled. The marginal response of drivers to flashing amber lights can be a leading cause of accidents occurring in signalised T-intersections at odd (night) hours.

Keywords: *Transport Psychology, Driver Behaviour, Driver Utility, Safety, Flashing Amber Light Signalling*

1. INTRODUCTION

Passenger transportation plays a vital role in human life and in the economy of a country. Surface transportation mainly consists of public and personalised transport with an operation of a vehicle. Since transport corridors are developed along expressways, highways, and arterial roads, the entire system evolves as a network in which many interactions among modes are inevitable. In such interactions, the decision making of the motor vehicle driver is vital to ensure public safety. Decision making is a cognitive process used by human beings when there are many alternatives to choose in different scenarios [1]. Driver decision making is a research area with a considerable amount of literature. Drivers make decisions on the road in various situations [2]. Some drivers are risk-takers and some others are risk averters [3]. Some decisions are appropriate and avoid accidents while some are inappropriate and lead to accidents of different levels of severity. Unfortunately, some decisions drivers take result in major accidents and fatalities.

People make choices when they select a mode of transport and route; these choices are based on the benefits that they get. Since the decision making of drivers is a cognitive process [1], it may result in a good outcome or an unsafe outcome. There are many factors influencing the decisions, some are internal to the driver (psychology) and some others are external to the driver (external environment such as the behaviour of other drivers and their decisions, the quality of road infrastructure, and traffic signalling and road signs). Relationship between some internal cognitive factors and the decision-making process of drivers has been widely examined in transportation research while assessing the psychological response to such external factors has not been the focus of previous research.

For accident prevention, as a Traffic Demand Management (TDM) strategy, amber lights are flashed at signalised T-intersections to alert motorists to drive cautiously. Flashing amber light is used mostly during night hours with a very low incidence of traffic or when signal cycle timing is dysfunctional. However, this precautionary action has not eliminated T-intersection collisions. During the last decade, there has been a tremendous increase in mobility and motorisation in the country [4]. Road deaths reached a startling total of 3,303 in 2016, while death toll remained high at 3,101 in 2017, at 3097 in 2018, and at 2,829 in 2019 [5]. There were 39,086 accidents reported in 2016, while 18,980 accidents occurred in the first six months of 2017.

A Sri Lankan dies every three and a half hours in road accidents, and the Western Province continues to be the most unsafe region in this respect [4]. During off-peak hours, many T-intersection collisions are reported. The occurrence of accidents at signalised T-intersections during off-peak hours is due to incompatibility between the expected and actual reactions of drivers to flashing amber lights or their complete ignorance by the drivers. Hence, the psychological state, decision making, and other behavioural aspects of drivers appear causing increased accidents at T-intersections.

The main objective of this research was to test the effectiveness of flashing amber lights in lowering the speed of vehicles as a measure to prevent collisions at T-intersections during off-peak hours. The study also aimed at recommending a technique for effective accident prevention in off-peak odd (night) hours, if the effectiveness of the flashing amber lights is found unsatisfactory.

2. LITERATURE REVIEW

Decision making is a cognitive process of every human being [1]. Many factors influence the decision-making process of humans. Belief in the personal relevance of people [4], age and individual differences [6], cognitive biases [7], and previous experience [3] are some of the factors identified in psychology as influencing the decision-making process [8]. Decisions of drivers or driving behaviours could be defined as the habits of the drivers to choose an option while driving in different kinds of situations [9]. A combination of both good and bad decisions influence behavioural differences among different drivers [10]. Literature has repeatedly examined risky and violent driving behaviours [11]. Consequently, it is proved that risky driving behaviours have larger negative impacts on the safety of road users [10]. It is very useful, therefore, to examine the behaviours of drivers in view of evolving strategies to ensure traffic safety [12].

Several research papers have focused on the decisions of drivers on the road with respect to a range of circumstances. Dinh & Kubota studied the driver's decision on speed choice and how it is influenced by other drivers. This study analysed the speed choice of drivers [13]. Results indicated that there was a strong relationship between observed speeds and drivers' reported speed, as well as between observed speeds and the intentions to maintain a certain speed [14]. Calisir & Lehto studied young drivers' decision making on safety and seat belt use. The results indicated that drivers' decision-making process towards the use of safety belts was principally influenced by demographic factors like gender, grade point average and age [15]. Kong, Zhang, & Chen investigated the young drivers' behaviour with the prediction of the personality, attitudes, and risk perception, mainly focusing on risky decisions of drivers. Results indicated that temperament traits primarily had indirect effects on risk-taking behaviour through their influence on perspective towards traffic safety [16]. Letirand & Delhomme investigated speed behaviour as a choice between observing and exceeding the speed limits. This research focused on behavioural decisions of drivers pertaining to speeding. Results showed that the performance of behaviour and behavioural intention formation were based not on analysis of a single behavioural choice, but on evaluation of many potential choices [17]. Bar-gera & Shinar studied the intention of passing other vehicles, in other words, the overtaking intention. The results of their experiment indicated that there was a robust tendency for drivers to pass vehicles that travel ahead of them, though these vehicles would be moving faster than their average speed, and therefore, this tendency to overtake explained drivers' speed variability [18]. Nordfjrn, Jrgenson & Rundmo studied accident association of personality and gender on risky driving behaviour, focusing on both the risky decisions of drivers on the road and how it led to accidents. Its results revealed that risky driving behaviour could be strongly predicted by gender and normlessness [19]. Gelau, Sirek, & Dahmen-zimmer examined the effects of time pressure on older drivers on left-turn decisions. They found a tendency in the older drivers subject to the survey to require an additional time gap to execute left turns [20]. Zhou, Yu & Wang analysed mobile phone use while driving. The results supported the effectiveness of the theory of planned behaviour in predicting the first activity intention, which was respondent's intention.

Cestac, Paran & Delhomme investigated speeding intentions among young drivers. This investigation focused on the decisions of drivers whether to speed up the vehicle or maintain proper speed limits while driving on the road. The results revealed that apparent "friends' behaviour" had an additional influence on the intention to interrupt the rule than apparent "parents' behaviour" had. Ladies were additionally considerably influenced by their feminine friends and boys influenced by their male friends [22]. Atombo, Wu & Tettehfio studied the motivational factors and unsafe decisions of drivers. This investigation revealed that the theory of planned behaviour corresponding to driver beliefs and to driver behaviour would predict drivers' intentions to rush and overtake to a greater extent than other variables of driver behaviour [23]. Kinnear, Helman, Wallbank, & Grayson also have undertaken an experimental study of factors associated with driver frustration and overtaking intentions. It has focused on overtaking decisions of drivers which resulted in speed and influenced frustration. The lower speeds were connected with higher self-rated frustration than higher speeds, and drivers' intention to overtake would be higher at lower speeds [24].

In relation to the present research, Wang, Mao, Jin, Wang, & Guo studied how the drivers take deceleration and acceleration decisions and the human factors influencing such decisions. The results showed that there was a strong relationship between a driver's response time to unexpected events and driving behaviour. Furthermore, risk behaviour of drivers retarded in their response time to unexpected events on the road which leads to accidents [1]. Zhou, Yu & Wang analysed driver's intention on un-signalised cross-intersections in China. The results revealed that straight-moving vehicle drivers from the proper aspect completed their sponge-like selections from 0.9 to 1.3 seconds before reaching the crossing point. However, straight-moving vehicle drivers from the left aspect completed their sponge-like selections from 0.9 to 1.2 seconds before reaching the crossing point [21].

In addition, Kong, Zhang & Chen examined the intention-aware autonomous driving decision making in an uncontrolled intersection. The study dealt with the kind of decisions that were made by drivers in an uncontrolled intersection. The study proposed a self-directed driving decision making algorithm seeing human-driven vehicle's undefined intentions in an uncontrolled intersection [16]. Similar to the current research, Li, Jia, & Shao predicted driver behaviour during the yellow interval. The study focused on how the drivers made decisions during the yellow interval and the results indicated that long distance traveling drivers were more likely to make "stop" choices when they approached intersections at the onset of the yellow signal [25]. Williams analysed the kind of decisions the drivers made under the condition of darkness. The results indicated that road traffic fatalities slightly increased during night times even though road traffic crashes significantly decreased at night. The higher fatal crash involvement rates brought evidence to suggest that night-time conditions would pose a greater danger to road users [26].

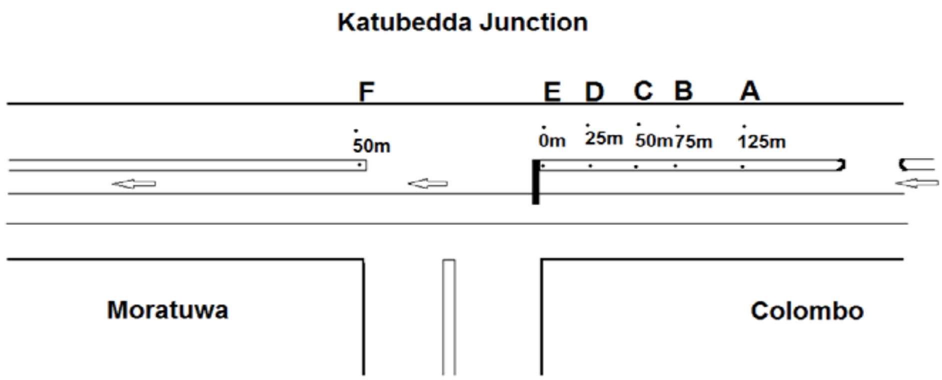
Previous research showed that drivers made many decisions on the road under different situations, and it is apparent that some decisions were good while some others were bad. Good decisions create a safer environment on the road while bad decisions cause problems to the road users. The studies also indicated that the decisions of the drivers were made in a cognitive process that varied from driver to another and would depend on several factors. It would be useful to analyse the kinds of decisions the drivers would make, and the factors influencing those decisions, in view of creating a safer environment for the drivers. In that respect, utility of driving could be linked with the driver's decision making and could be measured based on travel time, travel cost, safety, convenience, and privacy.

A frequently occurring pattern of accidents was found related to drivers with the right of way confronted by misjudgement of another vehicle crossing their path [27]. Therefore, predicting driver behaviour and assisting drivers in making correct decisions when they approach intersections would help reduce crashes at signalised intersections [25]. A driver assistance system could improve drivers' anticipation of the driving scene. Rittger et al., in agreement with previous research, found that Israeli drivers exhibited great variance in their reaction to the flashing green [28], and thus, flashing-green intervals at the end of the green interval could not be considered as increasing safety at signalised intersections. Warning beacons could be warranted at intersections when no conflicting vehicular approaches were faced. Beacons usually flash at a rate of not less than 50 and not more than 60 times per minute. The illuminated period of each flash should not be less than one-half and not more than two-thirds of the total cycle [22]. The response time of the drivers to the effect of amber lights could vary from 0 to 3 seconds [2].

The risk of vehicle crashes at road intersections during amber light operation is high. Relative to T- Junctions, the fatality risk at X-junction would also be higher during amber lights because of a greater number of approaching lanes and high likelihood of side-impact crashes [29]. Examining the driver behaviour, particularly at an X-junction, is a task of greater complexity. Even though not directly relevant to this study, *machine learning*, combined with probabilistic analysis, could be used to develop models pertaining to driver behaviour, which could be of help in evolving strategies to reduce risky driving behaviour [32]. Abuali & Abou-Zeid proposed a solution to prevent vehicle collisions based on advances of in-vehicle smartphone sensing capabilities and communication, and using recently developed applications in driver behaviour modelling such as cloud-based services [33]. The present research was conducted to examine how drivers psychologically react to flashing amber lights, by assessing speed levels of vehicles passing a T- intersection.

3. METHODOLOGY

The methodology used for the study was speed variation measurement. Five location-based speed levels of vehicles approaching a T-intersection were measured when amber lights were flashing. The measurements were taken to determine speed levels at distances of 25m (D), 50m (C), 75m (B) and 125m (A) away from the traffic light post, and at the traffic light post (E). The speed of vehicles passing the junction was measured 50m (F) away from the traffic light.

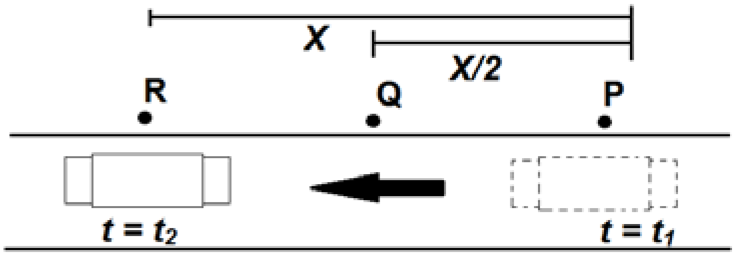


Source: Author compilation

Figure 1: Positions at which the speed levels are measured

Figure 1 demonstrates the demarcation of survey points at the selected T-intersection (Katubedda Junction, Moratuwa, Sri Lanka). The measurements were taken using the Speed Gun technique and Time-Distance technique. Hence, two types of speed, namely, "time mean speed" and "space mean speed", were captured during the survey. Later, space mean speed also was converted to time mean speed for the purposes of the analysis.

The average speed between any two points was determined by dividing the total distance by elapsed time, as depicted in the Figure 2.



$$Average\ Speed\ at\ Q = \frac{Distance}{Time} = \frac{X}{(t_2 - t_1)}$$

Figure 2: Graphical representation of Time-Distance technique

To determine a single-speed level, time values of two points were needed. A survey for the collection of data was conducted on 22nd March 2018 at Katubedda junction, Moratuwa, Sri Lanka. In the survey, vehicles moving towards Moratuwa direction in the 3rd lane (lane nearest to centre-median) in A2 road (Galle Road) were considered. The north bound traffic data (towards Colombo) were not collected in this survey. Speed variation measurement was implemented as the methodology in the study, as it could act as a proxy to the psychological response of the drivers.

Thus, the psychological response of drivers to flashing amber lights could be assessed. Three ideal situations, as depicted in speed variation graphs in the Figure 3, were expected to be representing the results, namely:

- A minimum point of the speed levels at the colour light position; representing the desirable psychological response for flashing amber lights,
- Constant speed throughout the surveyed distance; representing no psychological response for flashing amber lights,
- A maximum at the colour light position; representing undesired psychological response.

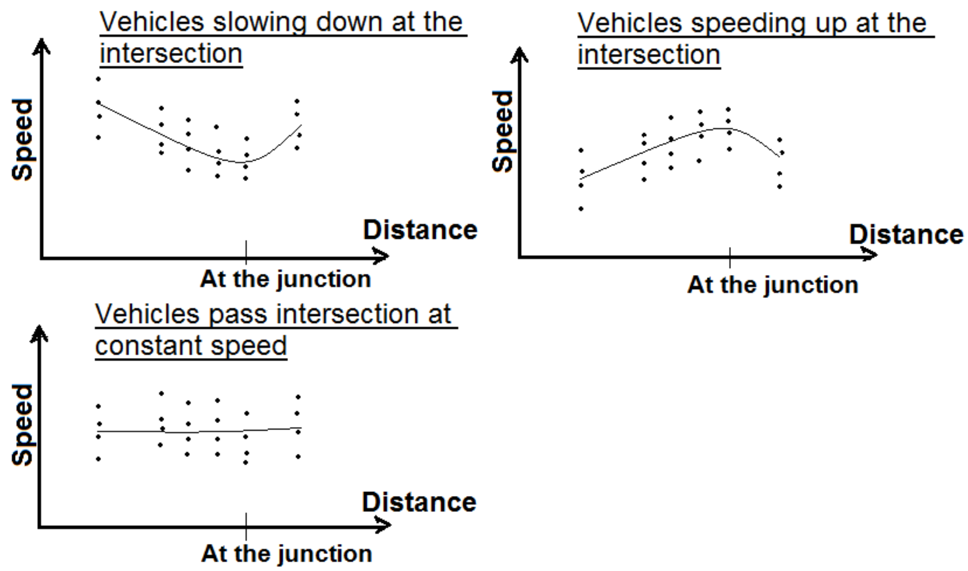


Figure 3: Rough sketches of the possible expected situations

4. ANALYSIS AND RESULTS

A total of 758 vehicles were surveyed and the speeds were calculated from the data collected in 3 samples between 10.50 pm to 00.50 am which were grouped into six speed levels. Table 1 summarises minimum, maximum, and average speed levels across all survey points on either side of the T-intersection.

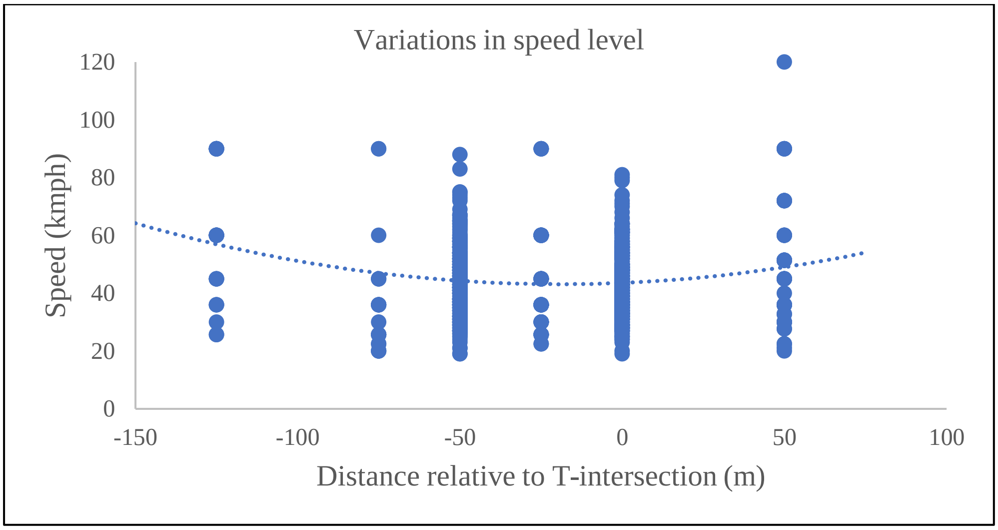
Table 1: Summary of the processed data

	A (125m)	B (75m)	C (50m)	D (25m)	E (0m)	F (-50m)
Maximum speed (kmph)	90.0	90.0	88.0	90.0	81.0	120.0
Minimum speed (kmph)	25.7	20.0	19.0	22.5	19.0	20.0
Mean speed (kmph)	59.2	36.5	44.8	45.4	43.2	49.1
Standard Deviation	22.5	19.8	11.8	17.1	11.4	21.5
Coefficient of Variation	0.380	0.542	0.264	0.376	0.263	0.437

Source: Primary data through speed survey

Table 1 presents the various attributes of data at different sections of the signalised T-intersection depicted in Figure 1. The variation of values demonstrates that the actual scenario nearly matches with the expected scenario – vehicle slowing down at the intersection shown in Figure 3. However, different minimum values were reported as vehicles had different speed levels. Therefore, the more meaningful way was to analyse the mean speed across the T-intersection. It would give an insight into driver behaviour in terms of vehicle speed and their decision making with respect to risk while crossing the T-intersection. The minimum mean speed was registered 75m away from the junction, in contrast to the expectation of observing the minimum mean speed at the junction. However, as expected, maximum mean speeds were registered at the far end of inbound vehicle flow and just after passing the junction. It means that drivers approached and passed T-intersections at free-flowing speed.

Considering solely the maximum speed at each point, it could be deduced that motorcar drivers responded to amber light at signalised T-intersections as intended by the authorities. That was because the minimum value of the maximum speed was recorded at the T-intersection. However, the scatter plot analysis of speed level variations, performed using data gathered through the survey, graphically depicted in Figure 4, indicated a marginal difference of the minimum speed of vehicles occurring before the midpoint of the intersection.



Note: The middle of the junction is at 0m

Figure 4: Speed level variations of vehicles passing Katubedda junction during amber lights

In Figure 4, the values of the x-axis represent distances from amber light at which speeds were calculated. Negative values of distances denote the approaching direction of vehicles and positive values denote the passing distances of vehicles from the junction. Only the through traffic at the T-intersection was considered. The impact on the speed of the following-on vehicles towards the T-intersection, from those turning vehicles to the minor road, is negligible because only the inner lane traffic was considered in the analysis.

The resultant speed variation curve against the distance to the amber light (Figure 4) was a quadratic curve with a “minimum speed” observed 20 metres before the midpoint of the intersection. This implied that the speed reduced when vehicles approached the amber lights at the T-intersection. However, although the speed reduced, the minimum average remained at 40km/hr (maximum recorded was over 50 km/hr for more than 1/3 of the vehicles counted). These observations brought suggestive evidence to infer that the drivers would be having a marginal response to flashing amber lights with a higher variance.

This is a serious issue at a T-intersection. It is a questionable behaviour of drivers, as they probably would glance at the incoming traffic towards the T-intersection from crossroads before arriving at the T-intersection and gradually speed up thereafter, if there was no sign of a vehicle approaching or passing through. Hence, drivers would possibly have less ability to react to any sudden vehicle approaching at T-intersections at the time of passing through it under amber light at a speed of 40 to 50 km per hour. This would also imply that the flow rate on minor roads could have an impact on the speed variations in the major road.

Tay revealed that there was an increased severity of crashes at intersections that occurred during the night-time. Due to the lower traffic density on the roads at night, the motorists showed a greater propensity to speed their vehicles. This behaviour would lead to increase the probability of occurring accidents and their severity [29]. Apart from this, drivers would be unable to respond quickly and effectively at night, because of late-night drowsiness and low visibility. Delay in driver reaction would imply that relatively a shorter time available for a driver to slow down the vehicle, giving rise to increased severity of crashes and fatalities.

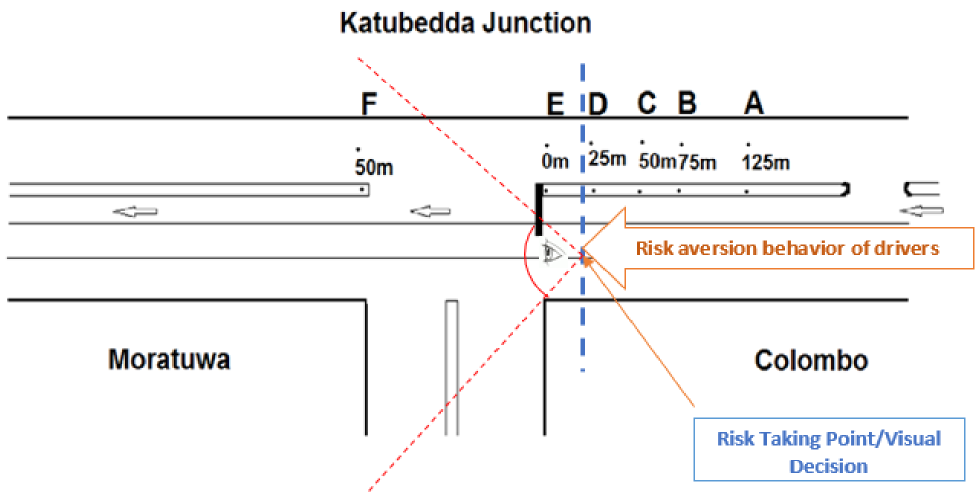


Figure 5: Driving behaviour with distances to amber light

Based on Figure 5, from 125m to 20m was the distance where the risk aversion behaviour of drivers was observed. At point 20m to the amber light drivers appeared taking the risk after analysing visual observations. This risk-taking point of drivers may vary depending on age, sex, human vision, stress level, and driving condition.

The utility is the level of satisfaction that a human being gets while they make any decisions. People make their choices based on the level of satisfaction that they get from their choices. The utility is the preferences of people that enable them to be represented in numerically useful ways [30]. Driving decisions also would be influenced by the level of satisfaction that the drivers get through driving. Utility matters when the drivers make the decision whether to drive or not and to choose which route to take and which mode to be selected for driving. Schubert evaluated the utility of driving toward automated decision making under uncertainty and the results indicated that the utility of driving could be evaluated toward pre-set decision making under insecurity. The level of utility varies from person to person. The drivers' travel utility maximization model confirms that the drivers display risky behaviour under certain circumstances [31]. The results of the present analysis also confirm the same, that the drivers take a calculated risk. When approaching a T-intersection, they behave differently; one with lower speed but another with relatively higher speeds. A greater variation in speed levels across T-intersections demonstrates the decision making of drivers regarding the speed level and hence their psychological response to amber lights.

5. CONCLUSIONS AND FUTURE RESEARCH

From the study, it could be concluded that the expected response of drivers from flashing amber lights was marginally reflected by the speeding behaviour of drivers. Flashing amber lights are implemented to signal drivers to drive with caution. Hence, it is expected that drivers would slow down vehicle speeds at the junction. However, results of the study produced suggestive evidence to infer those drivers would tend to slow down their vehicles before arriving at the T-intersection and accelerate even at the T-intersection.

The difference observed between expectation and responses could be a reason for T-intersection collisions at odd hours. Therefore, the effectiveness of using flashing amber lights as a measure for accident prevention at T-intersections is questionable. The results indicated that the traffic along the main corridor did not proactively respond to the amber light, and as a result, there would be a high chance of collision. Therefore, to mitigate the issue, the traffic light system facing the joining roads should guide and alarm the incoming traffic towards T-intersections. In this regard, system capable of capturing a speedy vehicle approaching towards T-intersection along the main corridor and indicating red signal to the vehicle approaching from the joining road, could be recommended.

Implementing a real-time intelligent traffic light system under *machine learning* concepts could also be recommended as a measure of preventing T-intersection collisions at odd hours. In such a system, the duration of traffic light transitions would change depending on the volume of the traffic passing along each lane, as detected by cameras placed at the junction along each lane. This vision-based decision making could thereafter be converted into a controlled decision-making process. In addition, more space for give-way at T and X intersections also could help reduce the impact of collisions during odd hours.

The findings of this study can be used as a steppingstone for further research on driver behaviour for flashing amber lights in signalised intersections. Out of several possible future research areas that can be explored beyond the present study may include investigating driver behaviour with respect to different times of the day, locations, types of intersections. The present research also can be extended to a four-way intersection and compare bi-directional traffic. With that extension, the statistical significance could also be compared. Further research may also focus on measuring the effectiveness of the aforementioned solutions to control traffic at intersections.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance given by the Transport Engineering Division, Department of Civil Engineering for providing speed measurement guns and the Moratuwa Police Station (Traffic OIC), and the surveyors in successfully conducting the traffic survey.

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Journal of South Asian Logistics and Transport
Volume 1 Issue 2 September 2021
JSALT 1.2.3: pp. 35-56
DOI: http://doi.org/10.4038/jsalt.v1i2.33

INNOVATIVE APPROACH FOR RAILWAY SIGNALLING IN SRI LANKA: AN APPRAISAL OF TECHNICAL AND ECONOMIC RATIONALE

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ABSTRACT

Sri Lanka Railway has been increasingly dependent on foreign sources for its signalling, particularly after the introduction of computer-based electronic technology for signalling. Not many companies have competence in the subject, and the resultant deficiency of market competition has compelled the Sri Lanka Railway to depend on foreign third-party contractors to obtain signalling solutions at high cost. Developing a home-grown railway signalling system, anchored on local technological knowhow which would use components that are readily available in the market, has been a long-felt need.

This paper summarises the research and development activities undertaken by the Railway Department in designing and installing a new signalling system to ensure a greater degree of self-reliance in maintenance, sustenance, and further improvement at lesser costs. The technology innovated was used to install colour-light railway signalling at four railway stations and over 28 km of automatic block signalling, resulting in a capital cost saving of around 90% compared to recently procured imported systems.

The new system has been found operationally reliable and easily maintainable. With this technological innovation, continued improvements to it, and expansion of its coverage in the railway network, Sri Lanka Railway could look forward to securing very significant operational and cost advantages while generating national economic benefits as well in the years to come.

Keywords: *Railway Signalling, Sri Lanka Railway, Technological Innovation, Self-Reliance, Operational Sustainability, Cost Economics*

1. INTRODUCTION

1.1. Background

An effective and reliable signalling system is a necessary condition for the provision of safe and efficient passage of trains operated by a railway network. Railway signalling systems are designed as fail-safe systems to avoid erroneous signals resulting from equipment failure. At a time of signal failure, trains have to be operated using manual signals in accordance with established rules and regulations. These manual operations carry much higher risk as well as delays, and thus have to be avoided as much as possible. Therefore, safety, reliability and ease of maintenance of a railway signalling system are of paramount importance for the safe and efficient train operations.

According to an analysis of train delays conducted by the Sri Lanka Railway Signalling and Telecommunications Sub-Department [1], there have been seven signal breakdowns in average per day in the Sri Lanka's railway network, causing approximately 43 minutes of overall train delays per day. This questions the reliability of the existing system and highlights the need to procure a new system or to upgrade the existing system.

This paper presents a summary of an innovative research undertaken to design, construct and implement a new signalling system for the Sri Lanka Railways.

1.2. Practices hitherto adopted

Signalling systems evolved from the initial mechanical systems to multiple-aspect colour light signalling in the early 20th century. Multi-Aspect Signalling (MAS), adapted in 1923 in Great Britain, is the leading method of operation throughout the world even today. In this system, unsafe situations are prevented by an arrangement of tracks and junctions by a signal apparatus (interlocking) in a way that bars conflicting movements [2].

Mechanical signalling systems introduced to the then Ceylon Government Railway (CGR) by the British colonial administration are still operational in much of the Sri Lanka Railway network. This relies on manual operations and adheres to safety regulations. With increasing traffic densities, however, it is unavoidable that inefficiency and human error would cause delays and accidents.

Colour light railway signalling was first introduced to Sri Lanka Railway in the 1950s. This relay-based system is currently in operation in Colombo and suburbs. Relays used for these systems were manufactured by a company called Ericsson from Sweden. Unfortunately, they no longer manufacture these relays.

Computer-based colour light signalling systems replaced mechanical signalling in the coastal line from Kalutara North to Galle in the year 2000. Even in this system, interfacing of wayside equipment to the electronic interlocking unit is done through relays, using half as many relays as in a totally relay-based system. It is a complex system to maintain.

The Sri Lanka Railway's network, indicating different sections with different signalling technologies, is depicted in the Figure 1.

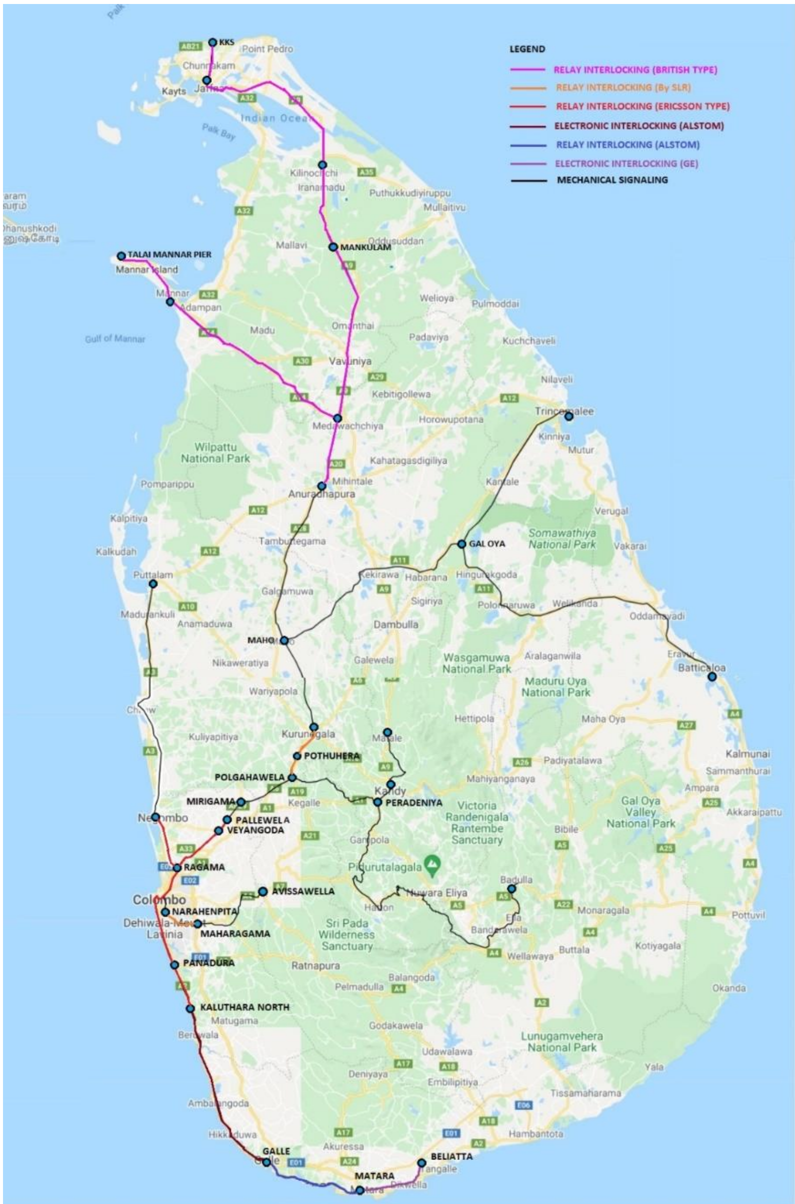

Figure 1: Sri Lanka Railway Network

1.3. Issues diagnosed

Railway Signalling systems introduced to Sri Lanka Railway since 2000 have many issues related to technology, diversity of systems and lack of components for replacement. For instance, the versions of electronic interlocking cards installed in the coastal line in year 2002 are no longer in production. Newer versions are not compatible with the system in place. To make matters worse, due to the complexity of the system, the contractor's assistance was required to carry out modifications, at an enormous cost and a significant delay. Although the signalling system on the coastal line from Matara to Beliatta was installed by the same company, the new section had to be installed with a different type of electronic card system; the reason being the non-availability of the existing older type, which was out of production.

The problems are not merely due to lack of components, diversity of systems or technical issues, but also to the cost involved in installation and maintenance. The Table 1 illustrates the escalation of capital cost intensity of signalling installation over a decade since 2008.

Table 1: Cost of installation and diversity of existing imported Railway signalling systems - Sri Lanka Railways

No	New signalling Project	Year	Cost per station	Type of interlocking used
1	Panadura - Veyangoda Ragama - Negombo	1960	Unknown	Swedish Ericson type relays
2	Kalutara - Galle Restoration	2008	USD 1.0 Mn	VPI Alstom (Computer based)
3	Northern Line beyond Anuradhapura	2014	USD 2.0 Mn	British interlocking using Q type relays
4	Matara - Beliatta	2018	USD 3.0 Mn	GE_XP 4 (Computer based)

Source: Author's estimates

As reflected in the Table 1, the signalling systems procured by the Sri Lanka Railway during the last two decades were from different manufacturers. This has made transferring of technical knowledge and keeping inventories, challenging tasks. Even if a single manufacturer with uniform systems was to be selected to upgrade the signalling, Sri Lanka Railway would then have had to be wholly dependent on that supplier for any future modification or expansion due to the proprietary nature of signalling equipment.

1.4. Research Problem and Objectives

Due to high costs and difficulties in technology transfer, Sri Lanka Railway could no longer depend on foreign contractors for signalling systems. Repairing and expanding the old and obsolete systems, currently in operation were becoming increasingly difficult, costly and unreliable. Yet, there were no locally designed systems which could meet Sri Lanka Railway's criteria. Hence, the problem arose as to how best it could design a reliable, safe, and locally adoptable system at an affordable investment and low cost of operation and maintenance.

The objective of this research and development effort was, therefore, to design and implement a new signal system which would be safe, maintainable, sustainable and economically viable, giving priority to local businesses and national development.

2. LITERATURE REVIEW

2.1. Technical consideration

The publications of the Office of Rail Regulation of UK [3], RISSB of Australia[4] and Pachel [5] described the criteria for developing an appropriate signalling system for railways and Safe management of movement, prevention of traffic from colliding with other rolling stock, derailing, colliding with pedestrians or vehicles at level crossings, being incompatible with infrastructure or colliding with rail safety workers or equipment in the rail corridor, can be identified as functional requirements of a railway signalling system. Palumbo [6] discussed the evolutions of the three main interlocking systems that are available for these purposes, namely the mechanical, relay-based and computer-based systems, analysing in detail their advantages and shortcomings. Mocki et al. [7] [8], takes the position that more sophisticated signalling arrangement would be desired for modern double, triple and more track arrangements, even though the manual interlocking is very sustainable. This is because the mechanical systems are time consuming with high technical risk due to the human factor and needs manpower, even though their life cycle is impressive. According to Knutton [9], even though the Computer-Based Interlocking (CBI) system has the advantages of saving space and remote operability, there could be delays in the acceptance process for CBI systems, caused due to lack of formality, diversity of applications, difficult maintenance and low estimated average of life of equipment. On the other hand, relay interlocking got a low technical risk regarding safety, operational performance that could meet all requirements, and economic life long enough to match the capacity of the industry to maintain and renew installations in the long term [9]. Mocki et al. opines that CBI would provide an interlocking similar to what relay interlocking could offer.

Table 2: Comparison of lifetime and capacity of different signalling systems

Signal System	Lifetime (years)	Capacity (Minutes/train)	Reference
Mechanical	75	30-50	Mocki [8]
Relay-based	25	3-5	Knutton [9]
CBI	10	3-5	Dohwa [10]

Source: Author

When considering the Sri Lanka situation, it is obvious that the country has to move fast away from the existing mechanical signalling system, because, as indicated in the Table 2, the desired train frequencies and punctualities could not be achieved with the train operating capacity provided by such systems. However, the data also indicate that there would be no advantage in going for CBI systems compared to the relay-based system, at least in terms of their comparative train operating capacities.

There is no consensus, however, on the preferable type of relay be used in a signal system. They have observed that, even though reasons were not specified, many relay rooms in Australian railway were using Q-type relays mounted in racks [7].

There is no particular compulsion, however, to use a single interlocking technology either. A combination of interlocking systems may be preferable, as stated by Mocki et al. [7], because some sequential process would be necessary whenever new technology or/and concurrent interlocking processing are introduced. Accordingly, advantages of both relay and CBIs could be combined when seeking new interlocking process and new technology implementation. Accordingly, the best technical option for Sri Lanka Railways would be to design a relay-based interlocking system with the incorporation of computer interface (hybrid system) to facilitate local and central control, event logging and the ability to integrate the system with future advancements.

2.2. Economical consideration

Mocki [8] compared the railway interlocking functionality of different systems with their respective costs involved. Accordingly, the CBI would possess improved functionality at a similar cost compared to a relay-based system. However, this cost-benefit relationship was not observed in the Sri Lankan experience.

Advantage of increasing local content in the procurement of infrastructure projects in low-income countries was clearly explained by the Institute of Civil Engineers and Engineers Against Poverty in their briefing notes in 2008. Wells et al. [11] explained that increasing the input of local labour, goods and services (local content) in the delivery of infrastructure projects in low-income countries could make a major contribution to economic growth. According to them, the immediate benefits of increasing local content in projects would include more employment in the construction and supply industry opportunities for local consultants, more work for local contractors and market opening for suppliers of materials and components [11].

The benefits of a national endeavour would not be limited to activities relating to procurement and installation but would extend to the area of further modification as well. When railway signalling systems are installed by foreign contractors, transfer of technology to local staff is not always forthcoming. Even if a certain degree of transfer takes place, it is often incomplete. Therefore, the institution and the country have to continue to depend on technical assistance from abroad for future modifications, implying significant costs and delays.

Furthermore, during the production of items used for signal systems installations, specific requirements of the railway would be transferred to manufacturers. Thus, with a steady stream of demand from railway signalling projects, reliable and technically competent manufacturers for railway signalling equipment would emerge in the economy. This initial opportunity, and the resultant space for further technological advancement, could one day enable them to enter into international markets.

ADB guidelines for economic analysis of projects stipulate that “resource inputs used by a project have an opportunity cost because, without the project, they could create value elsewhere in the economy. An economically viable project requires that, first, it represent the least cost or most efficient option to achieve the intended project outcomes; second, it generates an economic surplus above its opportunity cost; third, it will have sufficient funds and the necessary institutional structure for successful operation and maintenance” [12]. Similarly, when evaluating projects, the common practice is the selection of the most cost-effective solution that meets technical, functional and quality requirements. This criterion is clearly explained in the European Commission’s Guide to cost-benefit analysis of investment projects: “If different alternatives have the same, unique, objective and similar externalities, the selection can be based on the least cost solution per unit of output produced” [13] When these criteria are applied to railway signalling projects, importing a system having an expected useful life of 10 years, to run a train every 7 minutes along a railway line, at a cost of more than USD 3 million according to feasibility study done for Kelani Valley line signalling [10], cannot be justified, if the same requirement could be met by spending just USD 0.1 million with a 40-year life backed by readily available technical expertise.

In conclusion, promoting local technologies would result in reduction of foreign debt burden of the nation, and would possibly help economise Government expenditure. Also with reduced government borrowings, private sector would secure greater access to finances without being crowded-out by the Government spending. Injection of money into local economy would result in fiscal stimulus as emphasised by the Keynesian effect [14]. Therefore, the development of railway signalling using locally developed technologies would bring multifaceted benefits for the country's economy in the current juncture.

3. METHODOLOGY

The approach used in developing the new system, schematically represented in the Figure 2, included (a) gathering of knowledge from lessons learned from the past, (b) identifying features that need to be incorporated in the system, (c) examining the available technologies in the world and mapping them against the criteria that have been identified, (d) selecting the best model and developing a new signalling system, (e) comparatively assessing techno-economic viability, (f) implementing the new system and (g) conducting a post-implementation analysis of the degree of achievement of objectives.

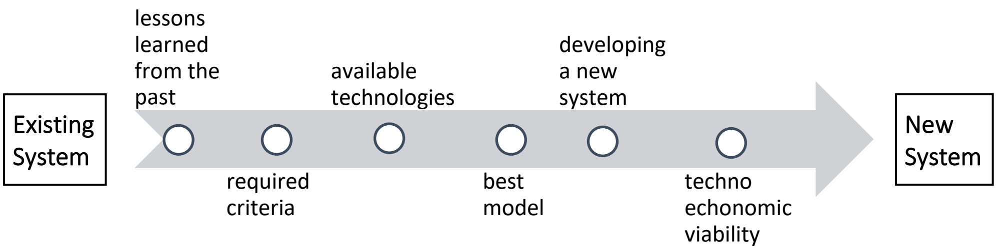

Figure 2: Schematic representation of methodology

4. ANALYSIS TOWARDS DEVELOPING A NEW SIGNALLING SYSTEM

4.1. Lessons learnt from the past

The relay-based interlocking systems had been in function since the 1960s and had been time-tested in Sri Lanka. The systems between Panadura-Veyangoda and Ragama–Negombo sections (Figure 1), installed in 1960, are still functioning, although they have out-lived their life span. With the modernisation of railways, new complex CBIs were introduced to railway sections between Kalutara and Galle, and Matara and Beliatta, at much higher costs. In addition to the high initial installation cost, Kalutara-Galle section had to be restored at a similar cost, following the Tsunami devastation in 2004.

The problems faced in expansion of Kalutara-Galle signal system taught a lesson to Sri Lanka Railway that it needed to adopt a system with universally available material and technology. The lack of uniformity in the system and the need for foreign contractor help for any modification highlighted the need for a simple system that could be locally produced and maintained.

This mandated the author to critically evaluate the systems that were available worldwide, and to adopt a system that would be technologically and economically suitable for Sri Lanka.

4.2. Required criteria and features

The fundamental criterion adopted was that the innovated system should be locally manufactured, reproducible, and maintainable at a low cost. It also had to meet the safety, reliability and operational efficiency standers required.

4.3. Available technologies

The Planning and Construction Division of the Signalling and Telecommunication Sub-Department of Sri Lanka Railways looked into the available options for upgrading the existing system. The first option considered was a CBI based Multi-Aspect Signal (MAS) system which was a widely used system in the world. An initial market survey, conducted mainly through vender websites, revealed the availability of a number of CBI based MAS systems from different manufacturers such as VPI (General Railway Signals, Now Alstom), Micro Lock (General Railway Signals, now Ansaldo STS), West Lock and West Trace (Invensys Rail, now Siemens), and Smart Lock (Alstom), MEI 633 (Medha), K5B series (Kyosan) and E132FA (Nippon Signalling).

However, there were many constrains to adopt this system. The first and the most important among those being the fact that these systems were rapidly evolving and thereby needing money and expertise to either upgrade or replace quite soon. For example, Nock in his study remarked that first generation processor-based MAS systems developed with the collaboration of British Railway, GEC-General Signals and Westinghouse Signals in the 1980s under the brand name of Solid-State Interlocking were no longer being manufactured [2]. The second factor was related to the installation and maintenance of the system, which concerns the impossibility of guaranteeing that the same brand, used for initial installation, would be selected, as per the available procurement guidelines, when bids are entertained for replacement or extension of the existing system. Due to the diversity of vender specific programming applications and programming techniques, it is not feasible or sustainable to have systems supplied by different manufactures. Even though both systems were installed by the same company, the latest system was installed using equipment manufactured by a different vendor and not the previous one. The original equipment manufacturers are not willing to provide spare parts or components for new installations due to small market size and differences on procurement guidelines. As a result, Sri Lanka Railway has to depend on middlemen to procure new signalling systems or spare parts for maintaining the signalling systems. Furthermore, due to complex nature of proprietary programming languages, it is difficult to sustain in-house capabilities for programming for future modifications or new installations.

When one considers these two electronic railway-signalling-systems installed in Sri Lanka, it could be clearly seen that the electronic interlocking systems consist of significant number of relays. Both systems depend on interface relays to connect wayside equipment to the interlocking systems. This requirement for interface relays in the electronic interlocking systems clearly indicates continuing demand for railway Signalling relays and their sustainability. Thus, when considering the requirement of interfacing relays in electronic signal interlocking systems for interfacing, it is difficult to see any advantages in implementing electronic interlocking-based railway signalling systems at stations other than at larger ones like Colombo Fort.

Figure 3: VPI interlocking at Gintota, 2002

Figure 4: GE interlocking at Kekanadura, 2018

A good example of the lack of universality is illustrated in the electronic signal systems in the Coastal Line at Gintota (Figure 3) and Kekanadura (Figure 4) of Sri Lanka Railways.

Furthermore, in a tropical country like Sri Lanka where lightning and electrical surges are prevalent in railway environment, maintaining a susceptible electronic system would not be easy; thus, interface relay usage becomes inevitable. In such a situation, saving 50% of relays used in a typical relay-based railway signal interlocking system, by substituting those with a complex manufacturer-specific electronic hardware, does not make sense.

The second option considered was the relay-based MAS systems. Just as much as CBI-based MAS systems, a number of different relay-based MAS systems were found available in the market. According to vendor websites, Siemen's relays, B-style relays used in USA, N. S1 relays based on French standard (SNCF), Arteche auxiliary relays and Q-type relays were a few in the lead. However, the relay-based MAS system (Ericsson) that has been in operation in Sri Lanka Railway since 1960s, is no longer available in the market.

Q-type relays based on BS 930 standard were widely available around the world. This was due to the fact that, BR 930 specifications had a number of variations catering to different applications leading to universality and versatility unlike others which were region specific. Also, the carbon-to-carbon relay contacts in Q-type relays would give lesser probability of contact welding than Ericson relays which used metal-to-metal contacts. This was an improved safety of the system. Furthermore, Q-type relays had a competitive price advantage, possibly due to availability of a large number of manufacturers. According to IRSE, UK had a demand for 50,000 Q-type relays in year 2013. Q-type relays were being produced by multiple manufacturers based in India, Australia, United Kingdom, Netherlands and USA [15].

Following are among the companies which manufacture Q-style/BR930 relays today:

(i) Mors Smitt Ltd. (UK)
(ii) Siemens Ltd. (UK)
(iii) Selectrail Pty. Ltd. (Australia)
(iv) Crompton Greaves Ltd. (India)
(v) Arteche Pvt. Ltd. (Spain)
(vi) M/s Radha Raman Eng. Co. (India)

Due to the generic nature of these products, they are all readily compatible with each other. The universal availability would offer the advantages of a competitive market with product availability for many decades to come.

Reliability and safety of BR930 based Q-type relays (Figure 5) have been proven by 50 years of service. Those relays were well adapted for operation in countries like Sri Lanka. Based on performance, the mean time between failures (MTBF) for BR 930 relays would be around 550 years.

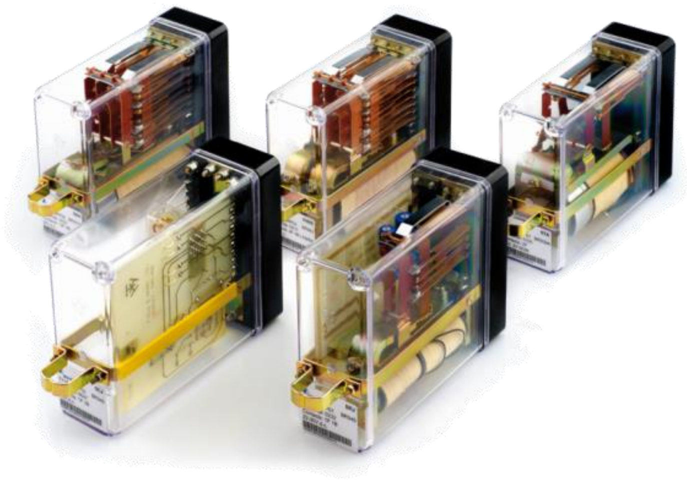

Figure 5: BR930/Q type signalling

In addition, operational safety of the Q-type relays also would meet SIL4 safety requirements by enabling a "Mean Time Between Wrong Side Failure" (MTBWSF)[1] of 6.89 x 10^9 hours [16].

The BS 930 based Q type technology is an evolving technology, coming up with innovations for better performance even today. BS 930 based solid state railway signalling relays are now coming to market to replace electromagnetic ones with longer lifetimes and lower energy consumptions.

Relay-based railway signalling interlocking technology is well established in Sri Lanka, having been used over more than half-a-century. Electronic railway signalling systems are now becoming more popular due to ease of installation and troubleshooting. Even though electronic railway interlocking systems have advantages over relay-based interlocking in power consumption and space saving, they are handicapped by the need for isolation from the hazardous external environment, complex proprietary programming languages and change of hardware versions with changing technologies.

Considering the above, and particularly the universal availability, reliability, economics and sustainability, a relay-based railway signalling systems using locally developed design technologies was decided as better suited for Sri Lanka. Furthermore, it would not be a farfetched idea to start manufacturing Q-type relays in Sri Lanka, possibly with private sector collaboration.

[1] Mean Time Between Wrong Side Failures (MTBWSF) is the measure of the average duration between two occurrences of erroneous signals being issued to trains by a signalling system.

5. THE INNOVATIVE DESIGN

5.1. Data and information gathered

Several factors, pertaining to both the relay type and positioning of signals, were taken into consideration when designing.

Q-type relays are available in both latch and non-latch types. But Q-relay based colour light signalling already introduced to Sri Lanka do not use latch-type relays and as a result of that design technique, power failures can result in memory loss of previous operations. Therefore, this approach requires extensive power arrangements to ensure power availability for safety. In comparison Latch relays retain memory of operations in progress even after power failure and they would give better safety with less demand on power supply. Also, using latch relays allows safety interlocking to be achieved with fewer relays relative to the Indian-Q relay interlocking approach.

Train accidents happen due to trains overshooting beyond a signal at danger if another train happens to be there in front within that range. During recent past, number of train accidents got reported in Sri Lanka railway network under the similar circumstances and therefore addressing this issue was a long-felt need. It has been statically proven that at 100Kmph operational speed, signal passing at danger seldom happen beyond 183m [2]. Therefore, under overlap protection principle, before activating an *Amber* signal to reach *Red* stop signal ahead, 183m section ahead of that Red stop signal also must be clear of trains. Even though overlap protection had been provided at varying degrees at station limits in earlier installations, overlap protection for block signalling was never provided before this.

5.2. Designing the New System

This new signalling system was designed using Q-type latch relays, deviating from the common practice of not using latch relays in Q-type relay-based systems. Under this new design approach, when train movement is allowed by one of the signals, locking relay relevant to that signal would be dropped to prevent any conflicting movements. In addition to locking conditions of relevant signals, track conditions, point conditions, level crossing and other required conditions were added to the relay diagram circuits as per safety requirements.

In addition, a computer based human-machine interface to counteract the difference in functionality between the relay-based systems and CBI was introduced for the first time by Sri Lanka Railways to be used by the Station Master for operational convenience and event logging. Centralised Traffic Control (CTC) allows a single controller to operate multiple stations, which would improve the efficiency of train operations. As an initial step in facilitating CTC, Programmable Logic Controller

(PLC) was incorporated as the interface between relay interlocking and human-machine interphase (HMI). Furthermore, it enabled the introduction of Graphical User Interface for high level process supervisory management (Supervisory Control and Data Acquisition - SCADA) while facilitating data logging for trouble shooting and incident investigations. Computer hardware for the local Control Panel and communications was obtained from compatible sources readily available in the market and software development was undertaken by the technical personnel of the Signalling and Telecommunications Sub-Department of the Sri Lanka Railway. LED bulbs were used for signal aspects, instead of incandescent bulbs to improve visibility and reliability.[2] Even gate signals were provided with five-aspect LED signalling manufactured at Dematagoda Signal Workshop for better visibility and distinction.

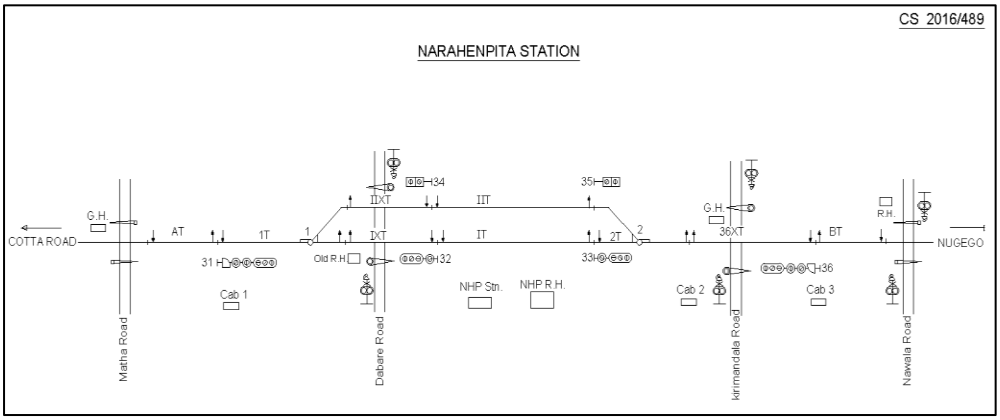

Figure 6: Narahenpita Station Signal Arrangement

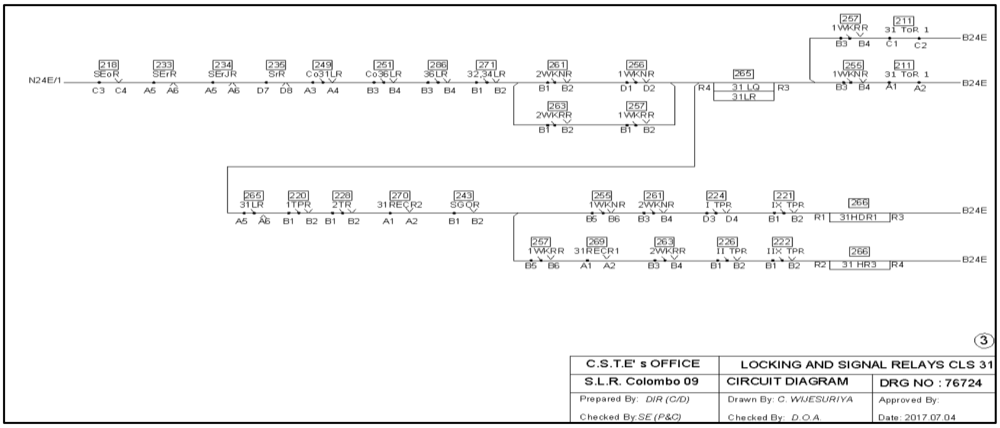

Figure 7: Relay Design Diagram

[2] Sri Lanka Railway has been using incandescent bulbs for signal lighting, except in the Northern part of the network. They frequently fail, and their focus and brightness are inferior to LED bulbs.

5.3. Implementation of the New Innovation

5.3.1. Features and functions

It was decided to implement the designed system at a single loop station as the first step towards standardising the signalling system of the Sri Lanka Railways. Narahenpita Railway Station (geographical location indicated in Figure 1) was thus selected to implement the newly designed signalling system for its close proximity to Colombo, and also for the ease of monitoring and implementation.

The earlier signalling system at Narahenpita consisted of C-type mechanical signalling, where points for track deviations were hand-operated by the station employees and the trains were admitted to the Station by the Station Master. The new system allowed the Station Master to operate points and signals, to admit trains to the station and also to dispatch them using the computer-based local panel, which minimises the manpower needed. Unlike before, the safety of train operation is assured by the new interlocking system.

Figure 8: Relay based system at Narahenpita, 2016

6. RESULTS AND DISCUSSION

6.1. Practical observations

This new system was installed at Narahenpita railway station in the year 2016. A continuous monitoring of its functioning, and entertaining any issues reported was ensured through the project. Several issues that were reported since commissioning, mainly owing to various teething problems, were related to contact defects in Q-type relays used, poor condition of tracks due to creeping of rails, flooding and defects in power supply. System performance improved to the expected level when inverters and relays with contact defects were replaced, and track defects were rectified, and rainwater drainage facilities at the yard was improved.

During the entire period of operation, ever since installation, neither accidents nor any events reflecting violation of the principle of fail-safe operation, were observed.

6.2. Technical evaluation of efficiency

The mechanical yard signalling arrangement that existed at Narahenpita station before installation of the new system only provided entry signals at both ends. Other than preventing both entry signals being issued at the same time, no other safety mechanism had been provided by that system. Diversion between tracks at the station was done by manual operation of diversion points by a Pointsman, who would raise green flag to the train until it passed through the point. Then again, the Pointsman had to go to the other end of the station loop line to do the same. As those manual operations are no longer necessary, the newly implemented system has markedly improved the efficiency of the system; the train operational time of a train at the station has been brought down by around 2 minutes.

Average number of failures of the new interlocking system installed at Narahenpita was less than five failures per year during the past three years; well below the network average failure rate of around eight per year, demonstrating the enhancement of reliability the new system has enabled.

Besides, neither train accidents nor system failure causing erroneous signalling have been reported to date, ever since the commissioning of the new system. This was an expected outcome, as the innovation has provided system-driven safety mechanisms, in contrast to the hitherto prevailed excessive reliance on the Station Master for safety assurance by following railway rules and regulations in manual operation of trains.

6.3. Economic evaluation

Noteworthy benefit of the new system is its capital cost efficacy. Based on the experimental installation at Narahenpita, it could be reasonably estimated that a single line station could be provided with the new signalling system at a cost of only USD 0.1 million. When compared with recent procurements of similar signalling systems for Sri Lanka Railways at costs more than USD 2 million per station, this innovation by the Signalling and Telecommunications Sub-Department would have saved approximately USD 1.9 million per station to the institution and to the national economy.

In the last two decades, very high price variations could be observed between locally designed and installed signalling systems and the signalling systems installed by foreign contractors (Table 3).

Table 3: Comparison between installation cost of local and foreign Relay based interlocking systems and reproducibility - Sri Lanka Railways

No	Project	Configuration	Year	Cost $	By
1	Northern Line	Single line/Single loop	2014	2.0M	Foreign
2	Narahenpita KV	Single line/Single loop	2017	0.1M	SLR
3	Nugegoda	Single line/Single loop	2017	0.1M	SLR
4	Pothuhera	Double line*/Single loop	2019	0.2M*	SLR
5	Maharagama	Single line/Single loop	2020	0.1M	SLR

Note: Geographic locations are indicated in Figure 1.
Source: Author

The replicability of the Narahenpita experiment to other localities could be observed through the information summarised in the Table 3. It is apparent that the designed system would be reproducible with similar costing as illustrated in the cases of recent installations of the new system at Nugegoda and Maharagama. The cost difference at Pothuhera was due to the different configuration of the track layout necessitating higher number of components to cater to the double line

It must be emphasised that this economic advantage is not limited to capital costs of installation, but also extends to favourable effects on national value addition and Balance of Payments. The new innovation reduces foreign inputs, and thus creates demand for local industries[3], stimulating a demand-pull effect on the domestic value added, as advocated by John Maynard Keynes [17]. Besides, only less than 20% share of the total costs involved in the locally designed system was purchased through foreign currency. This generates a positive impact on the country's Balance of Payments, compared to the imported systems where almost the entirety of capital expenditure (excepting for those spent on a few local inputs) drained out of the national economy.

The locally designed system has the added advantage of being more efficient in terms of operating costs as well. It gives rise to lower power consumption, in comparison

[3] In the new system installed at Narahenpita and other locations, the supply of copper cables, metal cabinets, power equipment and other items were sourced largely from local small and medium sized manufacturers, thereby supporting local industries.

to the foreign system. The average power consumption as mirrored through the payment requests on monthly electricity bills was only USD 150 at Narahenpita, when comparable stations in the Northern Line, signalled by a foreign company, have been receiving an average monthly electricity bill per station of around USD 250. The labour cost savings associated with the new system would not be negligible either, because, the station cadre could be reduced owing to automation of the point operation, who could be deployed elsewhere in more productive work.

It is in this context that Cumaratunga Munidasa's vision becomes relevant and important; according to which, "*Patriotic consumers would prefer local products. By this local product preference, local manufacturers would get motivated to invest more to increase production*" [18]. When foreign contractors undertake infrastructure development projects in a country, innovations, manufacturing capacity expansion and increase in productivity take place in the countries of the contractors, and not in the country receiving supplies. Therefore, such situations are nothing but lost opportunities for developing countries like Sri Lanka. Unfortunately, Sri Lanka appears to have failed to be guided by this wisdom of Cumaratunga Munidasa expressed many decades back; the financial difficulties the country is facing today could be, at least partly, a result of this failure.

6.4. Potential of Expansion of the Coverage and Associated Benefits

It is apparent that the relay based signalling system is a safe and reliable system that could easily be installed with the prevailing knowledge and could be maintained or upgraded according to the needs of the Sri Lanka's railway system. Therefore, the new system could be used to replace the old mechanical signalling system, which is still predominant in the railway network of Sri Lanka.

The fact that the implementation of this innovative design at one station alone has resulted in savings up to USD 1.9 million to the Sri Lanka Railway indicates the possibility of securing substantial cost savings, particularly in foreign exchange, when this new system replaces the mechanical Semaphore signalling at other stations in the network (Figure 1). The railway stations up to Maharagama have already been converted to colour-lights with this innovative approach, and currently the conversion of the signalling system in the remaining sections of the Kelani Valley line up to Avissawella is in progress. The total estimated cost for the project to be implemented using this innovative design is USD 2.5 million, reflecting a cost saving of USD 75.5 million on the Kelani Valley corridor alone, as the earlier estimate for the same to be constructed through a foreign contractor was USD 78 million [10]. Similarly, the railway section between Kandy and Wadduwa through Colombo Fort (150 km with 110 km double tracks, 27 crossing stations including major interchanges like

Colombo Fort, Maradana and Loco Junction, Polgahawela, Ragama, and Kandy), which carries more than 80% of the passenger traffic, is being considered for renovation (Wadduwa-Mirigama portion, consisting of Ericsson relay system which is more than 60 years old) or conversion to colour light signalling (Mirigama-Kandy portion presently having mechanical Semaphore signalling at 11 stations). Signalling this entire section with the locally innovated system would cost approximately USD 20 million, while it would cost over USD 200 million (ten times) to the economy if the same is to be realised through a foreign contract.

6.5. Shortcomings and Lessons for Further Improvement

The post-evaluation exercise revealed several shortcomings and possible avenues for further improvement. One such concern is the possible dysfunction of signalling owing to failures in Carbon-to-Carbon contacts used in Q-type signalling deployed in the new system at Narahenpita compared to that in the Ericson system which used relays having metal-to-metal contact yielding better communication. Obtaining relays from manufacturers with higher quality assurance would be instrumental in reducing, to the bare minimum, the probability of such contact failure. Also, poor track conditions at station yards were found creating problems due to track circuit defects. Railway tracks need to be renewed in every 50 years and thereafter can be maintained efficiently through mechanisation and less manual labour. Railway track technology is almost 150 years old, and therefore, local construction companies now excelling in highway constructions could be enticed to enter into railway track construction, if the in-house capacity of the Railway Department is found insufficient. A track renewal plan to bring railway tracks back to standard is a pre-requisite for this purpose.

Even though Narahenpita station area signalling system was converted to colour light signalling, train operation between nearby stations is still done using Tyler Tablet instruments. This necessitates handing over of a metal disc or tablet to the train driver to proceed to the next station, interrupting the continuity of the signalling system. Continuous upgrading, while introducing automatic block signalling between stations and providing local control panels (as the first step) to stations, would be the solution for this problem. Unlike with the tablet in an absolute block operation between two stations, automatic block signalling will enable more than one train entering a section between two stations one after the other, thereby increasing line capacity. In addition, by connecting station operations to central control, train operations can be streamlined and made more efficient. With the inclusion of PLC in the local panel operations and with laying fibre-optic cables along the tracks, train controlling in all these newly colour-lighted sections also could be managed by a Central Traffic Control facility at Maradana, thus, enhancing operating efficacy and reducing train delays.

7. CONCLUSIONS AND RECOMMENDATIONS

The research and development into innovating an appropriate, manageable, self-reliant and cost-effective signalling system for Sri Lanka Railway yielded positive results with a new home-grown design of Q-type relay-based colour-light signalling system. Experience gained through implementation of the new system, and operating it for nearly four years, enabled concluding that the locally made relay signalling system is robust, durable and could be operated on par with computer based signalling systems.

This new signalling innovation has the potential of generating substantial cost savings for Sri Lanka Railways and the national economy. For instance, there are several signalling systems that need to be upgraded urgently in urban and suburban areas as a part of reducing delays, and the innovated system could save substantial amounts of financial resources, both to the Sri Lanka Railway and to the national economy. For instance, the potential cost savings in converting and upgrading the existing signalling systems in the KV line and Kandy-Wadduwa section alone using this local innovation would amount to approximately USD 260 million (Rs.52 billion), which is over 7% of the capital budget of the Government of Sri Lanka in 2020, and around thrice the capital expenditure voted in 2020 for Sri Lanka Railways. With the availability of skilled and experienced project construction group in-house, Sri Lanka Railway is well positioned to realise these cost economics successfully.

In addition, the outcome of this applied research stands as a good example to showcase the effect of innovation in the field of railway signalling and contribution it could make towards development. The advancement made possible through the initiative is significant, in terms of gaining cost advantages, developing innovative culture, enhancing the system’s technological self-reliance, developing economic linkages and stimulating multiplier effect, and also creating wealth for the nation.

The research also found solutions to the few teething problems diagnosed of this system, whereby it is recommended that the best quality Q type relays be used to minimise failures as the system totally depends on the functioning of relays. It is also recommended that the train yards and the tracks be first assessed and upgraded to support the functioning of a reliable system rather than just upgrading the signal system. Finally, this system is recommended for signalling as a pilot study when Centralised Train Control (CTC) system from Maradana is introduced to the entire Kelany Valley line.

Further studies are recommended to calculate the lifetime cost of the system implemented and to compare the functionality and capacity among the currently implemented systems in Sri Lanka.

Finally, the knowledge and skills gained through this hands-on experiment, together with the motivation and dedication of inventors and innovators, Sri Lanka Railways could confidently look forward to further expansions into railway signalling solutions and to upgrade its signal system in an economical and sustainable manner.

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Sri Lanka Society of
Transport and Logistics

Journal of South Asian Logistics and Transport
Volume 1 Issue 2 September 2021
JSALT 1.2.4: pp. 57-72
DOI: http://doi.org/10.4038/jsalt.v1i2.34

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BUS SERVICE IMPROVEMENT PLAN FOR BATTARAMULLA ALONG WITH LOCATION ANALYSIS FOR A TRANSPORT HUB

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ABSTRACT

Deteriorating quality of public transport is a major concern in Sri Lanka. This study focuses on how to improve public transport in Battaramulla, which is the administrative capital of Sri Lanka, located in its Western Province. This administrative division has 11,000 government workers, of whom 56 percent use buses. It has, over 250,000 residents, 37 percent of whose trips also are made by buses.

This study was conducted to identify the demand and supply characteristics of the area, to analyse bus routes for service improvements and to comparatively evaluate among several sites available to locate a multimodal transport terminal.

Using the results of an Origin-Destination study, it was concluded that four new bus service routes, if introduced, would improve passenger connectivity. It also inferred, through a Multi-Criteria Analysis, and considering accessibility, connectivity and costs, that the best site to locate a multimodal transport centre would be that proposed by the Urban Development Authority.

Since, this study was confined only to bus passengers and bus transport facility improvement, further research may be necessary, including other parameters and transport modes, to validate its outcomes and recommendations.

Keywords: *Public Transport, Bus service, Origin-Destination Study, Multimodal Transport Hub, Battaramulla-Sri Lanka*

1. INTRODUCTION

The term 'multimodal transport' refers to the use of several modes to complete a journey. A multimodal transport hub provides facilities accessible by several modes of transport. Kotte-Sri Jayewardenepura is the administrative capital of Sri Lanka, where the Parliament and over twenty ministries and institutions under their purview are located; these institutes employ over 11,000 government employees. Battaramulla is a locality within that, where a majority of these institutions have their main office premises. It is a mid-sized city, 9.2 km away from the centre of the commercial capital, Colombo. Battaramulla is located in the Colombo District of the Western Province and administered by the Kaduwela Municipal Council. It is along the A000 road corridor and is a road junction connecting three major suburban towns namely Rajagiriya, Kottawa, and Kaduwela. Currently, there are eight major bus routes passing through Battaramulla; none of those originate from or terminate at Battaramulla. People transit from Kottawa, Kaduwela and Kollupitiya to take a connecting bus to Battaramulla. Inadequate bus supply resulted in over-crowded buses with a 120% of average load factor in the peak hour.

High trip-attractors such as the Department of Immigration and Emigration and the Department for Registrations of Persons are also located in Battaramulla, attracting many vehicles and passengers daily, resulting in average speed on main roads falling well below 20 kmph [1]. Roadside loading and unloading of passengers also contribute to traffic congestion. Further, the absence of a proper city plan and parking areas cause traffic congestion. It can be observed that taxies are parked on the roadside, blocking the road and consuming more road space. Being the administrative district of the capital city, Battaramulla has passenger demand from all parts of the country. Hence providing better connectivity and better public transport is essential. Growing passenger demand and the increasing road congestion demonstrate that Battaramulla requires a public transport network capable of providing better facilities to encourage the shift of more passengers from private vehicles to public transport.

This research was conceived with the aim of studying the current demand and supply of bus transport services to and from Battaramulla with a view to proposing bus service improvements, particularly through introduction of new services or extension of existing services, and through development of Battaramulla as multimodal transport hub. With regard to the latter, the study aimed at evaluating using Multi-Criteria Analysis (MCA) the suitability of a few potential alternative sites, including that proposed by the Urban Development Authority, to establish a multimodal terminal at Battaramulla. This study was limited only to bus transport connectivity and related facility improvement but would provide some insights into realisation of the broader objective of improving transport connectivity through different modes at the country's administrative Capital in the future.

2. LITERATURE REVIEW

The concept of 'multimodal transport' begins with freight distribution which aims at increasing the efficiency of distribution system mainly by optimising the cost and time. In common parlance, "multimodal transport" refers to carriage of goods or passengers by two or more transport modes on the basis of a single transport contract from origin to destination [2]. This differs from both intra-modal transportation (integration between the same mode) and inter-modal transportation (among different modes such as piggy-back, fishy-back or birdy-back, yet through different contracts).

The same concept was adopted for passenger transportation where 'multimodal hubs' were developed to provide ground facilities for smooth transfers among different modes. The concept of a 'hub' applies not only in transportation but also in telecommunication networks. The hub concept reduced overall transportation costs. Hub location design considers capacity constraints including the number of flows at the hub and available fleet capacity [3]. The modern concept of multimodal hubs not only facilitates transfers among modes; it also facilitates other passenger needs such as meeting places, shopping, commercial needs, and parking. This concept was developed to attract more passengers to public transport [4]. Based on studies carried out for the development of the European bus system, it was identified that elements such as strategic location, integration between different modes and mobility demand, transfer time, information and signalling, and accessibility should be addressed at the early stages of planning multimodal hubs [5]. The studies for proposed multimodal hubs at Kandy [6] and Kadawatha [7] were reviewed as part of this study to identify the methods to be used at the initial stages of the planning of a multimodal hub. Accordingly, a background study for such planning, including the geographical location, urban profile, existing transport network, demand, and supply, was conducted. Supply analysis was conducted using bus frequency counts and load factors survey data. Existing bus network and transport related issues were considered for further analysis. The objective was to improve passenger experience with minimum impact to existing travel patterns.

MCA is a common method used to identify the best location for a facility out of several alternatives. In this methodology, each location is evaluated against different criteria, which are independent of each other, using a weighted average score. The location securing the highest score would be selected as the best option to locate the facility. A study carried out by Awasthi et al. [8] proposed a location planning framework for urban distribution centres which consists of criteria such as accessibility, security, connectivity, cost, environmental impact, proximity to customer, proximity to supplier, resource availability, quality of service, and possibility of expansion. In their study, these criteria have been selected through literature review and discussions conducted with transport experts and city groups and categorised into cost criteria and benefit criteria. Proposed locations for the analysis have been identified using prior knowledge and considering city regulations along with stakeholders' interests. The researchers have used a technique called Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Situation) to evaluate the proposed locations. As the final step of the framework, a sensitivity analysis has been performed.

As indicated in Awasthi et al., the Fuzzy Theory, introduced by Zadeh, could be used to model systems having more uncertainty and vagueness which are difficult to define precisely. The parameters would be defined in linguistic terms first, and then a conversion scale would be applied to turn those into Fuzzy numbers [8].

Colombo city public transport development is a high priority project of the Government. The Megapolis Transport Plan [8] has identified that Colombo city needs transport reform to overcome existing congestion. Continued traffic congestion on urban roads and the deteriorating quality of public transport has inflicted major negative impacts on economic performance, environment quality, and liveability of the city. To mitigate those issues, several public transport improvement projects such as introducing luxury bus services, Rapid Transit System (RTS), inland water transport system, and multimodal hubs have been proposed. Moreover, the University of Moratuwa carried out a study to review JICA COMTRANS Masterplan [10]. This study highlighted Battaramulla as the main town within the Kaduwela Municipal Council with 252,100 residents. It is located on the Colombo-Malabe main road, which has only two to three lane capacity. The review study carried out by the University of Moratuwa [10] has recommended that introducing a Monorail system along with transit-oriented development would be the most suitable solution for this corridor.

3. METHODOLOGY

The study area included Thalangama North, Subhuthipura, Udumulla, Battaramulla North, Battaramulla South, Batapotha, Aruppitiya, Asiriuyana and Rajamalwatta Grama Niladari Divisions (GND), mainly because they were considered to be the potential catchment areas for the Battaramulla multimodal transport hub.

Data collection was done with the objective of identifying existing demand and supply. Primary data pertaining to the passenger demand were collected from employees of, and visitors to, Government institutions located within the study area. Secondary data used were sourced from Household Visit Surveys (HVS) and Bus Volume Counts (BVC) of Colombo Metropolitan Region Transport Master Plan [1]. HVS data had been collected based on Traffic Analysis Zone (TAZ) assigned to each GND to define the origin and destination of passenger trips. The plan of the proposed Multimodal Hub developed by the Urban Development Authority (UDA) was examined to assess the suitability of the proposed location.

The attraction and generation of travel patterns in the study area were observed together with their respective origins and destinations using HVS data, which were also used to calculate the traffic modal shares. Bus frequency along each route serving Battaramulla and load factors were calculated using the BVC data.

The JICA STRADA assignment model was deployed to examine bus passenger demand and supply on the existing road network. The road network, initial origin and destination by mode, and public transport networks, were given as input for STRADA along with other parameters such as speed and fare. The STRADA processed the data and allocated trips to routes by considering the shortest paths. Trip assignment was taken as an output by running the highway reporter module in STRADA which gave total trips for each road segment. Figure 1 below shows the STRADA analysis model with inputs and outputs.

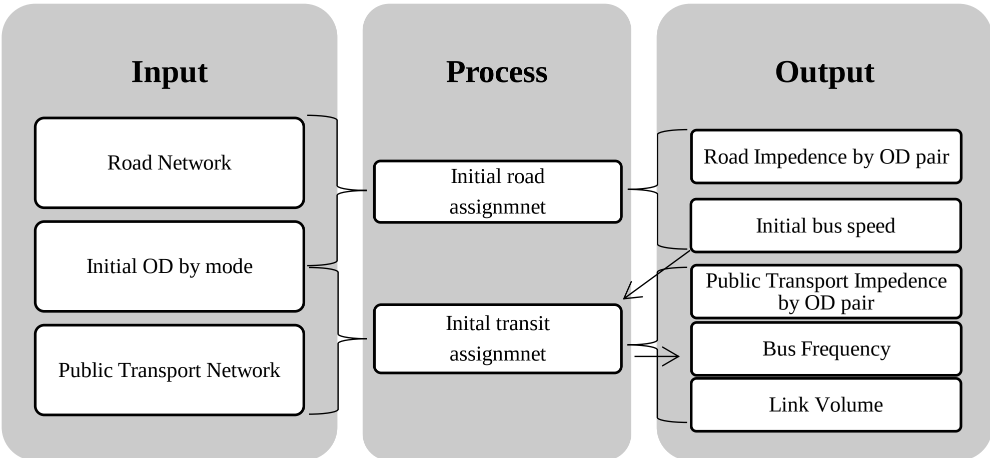

Figure 1: STRADA Analysis Model

Bus supply on each road segment and the bus-based household trip split of each road segment were identified with graphical presentation of the STRADA output. Based on the analysis of the above data the transfer points of existing bus users, the destinations with higher demand, and access roads with higher mobility were identified.

The UDA had already recommended to establish a Multimodal Transport Terminal at Battaramulla within close proximity to the building complexes, housing and most of the Government administrative institutions. The present research opted to perform a MCA to identify the most beneficial location, from among available alternative sites, to locate this Multimodal Terminal. Five candidate sites were subjected to this analysis, having been selected based on the same framework used in Awasthi et al. [8]. Two of those sites had been considered earlier by the UDA in its own evaluations (including the site which was selected by the UDA) 1 and the other three were brought in considering their space availability, proximity to trip attracting and generating points, and opinions expressed by transport experts. The decision criteria for MCA were defined through discussions with transport experts. Some decision criteria identified through the literature survey, including Awasthi et al. [8] in particular, were also considered, which included connectivity, environmental impact and proximity to user. The concept of Fuzzy model identified through the literature review was used to rank alternatives. The weightages for each criterion were decided by the author, based on the knowledge gained through the study. Considering the existing bus supply and future growth, peak hour design capacity requirement was calculated for the hub.

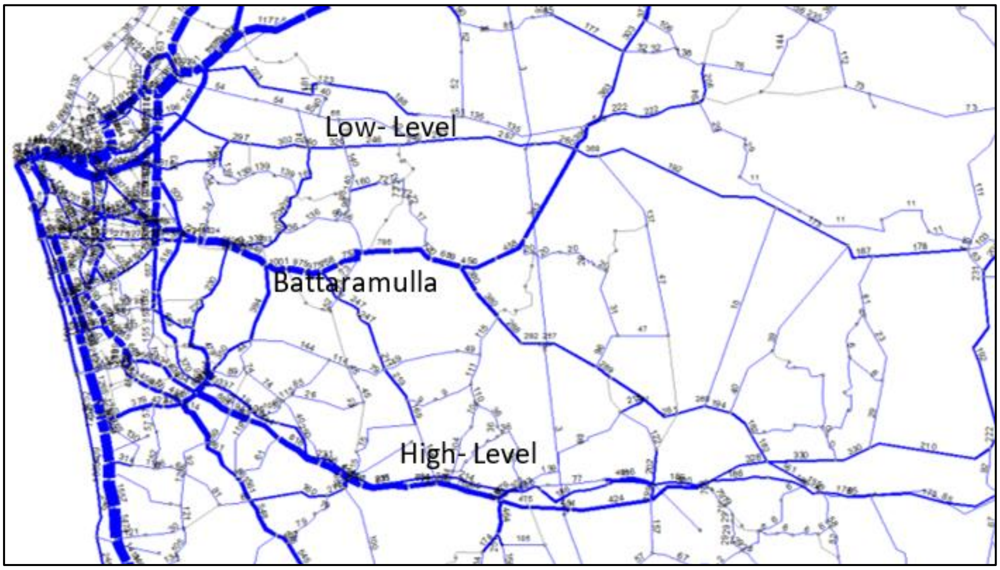

Figure 2: Trip Assignment Output from STRADA

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1 Two sites had been considered by the UDA for this purpose. The first candidate site was the area located in the vicinity of the Sethsiripaya and Suhurupaya office complexes which accommodated more than twenty Government institutions, and the second was in the Denzil Kobbekaduwa Mawatha area where there was another concentration of institutions

Figure 2 depicts the trip assignment output from the JICA STRADA. The width of the line represents the number of trips using bus mode for each link and numbers above the line denote the number of trips for each link. The demand for each corridor can be identified by the thickness of each link.

3.1. Results

The HVS data revealed that 85,833 person-trips were attracted to Battaramulla daily. Of these, 26,185 were intra-zonal trips, meaning that they were within the same DSD area. Another 37% of these trips were accounted for public buses. Around 2% of the trips were those transited to bus from railway at some connection point, while the balance being attributable to various other private modes.

Primary data indicated that there were around 11,285 Government employees working in Battaramulla area and it was estimated that around 10,680 visitors were being attracted by these institutions daily. Moreover, it was estimated that, on Wednesdays, being public days, an additional 6,000 people travel to Battaramulla to obtain various public services. Additionally, six schools are located within the study area attracting around 3,750 passengers including students, teachers, and school staff. Furthermore, 61% of Government servants were found using public transport as their main mode of transport while 25% used arranged transport services such "staff transport". 56% of Government servants arrived using bus routes carrying around 231 buses (in both directions) passing through Battaramulla during the morning peak period between 7 and 8 am. Table 1 below illustrates the details of bus routes going through Battaramulla along with peak hour average headway.

Table 1: Bus Routes through Battaramulla with Peak Hour Average Headway

Route Number	Origin	Destination	Peak Hour average headway (in minutes)
171	Kandawatta Junction	Colombo-Fort	4.5
170	Athurugiriya	Pettah	4.5
190	Meegoda/Godagama	Pettah	3
177	Kaduwela	Kollupitiya	2
163	Denzil Kobbekaduwa Mw	Dehiwala	4.5
17	Kandy/ Kurunegala/Nittambuwa	Panadura	20
174	Kottawa	Borella	3.5
186	Jayawadanagama	Borella	12

Figure 3 below depicts the load factors corresponding to each bus route, separately for Colombo inbound and Colombo outbound directions, during peak hours. The average load factor in buses during the peak period was around 120%, revealing an under-supply of bus services during demand peaks.[2]

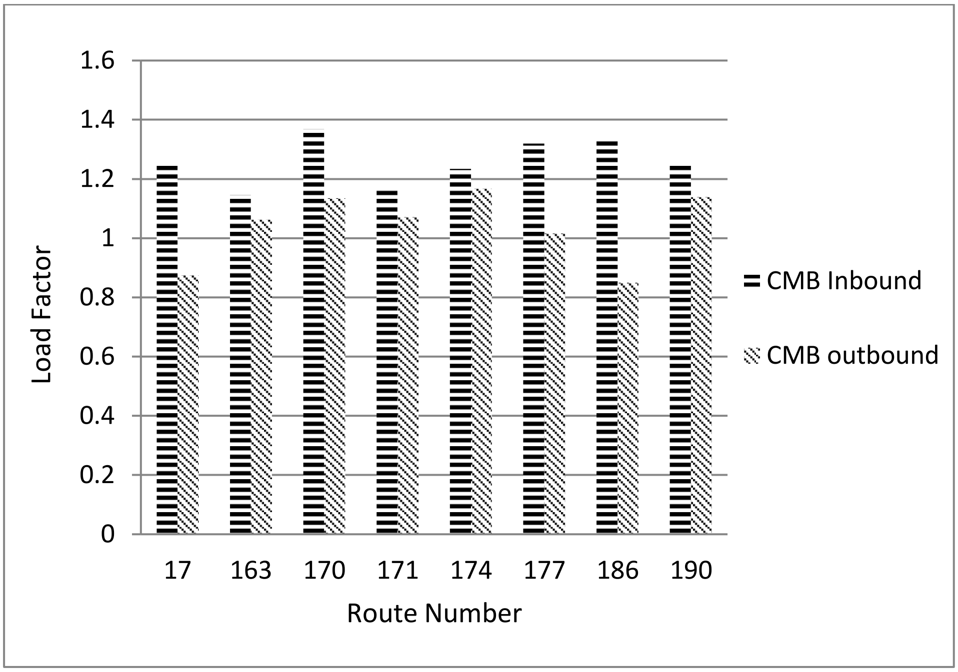
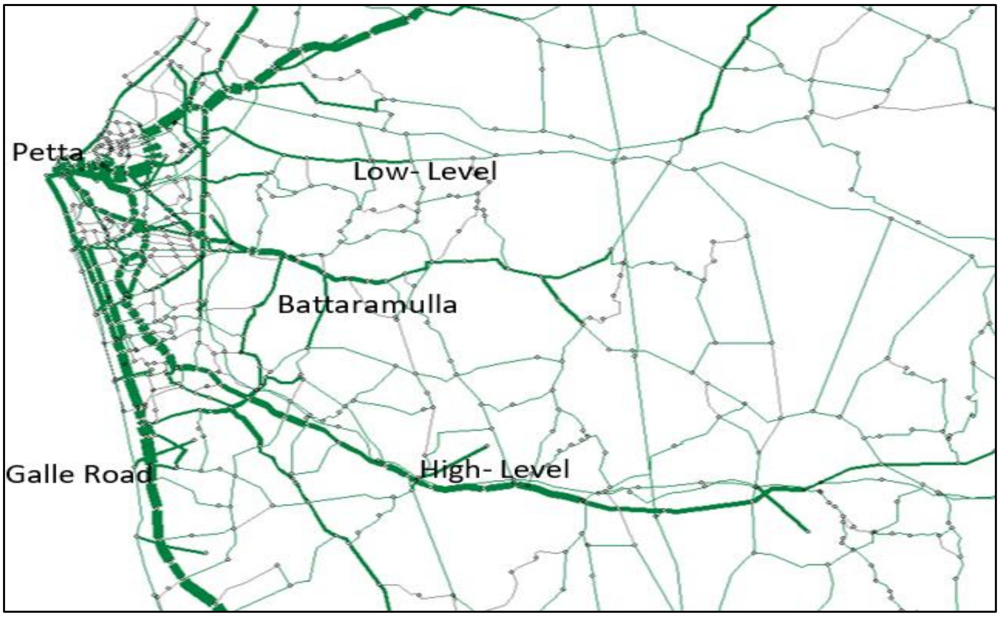


Figure 3: Peak Hour Load Factor

3.2. Analysis of the Adequacy of Bus Services

Given that buses have provided the backbone of public transport for over 100 years [11] in these suburbs, this analysis attempted to examine the adequacy of coverage of bus transport services in this developing area. The STRADA output pertaining to the current demand for bus services by passengers in relation to supply capacity, in terms of the existing bus routes and service frequencies, illustrates that many bus passengers to and from Battaramulla need to get a bus-to-bus transfer either at Borella or Pettah to connect to the major bus corridors serving Colombo city and its environs. Some other access roads to Battaramulla do not have a direct bus supply, thus, dominated by private vehicles. Figure 4 below depicts the existing bus supply within the study area.

[2] The causes behind this observation have to be identified through in depth studies. Some routes may even have excess availability of buses, but overloading could still prevail for other reasons such as not having proper schedules or non-adherence to schedules.



Note: Highlighted lines denote bus supply along the road sectors whereas tiny lines denoted only access roads. The thickness of the line is proportionate to frequency of buses

Figure 4: Bus Supply along the Road Sectors

Figure 5 below shows the attractions and generations to and from each zone along with the current spread of bus routes serving Battaramulla.

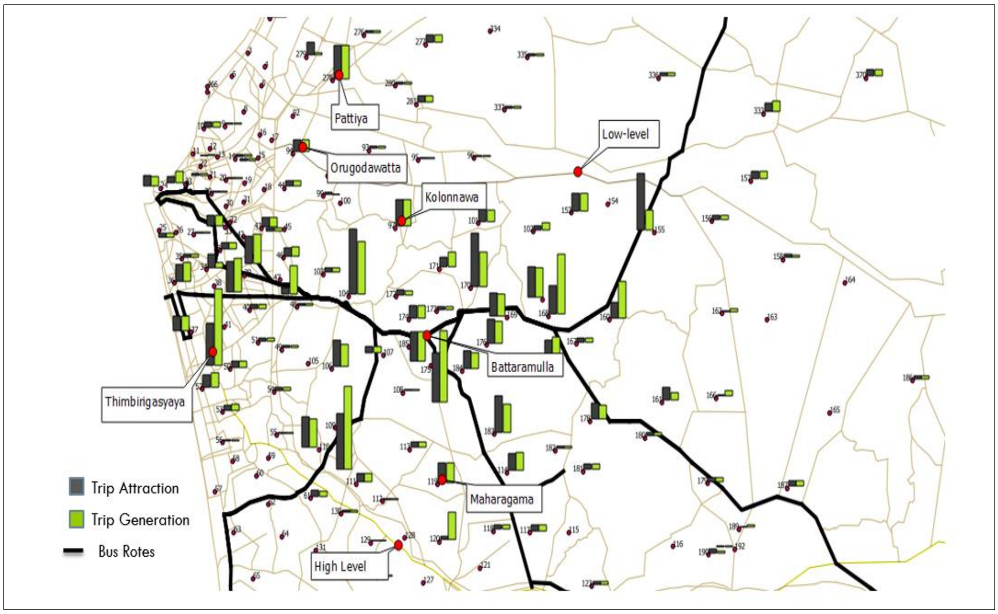


Figure 5: Demand for and Supply of Bus Transport by Zone and Route

Accordingly, it could be observed that places such as Thimbirigasyaya, Maharagama, Kolonnawa, Gampaha, Orugodawatta are found to be locations which, having a large passenger trip attractions and generations to and from Battaramulla, do not have direct bus routes.

Total number of trip attractions and generations at Battaramulla relating to the above identified locations, and the status of having direct bus service (or not) are summarised in the Table 2.

Table 2: Highest Trip Attraction and Generating points at Battaramulla

Location	Total number of trips to and from Battaramulla	Availability of direct bus supply to Battaramulla
Kolonnawa	5,779	No
Maharagama	6,350	No
Gampaha	12,685	No
Thibirigasyaya	52,371	No

Note: Orugodawatta and Peliyagoda zones were grouped in to Kolonnawa.

Source: Analysis of HVS data, and BVC data on current bus supply, 2013 [1].

Based on the above analysis, it is evident that at least four most significant Origins and Destinations of bus passenger trips connecting to Battaramulla have no direct bus services to Battaramulla, and those passengers have to transit at some point during their trip. The following new bus routes could therefore be introduced newly, and subject to their economic viability assessment, could potentially provide and sustain direct and regular bus services to and from Battaramulla:

- Battaramulla to Bambalapitiya (via Borella and Thummulla)
- Battaramulla to Maharagama (via Japanese Friendship Rd and Pathiragoda Road)
- Battaramulla to Peliyagoda (via Angoda and Low-Level Rd)
- Battaramulla to Gampaha (via Expressway E02 and Kadawatha)

Provision of direct bus services connecting those nodes to Battaramulla is likely to greatly convenience the passengers and could possibly encourage modal shift to bus transport.

As the next step, intra-zonal bus passenger trips within Battaramulla were examined. Data sourced from HVS and BVC surveys [1], which categorised the study area, Battaramulla, into seven Traffic Analysis Zones (TAZ), namely, TAZ170, TAZ173, TAZ174, TAZ175, TAZ176, TAZ184 and TAZ185, were used for this purpose.

Table 3: Bus mode user trips distribution within Battaramulla

Zone Code	TAZ 170	TAZ 173	TAZ 174	TAZ 175	TAZ 176	TAZ 184	TAZ 185	Total no of trips
TAZ170	0	65.8	53.2	750.8	29.9	130.4	0	1,030.1
TAZ173	65.6	77.2	0	59.7	40.5	0	0	243.0
TAZ174	52.7	0	0	0	0	0	26.6	79.4
TAZ175	319.8	59.5	0	172.6	257.3	153.0	0	962.2
TAZ176	29.9	40.5	0	291.9	72.2	0	31.0	465.6
TAZ184	216.9	0	0	100.9	0	0	38.1	356.0
TAZ185	0	0	26.6	0	31.0	38.4	481.6	577.7
Total								3,714.0

Sources: Data from HVS and BVC, 2013 [1]

Intra-zonal bus trips within this area, depicted in Table 3, clearly indicates that the highest number of trips made has been within the zone TAZ170 and TAZ175 (Between Thalangama North and Battaramulla North which is from Denzil Kobbekaduwa Mawatha to Battaramulla junction).

This observation suggests that the existing bus services within this section may have to be further strengthened. In this respect, the authorities may consider extending the presently existing bus route number 152 to serve Battaramulla, which is currently starting at Koswatta (Talangama North). This extended service could operate via Denzil Kobbekaduwa Mawatha from Koswatta to Battaramulla to provide a more direct service for passengers, as well as would provide better bus connectivity high trip generating Government agencies such as Department of Immigration and Emigration, which was relocated recently.

3.3. Seamless Bus Connectivity at Battaramulla - A Transport Hub

Public transport service improvement would not be successful unless those improved services are properly coordinated and inter-connected. Seamless transfer, fisrtly among bus services, and thereafter among all modes of transport, would be necessary, for improved bus passenger transport system is to sustain its service delivery efficacy, and also to ensure greater modal shift to bus transport. In this respect, the “Hub Concept” becomes important. This study atempted, (i) to estimate the bus loading and unloading facility requirement at Battaramulla, considering it as a “Bus Transport Hub”, and (ii) to examine a suitable site to locate it, developing it as a Multimodal Transport Terminal.

(i) Required Bus Bays for a Bus Transport Hub at Battaramulla

The study used STRADA calculations of bus passengers who would either board or transfer at Battaramulla to estimate the required number of bus bays for effective and seamless interchange. For this purpose, Colombo inbound and outbound buses during peak hours were clustered separately according to destination. The number of buses that could be allocated per bus bay per hour was calculated using assumed dwell times of 2 minutes, 10 minutes, and 15 minutes, for through buses, local buses starting at Battaramulla, and Expressway buses, respectively. The required number of bus bays to accommodate the number of busses per hour that would be needed to meet the estimated passenger demand on existing and newly proposed routes, could thus be worked out. Summarised results are presented in the Table 4.

Table 4: Number of Bus Bays Required for New Hub

Bay Cluster Number	Colombo Inbound Buses		Colombo Outbound Buses	
	Description	Number of Bus Bays	Description	Number of Bus Bays
1	Buses to Pettah (171,170,190)	2	Buses to Malabe Side (170,190,177,17)	3
2	Buses to Galle Road (17,163,177)	2	Buses to Denzil K.R (171,163)	2
3	Buses to Borella (174,186)	1	Buses to Pelawatta (174,186)	1
4	New Route Originate from Battaramulla (local & express)	8	New buses end from Battaramulla	1
Total		13		7

Assumptions:

(a) Buses going through the hub would have a dwell time of two minutes.

(b) Incoming passengers of buses terminating at Battaramulla would disembark at a common bay

(c) Local routes starting from Battaramulla would take 10 minutes of boarding time

(d) Expressway buses would take 15 minutes of boarding time.

(e) Existing bus frequency will be increased by 20% with improvements

Note: The calculation was based on the supply of and demand for buses only. The requirement for mode sharing within the terminal, when the Bus Transport Hub is upgraded to a Multimodal Transport Terminal, has to be estimated separately.

Accordingly, it is estimated that a totality of 20 bus loading and unloading bays would be required for a Bus Transport Hub at Battaramulla to accommodate and facilitate peak hour bus supply and passenger demand.

(ii) Location for a Multimodal Terminal

Battaramulla has limited land availability to accommodate a multimodal transport terminal. As described earlier in the methodology section, five locations were identified after examining the area carefully; these were considered as potential sites for the purpose. Figure 6 illustrates the geographical dispersion of candidate sites listed below which were selected for MCA:

- Location 1 - Rajamalwatta, near Timber Corporation Road
- Location 2 - Subhuthipura, near to Suhurupaya
- Location 3 - Udumulla, near to Kanatta Road
- Location 4 - Aruppitiya, Denzil Kobbekaduwa Road
- Location 5 - Between Suhurupaya and T-junction

(Locations 4 and 5 were considered by the UDA as well, in its analyses)

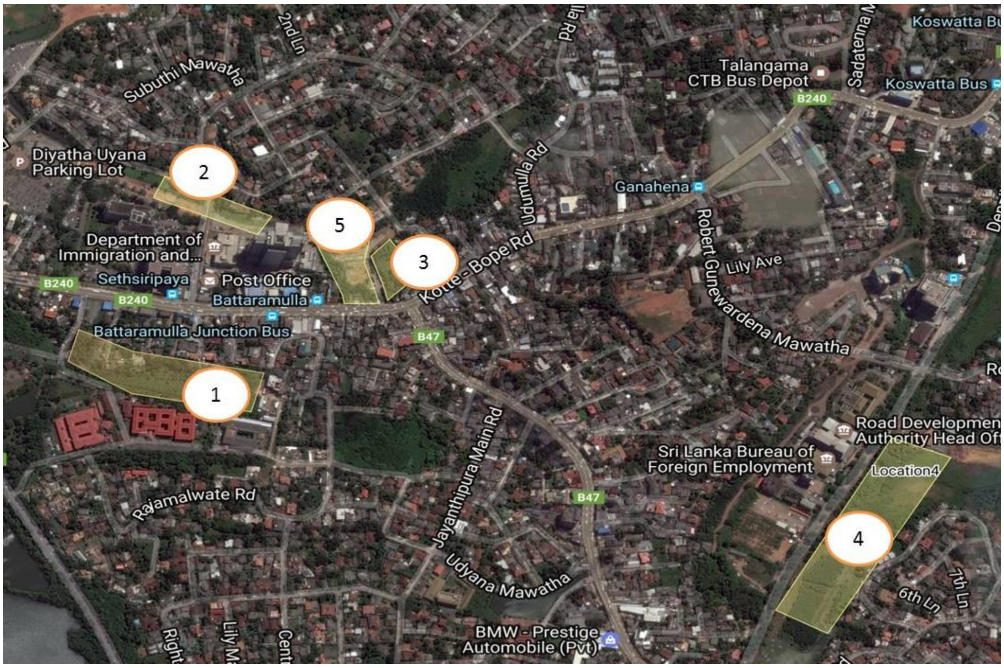


Figure 6: Alternative Locations for Multimodal Hub Development

All locations were subject to MCA. Decision criteria for the analysis were identified through literature survey and discussions during the field survey. Weight for each criterion was also determined by the author with experience gained through the study and those were further validated through discussions with transport experts. Accordingly, higher weights were assigned for more important criteria. Inputs were obtained from transport experts when ranking among criteria using the range from 1 to 5; the highest rank of 5 being assigned to the best choice and 1 for the worst.

Table 5: Multi-Criteria Analysis for Location Identification

Decision Criteria	Weight	Rating					Score				
		L1	L2	L3	L4	L5	L1	L2	L3	L4	L5
Connectivity to existing bus network	15	2	3	4	1	5	30	45	60	15	75
Minimum distance to the bus route	5	1	2	4	3	5	5	10	20	15	25
Space availability (land size)	15	5	2	1	3	4	75	30	15	45	60
Proximity to users (employees and visitors)	15	3	4	1	2	5	45	60	15	30	75
Demand (trip attraction, trip generation HVS)	10	3	4	1	2	5	30	40	10	20	50
Minimum environmental impact	10	2	5	3	1	4	20	50	30	10	40
Minimum impact on traffic during construction	5	5	3	2	4	1	25	15	10	20	5
Possibility of land acquisition	10	5	2	1	4	3	50	20	10	40	30
Expansion for future demand	10	4	2	1	5	3	40	20	10	50	30
Cost of site development	5	2	4	3	1	5	10	20	15	5	25
Total	100	32	31	21	26	40	330	310	195	250	415

Table 5 presents the results of the MCA. Outcomes revealed that Location between Suhurupaya and T-Junction (L5), the site selected by the Urban Development Authority (UDA) as well, would be the best option among all sites considered. Location L1 could be identified as the second-best option.

4. CONCLUSIONS AND RECOMMENDATIONS

The outcomes of the research were very clear, pertaining to the importance of Battaramulla as an important transport node, and to the need of improving public bus transportation to and from Battaramulla. This was amply reflected by very high load factors found in buses during peak hours. Analyses of data sourced from JAICA STRADA and Household Visit Surveys and Bus Volume Counts of Colombo Metropolitan Region Transport Master Plan, further substantiated this finding, particularly through trip assignment output and bus supply output of the research.

Investigations into ways and means of improving the bus services, and particularly those suggested in the previous studies, yielded several possibilities. First, bus services could be improved with four new services and two service route changes, the study revealed. Bambalapitiya, Maharagama, Peliyagoda, and Gampaha emerged as the most suitable destinations to introduce those new routes, while route number 152 could be suggested to be extended to Battaramulla via Denzil Kobbekaduwa Mawatha to provide better connectivity and accessibility at Battaramulla, while minimising the need to transit. Second, it was found that the improvement of the bus service could be further strengthened, firstly by coordinating the bus services at Battaramulla by organising it as a Bus Transport Hub, and thereafter by integrating it with the proposed Multimodal Transport Hub at Battaramulla.

The outcomes of the MCA conducted considering five criteria including connectivity, proximity, and cost of development, in view of comparatively examining the possible alternative sites for the proposed multimodal transport hub, enabled recommending the land behind the Suhurupaya building, proposed also by the UDA, as the most suited site to locate it. The Multimodal Terminal would perform as a hub and facilitate better connectivity among different modes, near-seamless interchange, parking and provide other facilities at one place. The newly proposed bus routes would help reduce bus load factors. These solutions, together with future development around the multimodal hub, could be expected to incentivise usage of bus travel, and to potentially reduce the use of taxi services and private vehicles, thus, would pave the way for a sustainable modal shift from private vehicles to public transport, resulting in reduced traffic congestion as well.

It may be noted, however, that this research was limited to bus network coverage improvement based on a demand and supply analysis. Besides, only a limited number of candidate sites, those were made known to the study, in the close proximity to Battaramulla town centre, were taken into comparative analysis in view of locating the proposed multimodal transport terminal. Furthermore, many situational changes have occurred since this study was conducted in 2017/2018, including the cancellation of the LRT project discussed in the study, the expansion of expressway and other roadways, the construction of a new road bypassing the Battaramulla junction, which have substantially changed the transport landscape. Therefore, future research may be required to update and re-validate the findings of this study, while, at the same time, considering other possible areas of service improvement and other potential locations for the proposed multimodal terminal, that may have become material since then.

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Sri Lanka Society of Transport and Logistics

Journal of South Asian Logistics and Transport
Volume 1 Issue 2 September 2021
JSALT 1.2.5: pp. 73-92
DOI: http://doi.org/10.4038/jsalt.v1i2.35

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USE OF ANALYTICAL TECHNIQUES FOR DECISION MAKING IN SRI LANKAN MANUFACTURING COMPANIES

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ABSTRACT

Optimising the use of resources through scientific methods is critical for efficiency and accurate pricing in the logistics industry. Analytical techniques (AT) play a decisive role in providing such analytical solutions.

This paper explores the use of Analytical Techniques for decision making in the Sri Lankan manufacturing logistics industry through a survey of practices in leading companies in the manufacturing logistics industry. The questionnaire focused on the familiarity of ATs and their use in the different logistics operations. The research reviewed and classified the different AT's most widely used in solving common logistics problems (LP).

Closing the gap between the theory and practice of AT in the logistics industry was aimed at through this research, by offering areas in which the industry could successfully adopt appropriate ATs. In this respect, different ATs in seven selected logistics decisions, regularly made in manufacturing firms, were discussed. The current practice in ATs was captured by interviewing leading practitioners in the logistics industry, bringing together the reasons for these gaps and their suggestions for overcoming them.

The findings of the research could open up exciting areas for future research on optimisation using ATs in manufacturing logistics.

Keywords: *Analytical techniques (AT), Optimisation, Forecasting, Problem-solving and Decision making, Logistics activities*

1. INTRODUCTION

There are several analytical techniques available to make appropriate decisions that optimise resource utility [1]. However, as logistics operations' complexity increases, the need for making accurate and efficient decisions in the manufacturing industry increases. There is less research to identify analytical techniques (AT) the industry prefers using in complex decision-making situations. The primary objective of this paper is to determine any gap between the availability of ATs and their adoption for decision-making by the manufacturing logistics industry in Sri Lanka. Three secondary objectives were formulated: (a) identify the current trend of AT practise within these manufacturing companies, (b) identify reasons for these trends, and (c) identify how the use of appropriate ATs can be encouraged.

2. METHODOLOGY

This research was conducted in three stages: comprehensive literature review, data collection, and data analysis. First, a comprehensive literature review identified globally available ATs used to make logistics management decisions in complex operations. Online journals, books, and websites were searched using the keyword's *analytical techniques, freight logistics, distribution, optimisation, decision making, real-world logistics application, operations research, and logistics problems*. In the second stage, a questionnaire was developed, based on the literature review, to gather data to understand the application of such ATs in the manufacturing sector in Sri Lanka. Leading companies in manufacturing logistics were the target group for the survey and collected mostly using an online survey with a few in-person interviews. The questionnaire included questions on the scale of using ATs for different applications on a Likert Scale. Other responses were obtained as multiple-choice questions, linear scale questions, and checkboxes. The questionnaire was distributed among executives and senior managers of companies dealing with logistics activities in different functional areas such as warehouse, transport, production, and distribution from the different databases available with trade chambers and professional bodies. A mix of random and convenient sampling methods was adopted to select the sample. From the 70 leading manufacturing companies in Sri Lanka to which the forms were sent, 37 responses were received, reflecting a response rate of 53%. In addition to the online survey, face-to-face interviews were held with fifteen higher-level managers directly involved in planning and managing logistics operations to identify reasons behind the current user behaviour in the use of ATs in their companies. Eight manufacturing firms representing various product manufacturing industries, four logistics service providers, one logistics consulting firm, and one logistics system development company were included in this face-to-face interview. Moreover, a focus group interview was carried out with 20 postgraduate students from the MBA in Supply Chain Management program at the University of Moratuwa, Sri Lanka.

The reasons for selecting these interview groups were the following.

- Manufacturing firms: Includes logistics decision-makers in the manufacturing companies.
- Logistics service providers: Includes decision-makers of the logistics functions.
- Logistics consulting firms: Includes providers of different consulting services to manufacturing firms to optimise the performance of logistics functions.
- Logistics system development companies: Includes firms developing and supplying tools for logistics support, including ATs, to optimise the logistics functions.
- Focus group interview: Includes executives and managers having knowledge of ATs, engaged in logistics functions.

The data gathered was analysed using SPSS software in the third stage of the research. Analytical methods, including hypothesis testing and examination of descriptive statistics such as comparison of means, graphical analysis, and frequency analysis, were deployed. Descriptive statistics were used to extract results and their meanings from the analysis. Spearman's Correlation Test and Mann-Whitney Test were adopted in hypothesis testing. Content Analysis and Discourse Analysis were employed in examining the primary data collected through interviews and focus-group discussions. Data were transcribed, coded, and analysed using NVIVO software.

3. LITERATURE REVIEW

3.1. Logistics in the manufacturing industry

Manufacturing logistics refers to planning, implementing, and controlling the flow of goods, services, and related information to carry out manufacturing activities from the point of origin to the final customer [2].

3.2. Types of Logistics Problems (LPs)

Logistics activities can be divided into two main functions, physical distribution and materials management. Physical distribution refers to the range of activities taken in freight movement from manufacturing to the point of consumption. It includes handling goods, transportation services, transhipment and warehousing services, trade, wholesale, and retail. Transportation services ensure the mobility requirements of supply chains are met. Material management includes all activities in the manufacturing of goods at any stage during a supply chain, including production, marketing, planning, demand forecasting, purchasing, and inventory management [3]. This research focuses on using ATs to solve common LPs, such as location selection, transport mode choice, optimal reverse and forward logistics network selection, vehicle routing problem (VRP), demand forecasting, inventory management, and production planning.

3.3. Types of Analytical Techniques (AT)

Analytical techniques used to solve problems or make decisions using qualitative or quantitative data have been classified differently in literature. Aguezzoul [4], for instance, identified multi-criteria decision-making (MCDM) techniques, mathematical programming models, artificial intelligence, statistical approaches, and integrated approaches as techniques applicable in the performance measurement of 3PL service providers. MCDM is a methodological framework that selects the best solution from a finite set of alternatives evaluated using multiple criteria. The mathematical programming models optimise objective functions that include cost, performance and time, under a set of constraints. Artificial intelligence is used for integrating quantitative and qualitative historical data with human expertise for decision-making. Correlation methods are used to analyse data gathered from empirical studies. Combining two or more techniques to select a better solution is usually called an integrated approach [4].

The majority of the companies use two or three ATs simultaneously for greater effectiveness. MCDM techniques, such as Analytical Hierarchy Process (AHP), are often used with mathematical programming and Fuzzy sets, which Bellman and Zadeh introduced in the 1970s. MCDM techniques are a vital tool to represent uncertainty and imprecision [5]. Grey System Theory and Fuzzy Set Theory can be used to engage with the uncertainty of human subjective judgments [6]. Fuzzy numbers developed by Zadeh in 1965 [7] could improve accuracy in many real-world decisions [8].

A classification of operation research techniques was conducted by Semini in 2011, [1] listing close to 200 Operations Research (OR) methods used in the manufacturing logistics industry. The primary OR techniques identified herein are Optimisation (Mathematical Programming), Dynamic Programming, Network Models, Simulation, Decision Analysis, Inventory Theory, Queuing Theory, Game Theory, Markov Chains, and Forecasting.

Further, multi-objective algorithms are listed as methods to optimise several objectives simultaneously [9]. Multi-objective Programming, also known as Goal Programming, maximises or minimises two or more objective functions [1].

Most forecasting methods belong to mathematical programming and statistical approaches. However, research in forecasting techniques classifies them in different ways. A study by Ghiani et al [10] classified them as quantitative and qualitative methods, with the latter further divided as casual and time-series extrapolation. Table 1 summarises the possible use of forecasting techniques in each category[10].

Table 1: Possibility of Usage of Forecasting Techniques

Category	**Comparison**
Quantitative Casual	• Difficult to implement, even for larger companies. • Difficult to identify any causal variable having a strong correlation with future demands. • Difficult to find a causal variable that leads the forecasted variable in time. • In practice, only single or multiple regression is used for logistics planning and control.
Quantitative Time-series extrapolation	• Easier to understand and explain. • Winter's method can be used whenever there are a linear trend and a seasonal effect. • In a business context, complex forecasting procedures seldom yield better results than simple ones.
Qualitative	• To estimate the influence of political or macro-economic changes on an item demand.

A study by Wang et al. has discussed big data analytics of supply chain and logistics management and classified the techniques into statistical, simulation, and optimisation methods [11]. Table 2 summarises ATs used by different industries in solving logistics problems, while Table 3 categorises ATs based on the technique and approach used to make decisions.

Table 2: Case studies in used AT

Ref.	**Industry/ Company**	**Problem**	**Analytical Techniques**
[12]	Brinova Fastigheter AB, Sweden	To determine locations of logistics hubs	AHP, Gravity model
[13]	Logistics service provider company	Capacitated VRP for inbound logistics	An ant-colony simulation-based optimisation
[14]	Household appliances, UAE	A reverse logistics network design	MILP
[15]	Supermarkets/ Brazil	Heterogeneous fleet VRP	Scatter search
[16]	Red meat industry	Multi-period location–inventory–routing problem	A linear mixed-integer programming model

Ref.	Industry/ Company	Problem	Analytical Techniques
[17]	Dairy company, Italy	A milk collection problem with incompatibility constraints	Mathematical programming and local search multi-start
[18]	Electronic appliances	To determine the best logistics partnership strategy	ANP
[19]	Chemical Company	For logistics optimisation: from the perspective of effective distance	A Physarum-inspired algorithm
[9]	Logistics service provider company	To minimize inventory holding and transportation cost	A multi-objective particle swarm optimisation algorithm
[5]	Multinational conglomerate company	Evaluation of five proposed locations for a logistic centre	The Fuzzy-PROMETHEE method
[20]	Furniture and Electronics Industries / Canada	Heterogeneous VRP with time windows	Class-Based Insertion Heuristic.
[21]	Biogas plant	The best reverse logistics network evaluation	MILP, AHP
[22]	Medical Items	To optimise the logistics for a fleet of drones for timely delivery	An optimisation model using mathematical formulation
[6]	Automobile - manufacturing company	To develop 3PL provider selection criteria	Grey system theory DEMATEL method
[23]	Soft drinks/ Coca-Cola/ USA	Optimises vehicle routes for efficient product delivery	ORTEC software based on savings and local search
[24]	Olive oil/ Tunisia	Multi-constrained VRP	Branch-and-cut
[25]	Furniture Company	Selection of third-party logistics providers	Integer programming:
[26]	Car parts manufacturing company	the selection of third-party reverse logistics providers	AHP, Fuzzy and grey numbers
[27]	Conglomerate company	To select the most suitable site for a logistic centre	ARAS–F method
[8]	Logistics service provider company	For examining the different modes for transportation of freight	Fuzzy analytic network process (ANP) method
[28]	The semiconductor company, Taiwan	To determine the manufacturing and logistics system design	DEMATEL
[29]	Sports fashion	To determine operations in DCs based on distribution strategy	AHP
[30]	Conglomerate / China	Multi-type fleet VRP	Threshold tabu search
[31]	Foods, Athens	The Pallet-Packing VRP	Tabu search and heuristic
[32]	Polyethene terephthalate bottles	Designing and solving a reverse logistics network	A mixed-integer linear programming model

Table 3: Classification of Analytical Techniques

Pure Mathematical programming			
– Linear programming – Nonlinear programming – Data Envelopment Analysis (DEA)		– Mixed integer programming (MIP) – Stochastic programming – Total Cost of Ownership (TCO)	
MCDM			
– PROMETHEE methods – Decision-Making Trial and Evaluation Laboratory (DEMATEL) – TOPSIS – Interpretive Structural Model (ISM)		– ANP – AHP – Additive Ratio Assessment Method (Aras) – Quality Function Deployment (QFD) – Utility Theory	
Statistical techniques			
– Correlation Method – Cluster Analysis		– Binary Logit – Multinomial logit (MNL)	
Artificial intelligence			
– Case-Based Reasoning/ Rule-Based Reasoning (CBR/RBR) – Data Mining		– Artificial Neural Networks (ANN) – Inference Method	
Uncertain theory			
– Grey system theory – Fuzzy set theory		– Probability statistics	
VRP Algorithms			
Extract	– branch-and-bound – branch-and-cut		– set-covering-based
Heuristics	– Clark and Wright algorithm – Particle Swarm Optimisation (PSO) – Genetic algorithm		– simulated Annealing – Tabu search – evolutionary strategies
Metaheuristics	– Benders' decomposition – polyhedral approach		– dynamic programming – column generation
Forecasting techniques			
Quantitative methods	Casual	– Regression – Econometric models – Input-Output models – Neural networks	– Life-cycle analysis – Computer simulation models
	Time series extrapolation	– Elementary technique – Moving averages – Double moving average method – Exponential smoothing techniques (Brown method)	– Holt method – Winters method – Decomposition approach – Box-Jenkins method – Revised exponential smoothing method
Qualitative methods	– Panel consensus method – Delphi method		– Salesforce assessment – Market research

Accessibility measurement models	
– Gravity method – Cumulative opportunity method	– Utility-based method
Integrated Approaches	
– Fuzzy-MCDM models	– MCDM with mathematical approaches
Multi-objective models / Goal programming	
– Fuzzy multi-objective mathematical models – Multi-Objective Particle Swarm Optimisation (MOPSO) Models	

3.4. Mapping of Typical ATs used for Solving Different LPs

Table 4 shows the summary of ATs by logistic function to solve relevant LPs. Highlighted cells indicate the techniques applicable to make decisions or solve problems.

Table 4: Mapping of AT Usage in selected Literature for Solving LP

Type of Technique / **Logistics Decision or Problem**	**Mathematical Programming**	**MCDM**	**Statistical Techniques**	**Uncertainty Theory**	**Algorithms**			**Artificial Intelligence**	**Predictive Models**			**Integrated Approaches**	**Multi-Objective Models**	**Accessibility Measurement**
									Quantitative					
					Extract	**Heuristics**	**Metaheuristics**		**Casual**	**Time-series**	**Qualitative**			
Vehicle routing problem and distribution					X	X	X					X	X	
Selection of transport mode	X	X	X	X				X						
Selection of location for DC, warehouse		X	X	X				X				X		X
Design of logistics network reverse and forward	X	X										X		
Demand forecasting									X	X	X			
Inventory management	X	X										X	X	
Production planning	X		X											

3.5. Global trend of using analytical techniques

With the prospect of Industry 4.0, companies focus on the principles of interconnectivity, digitalisation, and automation. Future research should focus on the field of artificial intelligence (AI), machine learning (ML), and deep learning (DL) in Smart Logistics [33].

A study conducted by Handfield et al. [34], using 62 interviews and 1757 international survey responses to observe the global logistics and supply chain trends revealed that introducing new technology by companies to increase the efficiency and effectiveness of logistics operations was a recognisable key trend. It also showed that respondents expected 30% growth in new technology investments in RFID, inventory optimisation software, analytics, and big data technologies. Top performers were found applying Cost-to-Serve Analytics for making logistics decisions that provide optimum solutions to transport and logistics problems. More than 65% of respondents were planning to invest in network optimisation technologies such as inventory optimization software, transport management systems, advanced planning systems, and better data collection processes in the next five years (since 2013). About 60% of respondents had planned to invest in "Big Data" analytical tools within those five years [34] for forecasting, and other analyses would help organisations to optimise their logistics functions [35].

4. RESULTS

4.1. Usage and Familiarity of ATs

The hypothesis that "*the usage of ATs is conditional to familiarity*" was tested using the Likert scale responses to two questions in the questionnaire. Those questioned about *usage* and *familiarity*, on a scale of 1 to 4. Table 5 shows that the p-value was less than 0.05, indicating that the H_0 would have to be rejected. It means data did not have normality. Therefore, it could be inferred that non-parametric tests would be necessary for testing this particular hypothesis. Spearman's correlation test was therefore used to determine the association between *usage* and *familiarity*.

Table 5: Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
Usage	0.288	37	0.000	0.776	37	0.000
Familiarity	0.399	37	0.000	0.689	37	0.000
a. Lilliefors Significance Correction						

As shown in Table 6, though *usage* appeared to be lower than *familiarity*, no significant relationship between usage and familiarity could be found, as per Spearman's correlation test. The H_0, that "*there is no significant relationship between the variables*", could be accepted because the p-value (0.843) was greater than 0.05.

Table 6: Spearman's Correlation

			Usage	Familiarity
Spearman's rho	Usage	Correlation Coefficient	1.000	0.034
		Sig. (2-tailed)	.	0.843
		N	37	37
	Familiarity	Correlation Coefficient	0.034	1.000
		Sig. (2-tailed)	0.843	.
		N	37	37

It was observed that, while familiarity with AT should be a pre-condition for use, it would not always happen. As shown in Figure 1, the response to AT *usage* had a smaller mean than *familiarity* with AT. It seemed that sound familiarity would result in usage only half the time, but that too, only intermittently, while partial familiarity would lead mostly to intermittent use.

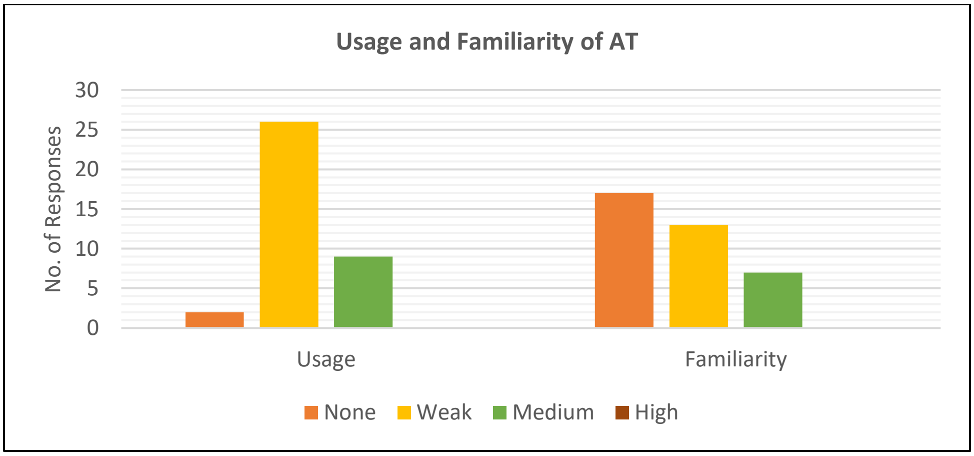

Figure 1: Distribution of Responses for Usage and Familiarity of AT

Further, as shown in Table 7, the mean (1.73) for *usage* is less than 2.0, which makes it evident that the usage of ATs is less than desired.

Table 7: Descriptive statistics of Usage and Familiarity

	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Usage	37	1.73	0.769	0.516	0.388	-1.100	0.759
Familiarity	37	2.19	0.518	0.265	0.388	0.332	0.759
Valid N (listwise)	37						

Figure 2 shows that only 29% were regularly using ATs, and 37% did not use ATs at all. ATs were mostly used for marketing, for example, demand forecasting, followed by inventory and production planning/procurement activities and logistics decisions. These activities were also tracked using ATs in ERP solutions. ATs for planning operational activities, such as Vehicle Routing Problem (VRP) or Location Selection, had a much lower incidence of use. In the logistics industry, selecting the best mode of transport appears to be handled mainly through experience rather than any ATs. Other functional areas, such as inventory management and production planning procedures, appeared to use ATs, most likely due to the technical characteristics of the functions involved.

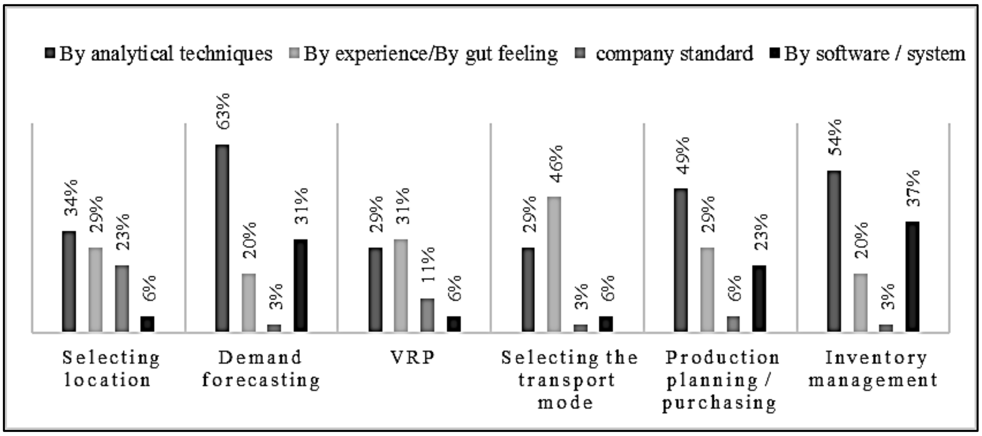

Figure 2: Decision Making Methods by Logistics Activities

The results of the Hierarchy Analysis performed using interview data, as illustrated in Figure 3, shows the frequency of different techniques used in the industry. Forecasting techniques such as moving averages, trend analysis and regression, inbuilt techniques, and the Gravity Model lead the use frequency. Respondents have identified they have started paying attention and using "Big Data" analytics, ML, and AI-related advanced techniques.

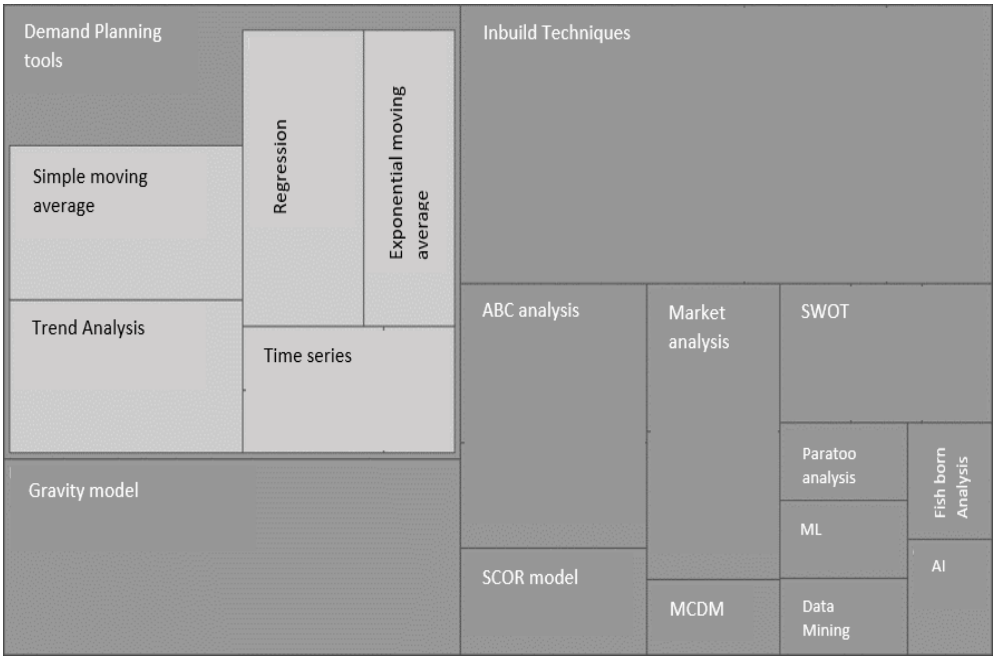

Figure 3: Hierarchy analysis for techniques used (using NVIVO software)

Moreover, Multinational Companies (MNCs) did not perform significantly different when compared to local companies in the use of ATs, with 37% of both types indicating they did not use AT regularly.

Table 9 shows that the Asymptotic Significance was higher than 0.05, which means that the H_0 could not be rejected according to the Mann-Whitney test statistics. Therefore, it is concluded that there is no evidence to infer that the distributions of these two groups on the usage of ATs in making decisions on logistics management were not significantly different from each other.

Table 8: Mann-Whitney test - Ranks

	Company Type	N	Mean Rank	Sum of Ranks
Usage	Local	20	18.75	375.00
	MNC	17	19.29	328.00
	Total	37		

Table 9: Mann-Whitney test statistics

	Usage
Mann-Whitney U	165.000
Wilcoxon W	375.000
Z	-0.165
Asymp. Sig. (2-tailed)	0.869
Exact Sig. [2*(1-tailed Sig.)]	0.892[b]
a. Grouping Variable: Company Type	
b. Not corrected for ties.	

The analysis by type of company reveals that 25% of companies in apparel manufacturing use ATs regularly, compared to 16% in the FMCG industry, while 47% of the companies in the FMCG industry appeared to use AT, but less frequently (Figure 4).

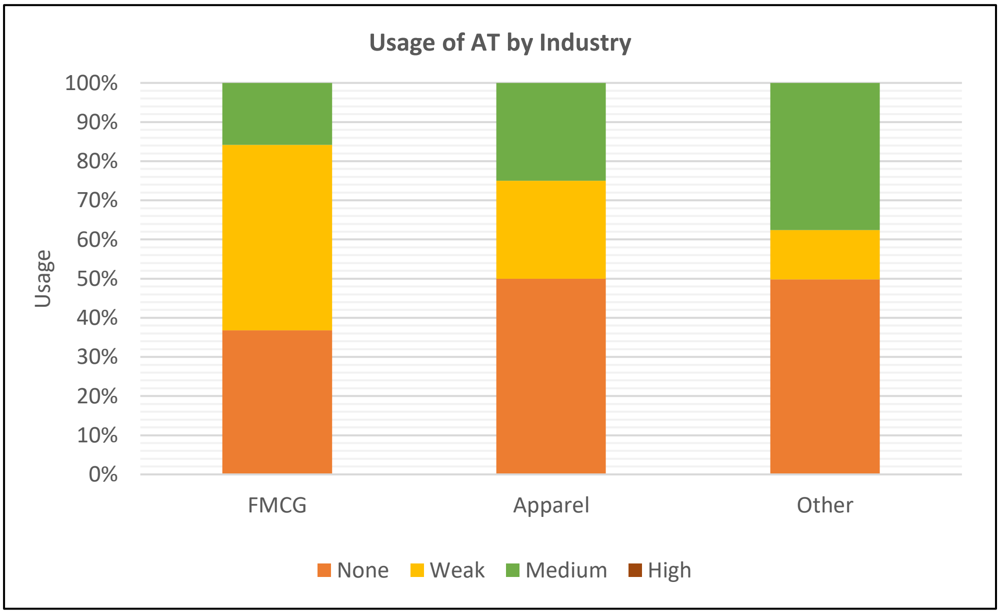

Figure 4: Usage of AT by industry

4.2. Reasons for the reluctance to use ATs

The use of Hierarchy analysis to identify the main reasons for the reluctance to use ATs yielded the key findings summarised in Figure 5.

Figure 5: Hierarchy analysis for reluctance to use AT using NVIVO software

Data availability and costs appear to be the two main constraints inhibiting the use of quantitative techniques in the manufacturing sector of Sri Lanka. Data capturing technologies are not being effectively used in manufacturing industries, the reason being their lower attention on R&D in logistics decision making, compared to R&D on product development.

Among other reasons revealed through the interviews, the inadequate understanding of ATs, lack of familiarity and confidence, the intensity of time consumption, availability of simpler decision-making methods, low user-friendliness of AT, lack of expertise in the firms, and reluctance to change are found to be significant constraints in ATs being used in manufacturing industries.

4.3. Industry requirements for increased use of ATs

A descriptive analysis was performed using SPSS software on interview responses and the online questionnaire, identifying the prominent requirements for increased AT use in logistics decision-making in the Sri Lankan manufacturing sector. The results are summarised in Table 10.

Table 10: Manufacturing Industry Requirements to achieve increased use of AT in Logistics

Criteria	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Flexibility (capability of integrating side constraints encountered in real-world applications)	37	4.5405	0.60528	-0.958	0.388	-0.002	0.759
Easy to use	37	4.2432	0.76031	-0.449	0.388	-1.105	0.759
Provides direct solution	37	4.2432	0.83017	-0.495	0.388	-1.371	0.759
Time required to get solutions using the AT	37	4.1892	0.81096	-0.699	0.388	-0.120	0.759
Accuracy of result	37	4.1892	0.90792	-1.338	0.388	2.644	0.759
Availability of data for AT	37	3.8919	1.02154	-0.434	0.388	-0.960	0.759
Software availability	37	3.6757	0.97337	-0.049	0.388	-0.999	0.759
Simplicity to use	37	3.4054	0.92675	0.403	0.388	-0.607	0.759
Availability of expertise to use	37	3.1351	1.22842	-0.081	0.388	-1.137	0.759
Cost (training/technologies etc.)	37	3.0270	0.92756	-0.276	0.388	-1.331	0.759
Valid N (listwise)	37						

All requirements identified and included in Table 10 as being significant, have mean values greater than 2.5, which are presented in the descending order of their mean values, showing their relative prominence. Accordingly, "flexibility to integrate", particularly with inputs and outputs of other software and ERP systems, emerged as the most critical criterion. Ease of usage, ability to provide straightforward solutions, less time consumption and accuracy of results ranked high in the order of importance, while the simplicity of use, availability of expertise to use, and cost have also been identified as contributory criteria.

4. CONCLUSIONS AND RECOMMENDATIONS

This paper focused on the use of ATs for manufacturing logistics optimisation by Sri Lankan manufacturing companies. It demonstrated that the use of such applications varied considerably across the logistics process and was mostly used for marketing-oriented functions instead of operational or planning processes. The use of ATs also seemed to vary across different organisations, with the FMCG industry in the lead. However, compared to Sri Lankan companies, multinational companies did not indicate a significantly higher use of AT. Sri Lankan companies would stand to benefit by using advanced technologies in the manufacturing supply chain for planning through the effective capturing and analysing of data, improving the efficiency of operations, and thereby reducing costs. Yet, the use of ATs for logistics decision-making in the manufacturing industry in Sri Lanka was observed to be low, with low familiarity and availability being the primary constraints.

The industry gave several reasons for the inadequate use of ATs, led by cost considerations and data availability. Practical problems surrounding their familiarity and difficulties in applying them were cited as constraints. However, the interview results varied to some extent, indicating that AT use could be enhanced by making them more user-friendly, integrating to existing ERP solutions, and making them easier to use and providing answers that could be directly applied.

Thus, developing ATs for the logistics industry would require greater attention paid to enhance the flexibility of techniques and user-friendly software for convenient use by industrial establishments. Increasing R&D in logistics operations could evolve better designs of AT solutions to meet these requirements.

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STRATEGIC PERSPECTIVES

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Journal of South Asian Logistics and Transport
Volume 1 Issue 2 September 2021
JSALT 1.2.SP: pp. 93-104
DOI: http://doi.org/10.4038/jsalt.v1i2.36

TRANSPORT LOGISTICS: REDEFINING LOGISTICS IN TRANSPORT

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ABSTRACT

The terms Transport and Logistics have historically been used independently of one another. While the meaning of transport relates to the critical function of providing mobility, the understanding of logistics varies sharply between its different application contexts, from Military Logistics in early stages to its current application in Supply Chains referred to as Business Logistics. Logistics is generally understood as the processes associated with handling goods within a supply chain from its raw material supply to production to consumption, including its Transport during the multiple segments of the journey. Transport research also treats Logistics as those activities that support consuming transport itself as a means of satisfying mobility requirements but again mainly confined to the movement of goods. The recent emergence of 'Transport & Logistics' in academia and research further confuses the scientific study of mobility issues. However, this understanding is less obfuscating in industry, as each employs it in its specific context and understands it differently.

This paper proposes the term Transport Logistics to identify the logistics associated with the different forms of transport provision. The etymology of terms Transport and Logistics have been consulted in its deduction. The paper concludes that passenger transport and goods transport have similar logistics activities to understand them as a single field of study. Moreover, the paper asserts that Logistics is a well-defined rational and logical process that can solve a difficult or complex transport problem.

Keywords: *Transport Logistics, Supply Chain, Passenger, Goods, Complex Problems*

1. DIFFERENT MEANINGS OF TRANSPORT

Transport is used as a verb to describe the physical movement of persons or goods between two different locations. Dictionaries define Transport meaning *'to transfer or convey from one place to the other'* [1] as illustrated by its use in *'Admiral da Gama, unable to leave the Bay of Rio de Janeiro on account of lack of transport for the sick and wounded and the civilians claiming his protection, could do no more than wait for Admiral Mello to return from Desterro'* [2]. As a verb, it refers to the function of being carried or taken, which is identified as the 'demand' side of mobility, represents the user's utility or requirement. The term Transport can also be used as a noun as illustrated in '*the client will provide the required transport'*, referring to it as a means of satisfying the desire for mobility, representing its supply side.

The English word *'transport'* we are discussing is derived from the Latin words '*trans'* meaning *'across'* and *'portare'* meaning to carry; when combined, made up the word *'transportare'*, which, adapted initially as '*transporter'* in the old French, was translated into English around 1690 [3] as *'transport'*. Even though this definition aligns better with the supply side of mobility, as explained above, its everyday use refers to both the demand and supply sides of mobility. The word Transportation, of more recent American origin, further defines the supply side of transport as a '*system for carrying people or goods from one place to another using vehicle*, and related infrastructure'[4], illustrated in *'the rising transportation cost was a matter of concern'* or *'the transportation system needs to be modernised'*.

2. LOGISTICS AS A PROCESS OF OVERCOMING COMPLEX OPERATIONAL PROBLEMS

The Oxford Dictionary defines Logistics as *'the detailed organisation and implementation of a complex operation'* [5], following the understanding of the Latin word *'Logos',* as the use of reasoning and logic. Logistics can therefore be understood as a supply-side function that facilitates a difficult or complex operational issue. Logistic is defined as the *'art of arithmetical calculation'* dating from the 1650s [6]. It is derived from the Greek word *'Logisikos'*, translated to English as *Logistic* [7]. The more recent adoption of the term logistic in statistics includes logistic modelling (also called logit modelling) or logistic regression. It is used as a statistical technique to estimate the probability of an outcome of a decision, or an event known to be dependent on many identifiable independent conditions on which such outcome depends.

Thus, in this paper, the term Logistics will mean applying reason and logic in deriving solutions to complex problems of providing for the mobility of goods and people.

The first recorded application of Logistics as a rational approach or science in goods transport was AN Tolstoi's work in 1930 titled '*the methods of finding the minimal total kilometrage in cargo-transportation planning in space'* being an effort to solve the complex problem of optimising the movement of salt, cement, and other cargo between some 10 origins and 68 destinations on the Soviet railway network [8]. The first application of Logistics in passenger transport is recorded from the 17th century when the French mathematician Blaise Pascal successfully designed and implemented the world's first bus network, called the Five Penny Carriages in Paris, in 1662 [9]. Though the carriages were drawn by horse and could only carry eight passengers, it had all the complexity of a modern transport network that eventually expanded to five routes with frequencies every seven or eight minutes, an affordable fare regime and even demand-based late evening services. Since then, mathematics, especially Operations Research, modelling and simulation, have been used to tackle a vast array of complex problems in transporting goods and passengers across unimodal and multimodal transport networks.

This paper defines this application of Logistics in Transport as 'Transport Logistics'. However, since Logistics has well-defined meanings in other sectors, this definition must be set apart from its other applications and its common everyday use as *'making suitable arrangements' or 'handling the details of an activity'*.

3. LOGISTICS IN MILITARY PROCESSES

It has been noted that while the word *'Logic'* was derived directly from the Greek word '*Logos'* meaning reason, the word Logistics though initially stemming from the same concept of reason, was a translation from the French word *'Logistique'*, found to have been used by Baron de Jomini in 1830 [10] as *'Logis'* or arrangement of lodging of troops. From its earliest use in military functions, the term is defined as *'the aspect of military science dealing with the procurement, maintenance, and transportation of military matériel, facilities, and personnel* [11]. Military logistics refers to this long-established practice of handling men and material required for war and military engagement by moving resources to specific places when and where needed. This definition of military logistics interestingly includes the movement of material and military personnel [12].

4. LOGISTICS IN SUPPLY CHAIN PROCESSES

In non-military use, the term Logistics is mainly associated with the supply chain processes and handling goods and not people. The Council of Supply Chain Management Professionals (CSCMP) defines a supply chain as the *'planning and management of all activities involved in sourcing and procurement, conversion, and* *all logistics management activities'* [13], where Logistics is defined as an integral function within supply chains. The CSCMP [14] also defines Logistics as the *'process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods, including services and related information from the point of origin to the point conforming customer requirements.* It clarifies that Logistics in supply chains requires the integration of a sequence of activities in the processes required to produce and distribute the material.

Peter Drucker, who defined Logistics as 'the last frontier of economics' [15], foretold Logistics taking centre stage of business. The International Society of Logistics (SOLE) has a broader definition of Logistics, giving it as '*the art and science of management, engineering, and technical activities concerned with requirements, designs and supplying and maintaining resources to support objectives, plans and operations* [16]. It aligns with the current scope of Logistics within supply chain management. It has moved from being understood as integrating the internal processes in an organisation to a strategy that includes the planning, design, operation and management of the entire supply chain from producer to consumer.

Logistics is currently considered any supporting activity that enhances the value of the supply of a product or service to the end consumer. In this respect, the application of Logistics has expanded from manufacturing to service industries such as healthcare and hospitality. Key activities in Logistics within a supply chain are commonly identified as order processing, materials handling, warehousing, inventory control, transport, and packaging. In transport, the sub-activities are usually identified as modes of transport, freight consolidation, vehicle routing, delivery scheduling, equipment selection, rate setting and claims processing. These are supply-side activities for a consumer and are often called Logistics for Business, a subset of activities within the supply chain that involves the movement and storage of material [17], sometimes called Business Logistics [18]. However, most businesses require handling both material and people, namely employees and customers, to be moved from place to place. Nevertheless, academia and research in supply chain management have mostly considered material handling issues rather than people movement.

5. GAPS AND OVERLAPS BETWEEN TRANSPORT & LOGISTICS

The objective of this paper is not an etymological discourse on the derivation of the words Transport and Logistics, but to determine their suitability and current relevance in the intersection of their combined use, particularly in academia and research. Transport and Logistics are two words used separately in academia, where Logistics is treated as a function within supply chain management, mainly relating to that of goods. It is generally treated separately from problems concerning the mobility of people, which is dealt with under Transport [19]. Passenger transport has traditionally been seen as a public issue, with significant economic and social implications, to which a government should lend its attention. On the other hand, goods transport is mainly treated as a commercial activity of private sector concern. However, these traditional boundaries are fast-changing with disruptive technologies such as mobility as a Service (MaaS) applications, Industry 4.0, and other IT-based innovations. Thus, the traditional boundaries between transport as the movement of people and logistics referring to an activity within the supply chain now require reset.

The marriage of the terms of Transport with Logistics was formalised at the incorporation of the Chartered Institute of Logistics and Transport (CILT) in 2001 when the Chartered Institute of Transport (CIT) merged with the Chartered Institute of Logistics (CIL) [20]. The CILT, which does not appear to have a definition of its own for the term Logistics, borrows that of GeorgiaTech given as *'that part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption to meet customers' requirements'* [21]. It is a slight modification of the CSCMP definition restricting it to goods and related services between origin and point of consumption; since the CILT perceives Logistics as for goods. Since Transport is interpreted to be without any such restriction, the word Logistics overlaps with that of Transport.

Consequently, the term 'Transport & Logistics' or ‘Logistics & Transport' causes immense confusion in academia and the scientific study of mobility. Its understanding in the industry has been less problematic, as each sector uses it in their specific context, mainly using the term Logistics for the handling of goods, including its Transport. In contrast, the term Transport is understood to refer to the movement of people and goods, including their Transport Logistics. Therefore, this paper ventures to postulate that the term Logistics is equally applicable to support and arrange the handling of passengers as for the movement of goods.

6. SIMILARITIES AND DIFFERENCES BETWEEN GOODS AND PASSENGER MOVEMENT

As shown in Table 1, the mobility of passengers has near-identical activities to that of goods. They both require the planning, the infrastructure, the implements, and the controls for completing the practical mobility requirements of the customer commonly set out as the seven R's; getting the right product, in the right quantity, in the right condition, at the right place, at the right time, to the right customer and at the right price. When applied to passenger transport, except for the right customer, since it is the customer who is being transported, it is identical to goods transport.

Table 1: Comparison of Processes between Mobility of Goods and Passengers

Feature	Goods Transport	Passenger Transport
Customer	Shipper / Recipient	Passenger
Origin	Producer of Material	Trip Generator
Destination	Consumer of Material	Trip Attractor
Travel Segments / Trips (examples)	• Producer to Warehouse • Warehouse to Retailer • Retailer to Consumer • Returns to above	• Home to Work • Home to School • Home to Non-work • Return of above
Decision Making	Shipper or Consignee	Usually by Passenger
Consolidating	Package items travelling together	Passenger & baggage travel together
Movement	Externally Assisted	Self-propelled and externally assisted
Aggregation / Disaggregation	Distribution Centre	Terminal, Station or Airport
Departure / Arrival Location	Dock or Bay	Platform or Gate
Pre-Departure Activity	Loading	Boarding
Vehicle of Movement	Goods Transport Vehicles	Passenger Transport Vehicles
Infrastructure Facility	Multimodal Transport Network	Multimodal Transport Network
Information Required by	Shipper and Consignee	Passenger
Activity on Arrival	Unloading	Alighting
Transfer and Storage	Dock or Warehouse	Terminal, Station or Airport
Returns	Reverse Logistics	Unfulfilled Return Trip
Payment	Shipper/Recipient	Passenger

While there are many similarities in the many activities, as shown above, there are also several critical differences that set apart goods transport from people transport:

a. In people transport, the passenger makes decisions on each of the processes in the journey, most often based on information and choices offered at each such decision point or beforehand. However, in goods, all decisions are usually made beforehand by the shipper or consignee on information provided by the different service providers.

b. In the case of goods transport, all movements must be assisted or enabled by humans or automated. In contrast, in people transport, some activities such as boarding and alighting and even access or egress are usually unassisted, even though implements such as lifts, escalators and walkways are increasingly used to assist such movements. People also operate conveyances and drive, propel, or fly themselves while carrying others.

7. INTERCHANGEABILITY BETWEEN GOODS AND PASSENGER TRIPS

The other primary consideration is understanding the growing interchangeability between people transport and goods transport. For example, a person who wishes to eat pizza will have three basic options to satisfy the mobility requirements if he does not have a pizza. First, he can go to the restaurant and enjoy his pizza at leisure and with others resulting in a leisure passenger trip. He can enjoy his pizza while entertaining guests at home and by ordering the delivery of the pizza, which would result in a goods trip between the restaurant and house. Thirdly, he could travel to the restaurant and pick up the pizza himself and bring it home, which will be a shopping trip. All these achieve the same customer purpose while the passenger trips originate at home and terminate at the restaurant before returning home, and the pizza delivery does the opposite. Similarly, during COVID-19, many personal shopping trips are substituted by online deliveries where the last-mile delivery is provided by the supplier’s door-to-door delivery service. The innovations in technology have significantly facilitated the interchange of personal and goods transport, while improving customer service.

Moreover, both person and goods trips usually occur across the same transport infrastructure such as roads, railways, airports and ports and the respective networks they create. Vehicles used on these networks are usually customised for passengers or goods, though often vehicles carry both passengers and goods. The same IT platforms can now provide both passenger services and carrying goods, often using a common fleet of vehicles. Though urban logistics is referred to as the study of the movement of goods in cities, and urban transport refers to studies the movement of passengers, the foremost issues of urban congestion and the challenge of urban planning now require the combined study and analysis of both these as city centres once congested with passenger vehicles, are increasingly congested with delivery vehicles.

Therefore, the proposed term Transport Logistics includes the role of Logistics in both people and goods transport instead of its applications in supply chain and material flow only.

8. DEFINING TRANSPORT LOGISTICS

The term 'Transport Logistics' could be defined as *'the detailed planning, design, implementation and control of complex operations in the movement of goods or passengers'*. Moreover, Transport Logistics sets it apart from other references, such as military logistics and logistics in supply chains.

A necessity for this new understanding is the future role of Transport Logistics research and study to meet the challenge of Industry 4.0 requirements, expressed as *a highly integrated smart factory, in which individual goods are produced sustainably in a mass-production manner to fulfil customer demands in a global competition'* [22]. Smart logistics systems' corresponding development and application employ the Internet of Things (IoT), big data, cloud computing, and Artificial Intelligence (AI). Smart transport systems use the same technologies and platforms as smart logistics systems, giving credence to developing Transport Logistics as a unified field of academic pursuit that combines the different modes of Transport to simultaneously study the movement of people and goods in a given area or period.

Therefore, unlike in the casual use of the word Logistics in industry, the term Transport Logistics in academia has potential for applications of significant complexity, where reason and solutions are derived using calculations based on logical inferences. The term Logistical Analysis, which when applied to Transport Logistics should be read as *'the systematic study of quantifiable measurements to determine the means of improving movement and handling of goods and people by improving the efficiency of the delivery of the respective services and increasing its value to the customer'*. The corresponding functions for designing the complex multimodal networks, supporting their efficient operation and any auxiliary systems for delivery of services such as scheduling, routing, ticketing, tracking and tracing, falling within the definition of Transport Logistics Engineering, a developing new area of academic pursuit. The more traditional role of Transportation Engineering in Civil Engineering, which is the author's background, is mainly in the planning, design, construction, maintenance, and operation of physical transport infrastructures such as roads, railways, ports and airports required to move goods and passengers. However, it has expanded to include public transport services and the use of goods delivery algorithms in recent times.

Many academic programs use the word transport or transportation but predominantly study the features of only one mode of Transport, its infrastructure or its services and in some cases, both. The pull from jobs in the industry results in the demand for mode-specific competencies instead of a sector-based competency. Consequently, this has given rise to a global phenomenon of insulated sub-sectors, agencies and even professionals competent in one mode of Transport and its development, but have not been privy to a holistic understanding of the fundamentals of mobility as the determinant of the demand for all the modes of Transport and their related Logistics as defined by the word Transport Logistics. Transport Logistics can therefore be understood as a supply-side function that facilitates the solution of a difficult or complex operational issue in transport.

9. CONCLUSIONS

This paper discusses the necessity to reconsider the definition and use of the words Transport and Logistics in academic instruction and scientific study as there is considerable overlap between the meanings of the two terms. The paper argues that:

(i) The role of Logistics in supply chain management is different to the role of Logistics in mobility. The latter could be more accurately defined as Transport Logistics to set it apart from Military Logistics, Logistics in Supply Chain (sometimes called Business Logistics), Service Logistics or its application in other areas.

(ii) The proposed term Transport Logistics is applied to both passenger and goods transport and not to goods only as defined by professional organisations in supply chain management and logistics.

(iii) For further clarity, the term Transport Logistics could be categorised as,

  a. Goods Transport Logistics – referring to the logistical support in the movement of goods across a supply chain.

  b. Passenger Transport Logistics – referring to the logistical support in the movement of people across a multimodal transport network.

(iv) Terms such as maritime logistics, railway logistics, airport logistics etc., may be used when analysing the mobility function within a single mode of transport. Transport Logistics essentially captures the complexity of multimodal operations that reflect the nature of the demand for mobility but can include these unimodal logistics functions.

(v) Moreover, the term Logistics in any of the above applications should refer to solving a complex operational problem by a rational and logical process that can be mathematically expressed. The term should not be used in academia or scientific literature for non-complex transport functions as commonly observed.

ACKNOWLEDGEMENTS

The author acknowledges with appreciation the invitation from the Editor of the Journal of South Asian Logistics and Transport (JSALT) to submit a Strategic Perspective. The author also wishes to thank Dr Pradeepa Jayaratne and Dr Niles Perera for their valuable insights in supply chain and logistics that have vastly contributed to refining the concepts presented in this paper.

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ISSN 2783-8897
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