PASSENGER PREFERANCE CRITERIA FOR SELECTING RAPID TRANSIT SYSTEM FOR CITY OF COLOMBO

Gode Gamage Sanjaya Geethanga

M.Eng. in Highway & Traffic Engineering

Department of Civil Engineering

University of Moratuwa

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Contents

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II. Abstract

Traffic congestion is a condition on road networks that occurs as use increases and is characterized by slower speeds, longer trip times, and increased vehicular queuing. As demand approaches the capacity of a road, extreme traffic congestion sets in. Traffic congestion contributes to waste of time and money every second. Many developed/developing countries find solution for the traffic congestion at roads with the help of rapid transit systems.

Rapid transit systems can be dividing in to four major categories;

- Bus rapid transit (BRT)
- Monorail system
- Light rapid transit (LRT)
- Mass rapid transit (MRT)

The main objective of this research is to propose a methodology to select most appropriate rapid transit system technology for a given transport corridor with emphasis on passenger preference criterion for selecting rapid transit system for city of Colombo. The study consists of collecting user preference based on a questionnaire survey. Jayawardenapura corridor has been selected as a case study.

This corridor is highly congested at peak time and it will be increase at future due to administration city will become Jayawardenapura corridor. Hence it is essential to give proper solution for the increasing traffic in this corridor.

In addition to user preferences the questionnaire focuses on the drawbacks in existing systems, user expectations for a new system. These were used to identify the user related issues in existing systems and to find whether a rapid transit can address those issues.

According to the survey results of, 48% respondents of indicated that BRT may be the better option for selected corridor. Balance prefer an elevated system as opposed to BRT.

It is required to establish criteria based on the not only passenger’s preference, but also constructability, connectivity with other modes, extendibility in future and environmental friendliness.

According to the research, passenger most preferred for the BRT system. With the connectivity with other modes monorail systems is better than BRT. Possibility of future expansion of the system, difficulty face with BRT system due restrictions of land acquisition. From the environment point of view, more emissions are expected from BRT system than Monorail system. According to the cost calculation it is lesser cost required to introduce BRT over Monorail or other elevated system.

III. LIST OF FIGURES

IV. LIST OF TABLES

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CHAPTER 1

1. Introduction

1.1. Problem Identification

Traffic congestion in Colombo city is a common issue and one of the currently discussed topics in various media such as radio, newspaper, and television. Any commuter who travels to Colombo for work or any other purpose has to suffer wasting of time due to traffic congestion in Colombo City, irrespective to his/her transport mode.

At present, the government plans to implement Megapolis project to enhance Colombo metropolitan area development, including improvement plans for transportation infrastructure. At the initial stage of Megapolis project, proposed transportation plans will follow recommendations submitted under "Improvement of Urban Transport System in Colombo Metropolitan Area, 2014."

Study of "Development of a Multi-Modal Transport Centre for Sustainable Urban Transport - A Case Study in Colombo Metropolitan Area" emphasizes not only on the increase of private vehicles during the last 12 years, but also on the reduction of travel speed to 15-17 km/h.

In the study of "Colombo Urban Transport Master Plan (CoMTrans) with JICA, 2013," recommendations are provided for the Monorail transport system for the Jayawardenapura corridor.

The draft Urban Transport Master Plan for Colombo Metropolitan Region and Suburb, December 2013, has predicted the economic loss of traffic congestion as Rs. 471bn. per year.

Various proposals are at the discussion level to decide a suitable method to implement rapid transit. Solutions for traffic congestion can be identified by addressing two levels:

I. As an entire road network

II. As an individual corridor

CoMTrans study has focused their recommendations on individual corridor basis. This research was conducted to develop a methodology to identify an appropriate public transport system for an individual corridor.

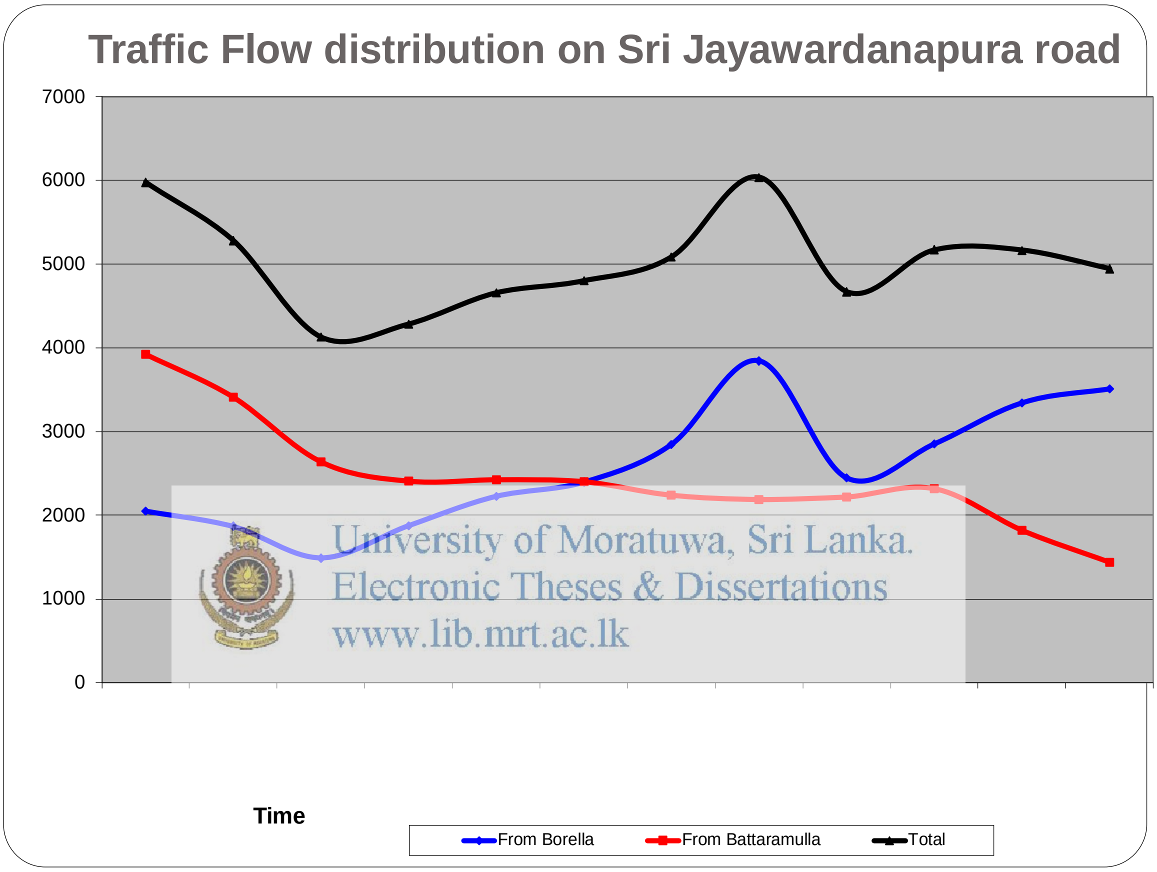


Figure 1.1: Traffic flow distribution on Jayawardenapura road (University of Moratuwa)

Traffic flow distribution of Figure 1.1 illustrates peak values on Total line occurring between 07:00 – 08:00, probably due to school and office starting times. Reason for the afternoon peak at 14:00 – 16:00 may be due to most government offices located on this corridor.

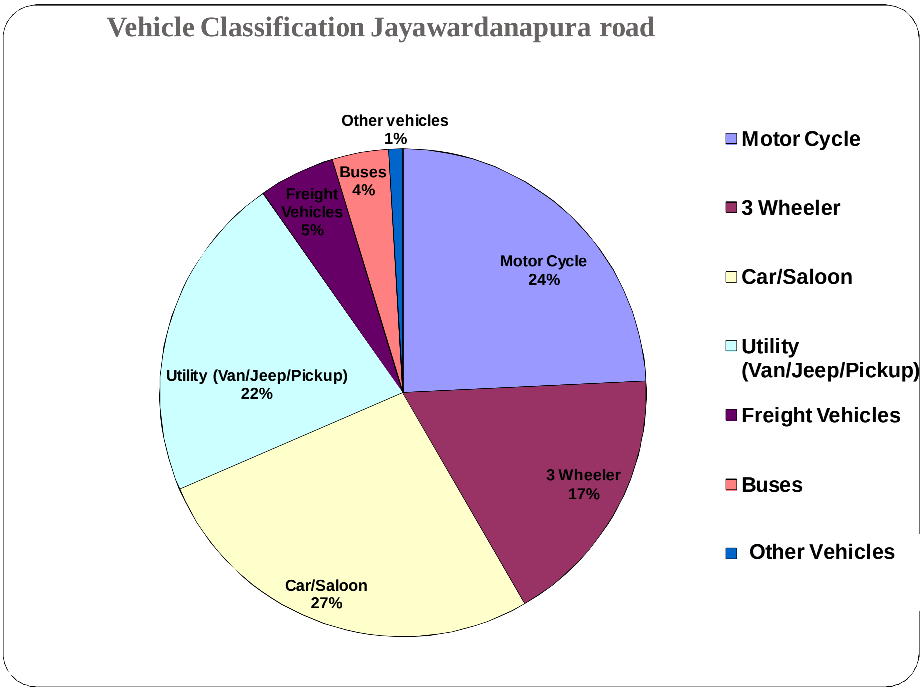


Figure 1.2: Vehicle classification on Jayawardenapura corridor

According to vehicle classification chart in Fig.1.2, buses represent only 4% on this corridor and contribute to the lowest percentage, compared with other vehicle categories. Major portion (68%) consists of cars, vans, jeeps, motor cycles, and three wheelers. This provides a clear picture of this corridor, where less efficient passenger carrying modes consume more space.

Department of Census and Statistics indicates the population increase was significantly higher up to 2014 in Colombo district, Sri Lanka (Fig 1.3)

Dark coloured areas of the Population density map (by province) in Sri Lanka indicate highly populated areas. Among the high population areas, Western province reveals the highest number of 1568 persons per sq. kilometer (Fig 1.3).

According to the Urban Development data for the land use of Colombo city, housing and commercial work are higher than other categories. It indicated high buildup areas were due to high population in the Colombo city. Due to increase of the population, many residence and commercial places will be created in newly built up areas, and in order to cater with their infrastructure facilities, transportation of people must be addressed properly.

It provides evidence for the necessity to increase land utilization for transportation with the increased population, and the need to address this issue by the government and the private sector.

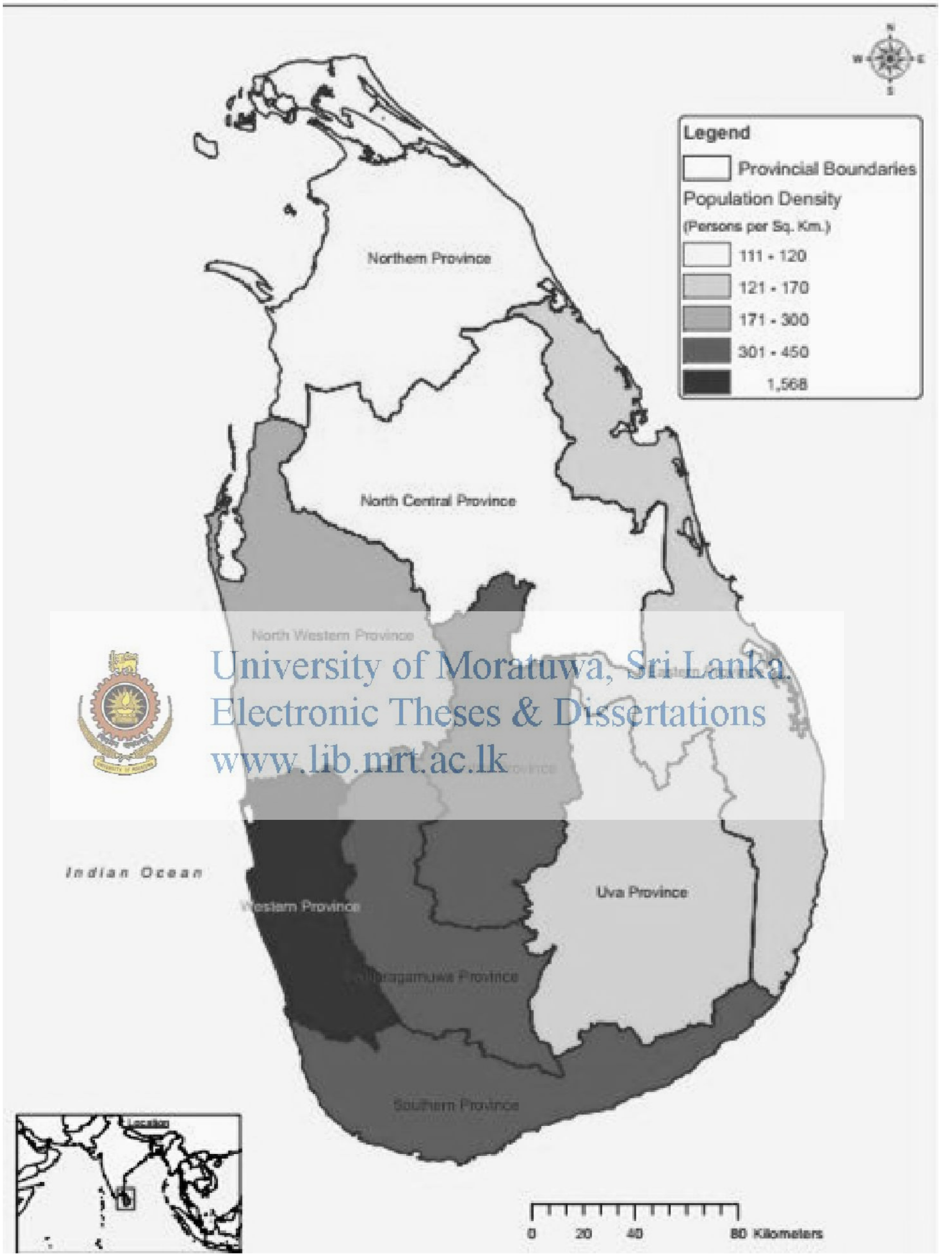


Figure1.3: Population density by province, 2012 in Sri Lanka (Department of Census & Statistics, 2013)

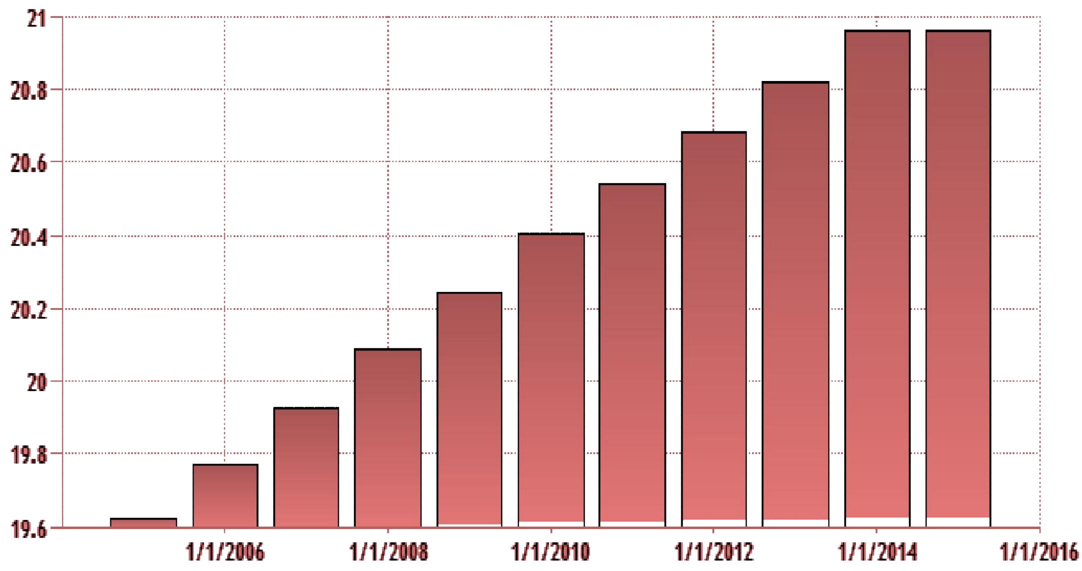


Figure 1.4: Population in Sri Lanka (Department of Census & Statistics, 2013)

1.2. Present Infrastructure and Distribution of other facilities in the Colombo City

1.2.1. Land usage in Colombo city

According to National Building Research Organization, the commercial capital of Sri Lanka is the most vulnerable city in the country with a threat of air pollution. The emissions additionally create due to rapid growth of cities together with associated industries, transport system, power generation, domestic activities etc. It was estimated that over 45% of the vehicles and 80% of industries in Sri Lanka are accumulated/located in Colombo region, which is about 1% of the total land in the country. This demands authorities to address these emissions effectively, particularly SO_2 and NO_2 emissions (National Building Research Organization, 2010).

Table 1.1: Land use distribution in the city of Colombo (Land use survey, 2012, projected by UDA)

	Area (Ha)		
Use of lands	**Year of 1977**	**Year of 1996**	**Year of 2012**
Housing	1687	1402	780
Commerce	201	225	1052
Education - Banking	465	411	238
Industry	151	149	0
Transportation	610	650	700
Port	0	0	506
Open area	142	262	355
Lake-river	98	98	98
Other purposes	375	532	0
Total	**3,729.00**	**3,729.00**	**3,729.00**

According to Table 1.1, land use of Colombo from 1977 to 2012 indicates housing area is decreasing remarkably. Housing is accounted for 37.6% of all in 1996 but it decreased to 20.9% in 2012. The growth density of housing area compensates for the decrease of housing area. Hence, future buildings will give priority to high-rise building developments. High-rise buildings in this area are more popular due to the land unavailability for all categories of people with their income generation. Only most people in the high-income group can buy a land and build a home while others cannot bear such costs.

No rail lines are connected in the Jayawardenapura corridor, and thus, the commuters have no alternate mode of transportation in this corridor. Here, commuters use public buses and private vehicles only. The new rapid transit system with the available rail transport system facilitates attracting commuters immediately than other corridors.

When considering the case study of the area (Jayawardenapura corridor), several issues affecting to the environment need to be addressed. Following types of environmental impact can be anticipated whether it is a monorail system, Bus Rapid

Transit (BRT), or any other rapid transit system introduced as a solution to the traffic congestion:

- Air pollution
- Surface and ground water pollution
- Impact on flora and fauna
- Impact to the social environment

Mitigation Measures

It is not possible to prevent 100% of all affects by implementing the new project. Relevant mitigation measures for the identified and anticipated impacts generating from the proposed development should be addressed effectively. It is impossible to establish the no-damage condition in a development and therefore, it is important to mitigate the impacts damaging the environment to secure natural environment for the future.

1.2.2. Why need Rapid transit system?

According to present stuation of the road network in Sri Lanka and relevant references, following reasons can identify as requirements to introduce a Rapid transit system:

1. To reduce congestion.
2. To reduce travel time.
3. To have less emission to the environment and minimise air pollution.
4. To provide safe and reliable transport mode to commuters.

To achieve above requirements, many proposals have originated aiming different directions. Most proposals base on Rapid transit methods but no specific method was proposed to select an appropriate transit mode for a specific corridor. Expertise provide their ideas and relevant authority need to make a policy decision. Funding agents, which may base on the selected companies by the government, are proposing their terms and conditions. Media publish the advantages and disadvantages against new rapid transit systems. Thus, no clear-cut method is available to select and implement an appropriate rapid transit system.

1.3. Project Objectives

Main objective of this research is to develop criteria for selecting suitable rapid transit system for the Colombo city based on following parameters:

Among different parameters that can influence the selection of appropriate option, social environmental considerations, constructability, connectivity and accessibility, cost parameters, extendibility connection with other transport modes, and passenger preference are considered as important.

Amongst the above parameters, passenger preference is subjective. Because the passenger preference is not well defined and need to assess the secondary objective that narrows down to passenger preference criterion, then rapid transit system is selected for the city of Colombo.

CHAPTER 2

2. Literature Review

2.1. Definition of Rapid Transit

Rapid transit is defined by https://en.wikipedia.org/wiki/Rapid_transit, 2014 as follows:

"An underground subway, elevated railway, metro, or metropolitan railway system is a passenger transport system in an urban area with a high capacity and frequency, and grade separation from other traffic".

2.2. Research on the selection of rapid transit in Istanbul

According to Topcu and Onar, 2011, there is no specific hard and fast way to new transit decision. The best-designed system will depend upon,

- Geographical and physical situation
- Topological configuration
- Financing, know-how
- Technical capability
- Institutional capacity
- Political constitute local conditions whilst low cost
- High customer service level
- Rapid journey
- Convenience
- Comfort
- Frequent service
- Safety and security constitute
- Passenger preferences

Therefore, selecting an appropriate mass transit system necessitates a multi criteria decision aid, which considers all these conditions and preferences. Further, this study proposes a multi-criteria decision model for urban mass transit systems. The proposed model evaluates suitable mass transit systems for a transit corridor. There are several conflicting, weighted, and incommensurable evaluation factors such as geographical and physical situation, topological configuration, financing expertise, technical capability, institutional capacity, and political constitute local conditions whilst low cost, high customer service level, rapid journey, convenience, comfort, frequent service, safety, and security constitute passengers' preferences. Besides, interrelationships among these factors cause dependences and feedbacks. Due to this complicated nature of the problem on hand, it can be modeled as a network and treated with a network based multi criteria decision-making approach.

In this study, researchers identified the passenger preference as an important factor to select a new rapid transit in the selected corridor. However, there was no significant importance in selecting the passenger preference in this research and they have developed a computer model based on the transport expertise. Relations among criteria are assessed and a network formed. The Analytical Network Process (ANP) was then applied to evaluate possible mass transit systems.

During this research for Sri Lankan passengers, passenger preference is considered more important than other facotrs; hence, passenger preference was separately evaluated. The new system should attract passengers and will help to avoid congestion on roads and high income mode for the operators.

2.3 Traffic congestion and Traffic control of Colombo City

Urban Development Authority, City of Colombo Development Plan (1999), has proposed following method and their recommendations to control traffic at Colombo.

Considering present situation in the city transportation and the expected changes in coming years, following proposals are considered as important to improve its efficiency.

Parking spaces must be provided to the maximum possible extent in given areas (Zones). Parking fees should be determined according to building regulations in the area and the availability of off-street parking facilities. The on-street parking fees, for example, should be in areas where substantial off-street parking is available.

An entry fee should be introduced for vehicles entering the city during peak hours.

Sources that generate high traffic need to be identified and necessary changes to distribute traffic more evenly during morning and evening peak hours should be considered. For example, a popular school in Colombo attracts many vehicles and, when added to office time traffic, it cause serious traffic congestion in the city during peak hours. This can be avoided to a certain extent either by starting schools earlier or by opening offices later in the morning.

The Colombo Metropolitan Transport Master Plan, Ministry of Transport Sri Lanka, 20th November 2014 state, vehicles that carry more passengers, i.e. busses, should be specially dealt by providing exclusive lanes and giving priority of turning at traffic signals.

Colombo Metropolitan Area (Colombo City and the suburbs) Urban Transportation: General Overview report, (2013) state following details:

Being the largest city and the capital of Sri Lanka, Colombo attracts more than one million daily commuters by 160,000 vehicles.

- ⇔ Travel demand in the city increase rapidly due to increased mobility of the people after 30 years of war, ongoing massive urban development projects, and increased number of privately owned vehicles with economic growth of the country.
- ⇔ Modal share of public transport is rapidly decreasing (67% in 2004, and 58% in 2013) and private vehicle usage increased to 42% in 2013.
- ⇔ Average speed of vehicles during peak hours in major transport corridors falls below 10 km/h.

The Preliminary feasibility study report for Colombo Monorail system by Garamspace Co. Ltd. and Garamspace Research Institute, Feb 2011, provide supportive data for several alternative routes that connect with main control station at Fort.

This report focuses only on the Monorail system and they embrace all positive factors regarding Monorail system. They have not concerned about other positive rapid transit modes. They have concentrated on Battaramulla to Moratuwa, Battaramulla to Fort, and Kollupitiya to Battaramulla routes.

This report encountered a complete study about the population of Sri Lanka and how it increase in the next 25 years, the work force, passenger demand, and economic advantages to Sri Lanka. It includes cost calculation for installation, revenue, and demand increase for the next 25 years.

It is essential to consider cost factor for the new transit, revenue to maintain the system, and profit for the service provider. This report provides good examples for calculating those factors.

2.4. Rapid transit systems for Sri Lanka

The Halcrow Fox in association with traffic and transport consultants (2000) study Mass Rapid Transit (MRT) in developing countries. MRT carry extensive passenger volumes, i.e. 60,000 passengers per hour per direction (pphpd) or higher. Most mass rapid transits are metro systems, which require high quality technology to produce and installation.

According to the Halcrow Fox study, for a country like Sri Lanka, mass rapid transit system (such as Metor) is less suitable due to low passenger demand, high initial cost, and construction difficulties. As per the Colombo Metropolitan Transport Master Plan (2014), the number of commuters enter to the Colombo city is over one million per day. This value provide evidence for the less demand of passenger in Colombo for the MRT system, and hence, rapid transit can be introduced with the passenger demand.

According to the Colombo Urban Transport Master Plan (CoMTrans) with JICA 2013, Figure 2.1 illustrate that rapid transit modes can be selected with passenger demand and capital cost.

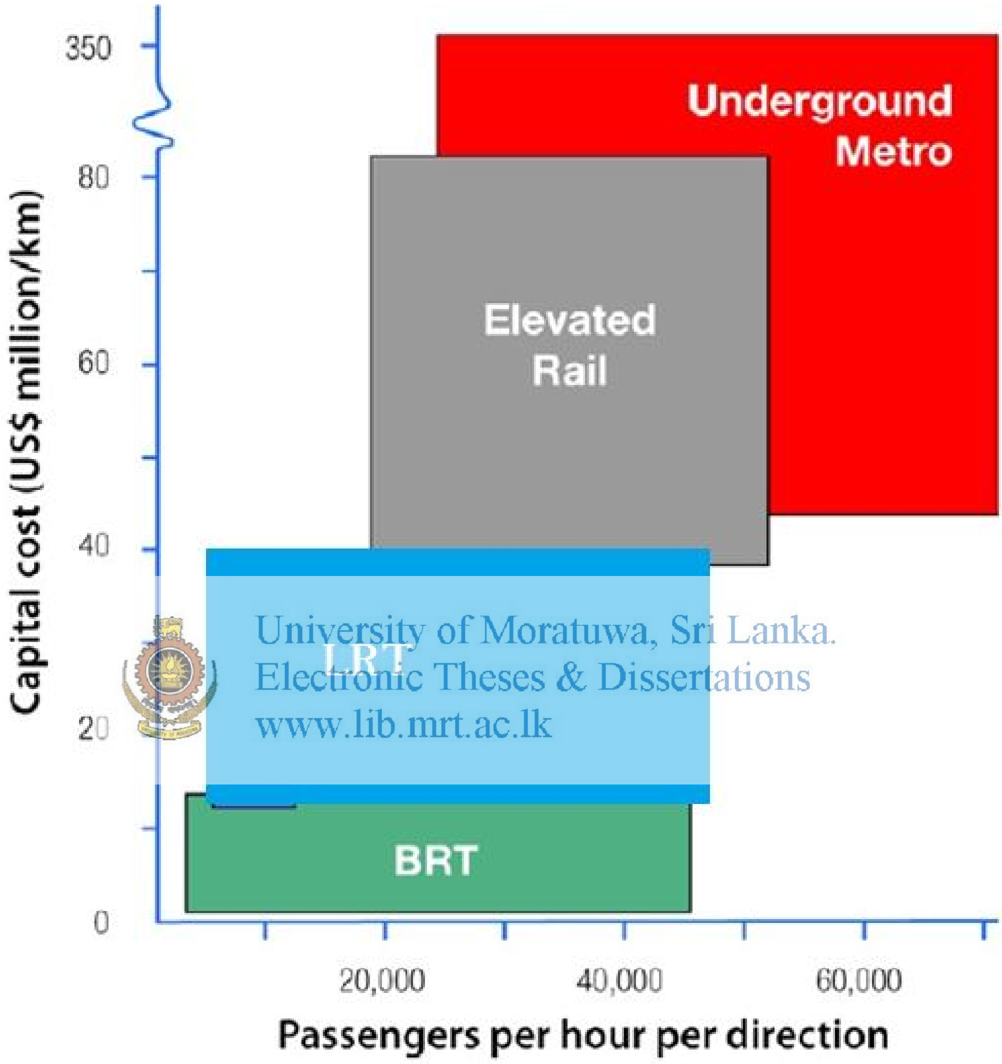


Figure 2.1: Recommended Rapid transit against Passenger demand and capital cost (CoMTrans, 2013)

According to Figure 2.1, there can be suitable systems of BRT, LRT, Mono rail, and improve existing mode, or mixed systems of this modes for Sri Lanka.

Concern of less pollution and eco friendly system:

There are many discussions and technologies that introduce less environmental pollution. Presently, other countries use hybrid vehicles, electric vehicles, less carbon emmition fuel etc. and Sri Lanka also have to practice an eco friendly sustainable transport system.

System extension is possible in future, due to articulate. Extension of the system should be essentialy match the demand. It is not possible to initially introduce for the full demand, as theorotically expected. The actual demand may be less than the theoritical expectation. It is advisable to aim for a medium value of demand for the Bus priority system that can be an effective solution for the traffic congestion. Inter-connecting different transport modes is more attractive for new systems.

Compared to other counties and their Rapid Trasnist systems, Sri Lanka faces distinguished difficulties.

Sub ways (underground tunnel) are not suited due to high water table around Colombo city, and hence construction costs will be higher than normal figures. Thus, waterproofing work demands high concern and monetary allocation than major items.

Capital cost for the instalation of the system is much higher than other traditional modes since it needs to build dedicated modes of transport and buy new coaches or buses for relavant rapid transit sytem.

Relocating people is complicated on the specific road traces. Land acquisition is a more complicated issue when relocating people living by the road trace.

During changes of the central government, transport development plans completely change and new plans will alter with new governers. Many investors get discouraged to invest on new projects due to this uncertainty of the Sri Lankan economy and future plans.

2.5. Traffic congestion and controls in other countries

According to Topcu and Onar (2011), the quality of life, the economic productivity, and the safety and security are affected by transportation mobility. In the present situation, increase in population, income level, car ownership, and in commuting cause traffic congestion. Our mobility in urban road networks is interrupted due to traffic congestion. It is well known that traffic congestion pose many negative effects such as wasting time, delays, late arrivals, increased fuel use, depreciation of vehicles, prevention of emergency services, and mental illness for drivers result in productivity decrease and economic health reduction as well as air pollution and global warming.

According to the Bus Rapid Transit: an overview, by Levinson.(2002) several planning research studies have described the parameters where BRT would work and how it might be configured. Wilbur Smith and associate study set forth broad planning guidelines (Wilbur Smith and Associates, 1966). It indicated that bus rapid transit is especially suitable in cities where downtown most attracts its visitors from a wide, diffused area. It stated that, "BRT could involve lower capital costs, provide greater coverage, better serve low- and medium-density areas, and more readily adapt to changing land-use and population patterns than rail systems. BRT also has applicability in larger cities of much higher density because of its operational flexibility and that with proper downtown terminal design; bus rapid transit systems could provide adequate capacities to meet corridor demands in nearly all of the Nation's cities, which did not have rail systems.

To achieve high average speeds on downtown approaches, buses could operate within reserved lanes or exclusive freeway rights-of-way on key radial routes and travel outward to the intermediate freeway loop, with provision for subsequent expansion. Downtown, buses would operate preferably on private rights-of-way and penetrate the heart of the core area (either above or belowground) or, alternatively, they could enter terminals. Successful BRT, however, would require careful coordination between highway and transit officials in all stages of major facility planning. In this regard, resolution of several downtown cordon volumes up to 125,000 persons, an ample capacity for the vast majority of nation's cores. Moreover, as bus technology improves and electronic bus train operation becomes a reality, substantially greater capacities would be achieved." Thus, ultimately, differences between rail and bus transit could become minimal.

2.6. Cost calculations

Suitable facts are provided to calculate cost per each transit mode by *How much does a transit trip cost* (Taylor & Garrett, 2000). This calculation method mostly includes USA relevant systems and it is adopted to Sri Lankan departments etc.

For calculation works, land values and land use data were obtained from the Urban Development Authority (2008), and City of Colombo Development plan volumes I and II. Land values can change with new developments and has increased slightly than 2008, according to UDA.

The Potential for Bus Rapid Transit:

This study in 1970 indicated that freeway systems are potentially usable by express buses and, with modifications, for exclusive bus lanes or bus ways (Wilbur Smith and Associates, 1970). Key factors in evaluating the potential benefits of BRT include: (1) capital costs, (2) operating costs, (3) route configuration, and (4) distribution in the city center and other major activity centers.

Bus Rapid Transit Options for Densely Developed Areas:

This study (Wilbur Smith and Associates, 1975) described and evaluated the cost, service, and environmental implications of bus lanes, bus streets, and bus ways. The report explained how various bus priority facilities would be coordinated in the central area and suggested a multi door articulated bus for BRT operations. Most of these concept studies focused on the facility aspects of BRT, often as an adjacent to urban freeways. Less attention was given to the service and amenity/identifies aspects of BRT.

According to the studies of Herbert, Zimmerman, and Clinger (2002), other countries identifies BRT and Monorail systems as commonly used Rapid Transit systems.

2.7. Bus rapid transit

What is Bus Rapid Transit (BRT)?

"Rapid mode of transportation that can combine the quality of rail transit and the flexibility of buses" (Thomas, 2001).

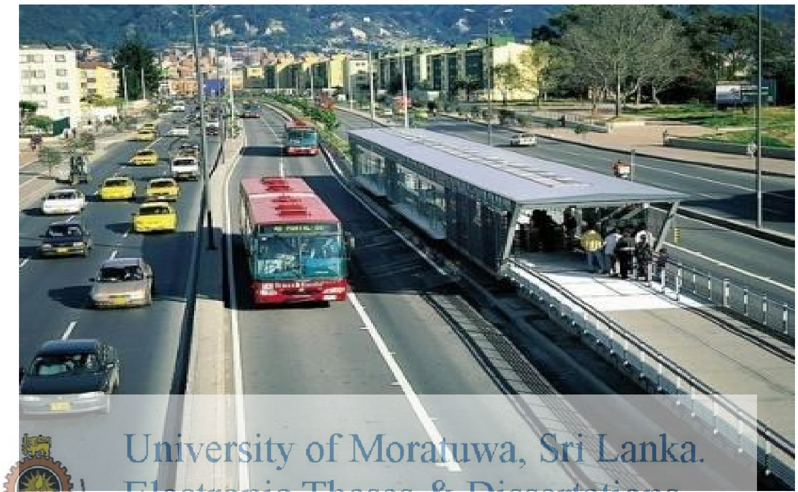


Figure 2.2: BRT system in Bogota (Original in Colour)
(Lightrail now team, 2009, http://www.lightrailnow.org/myths)

Figure 2.3: Examples for Jarkartha BRT system (Original in Colour)

(Florowski, 2013, http://www.reeep.org/news/brt-mega-cities-reeep-speaks-out-information-daily-article)

BRT is a bus-based mass transit system that deliver fast, comfortable, and cost effective urban mobility. Through the provision of exlusive right of way lanes and excellence in customer service, BRT essentially emulated the performane and amenity characteristics of a modern rail-based transit system, at a fraction of the cost.

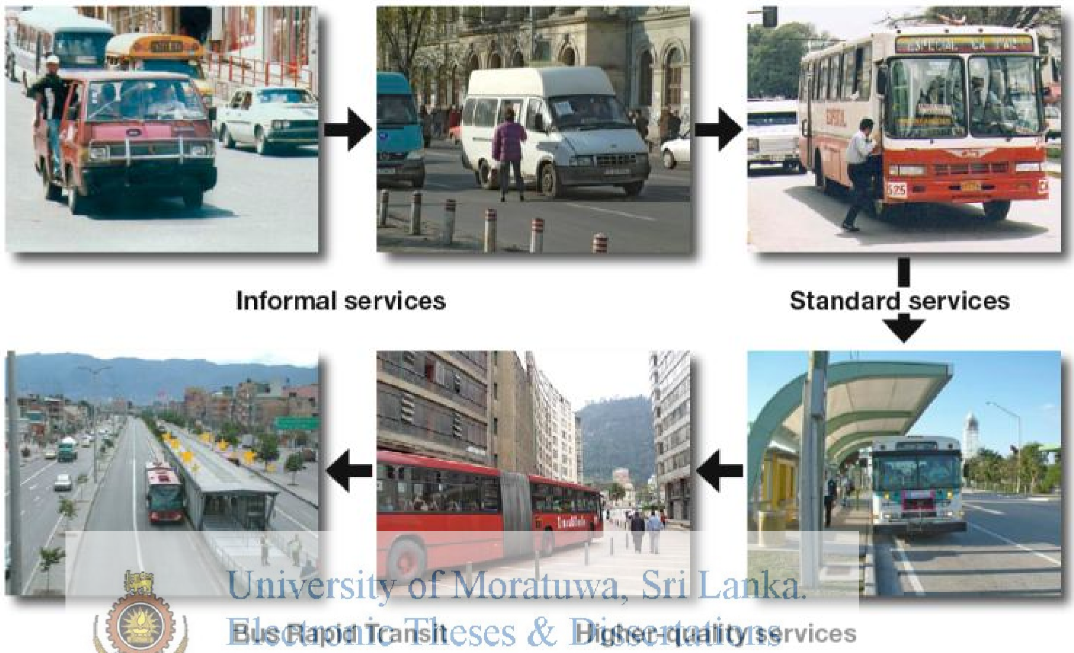


Figure 2.4: Path to the BRT system from informal services (Original in Colour)

The BRT system require essentially distinct space than normal road, and the BRT track should be separate from other vehicle tracks. It is shows typical section of the road with BRT system.

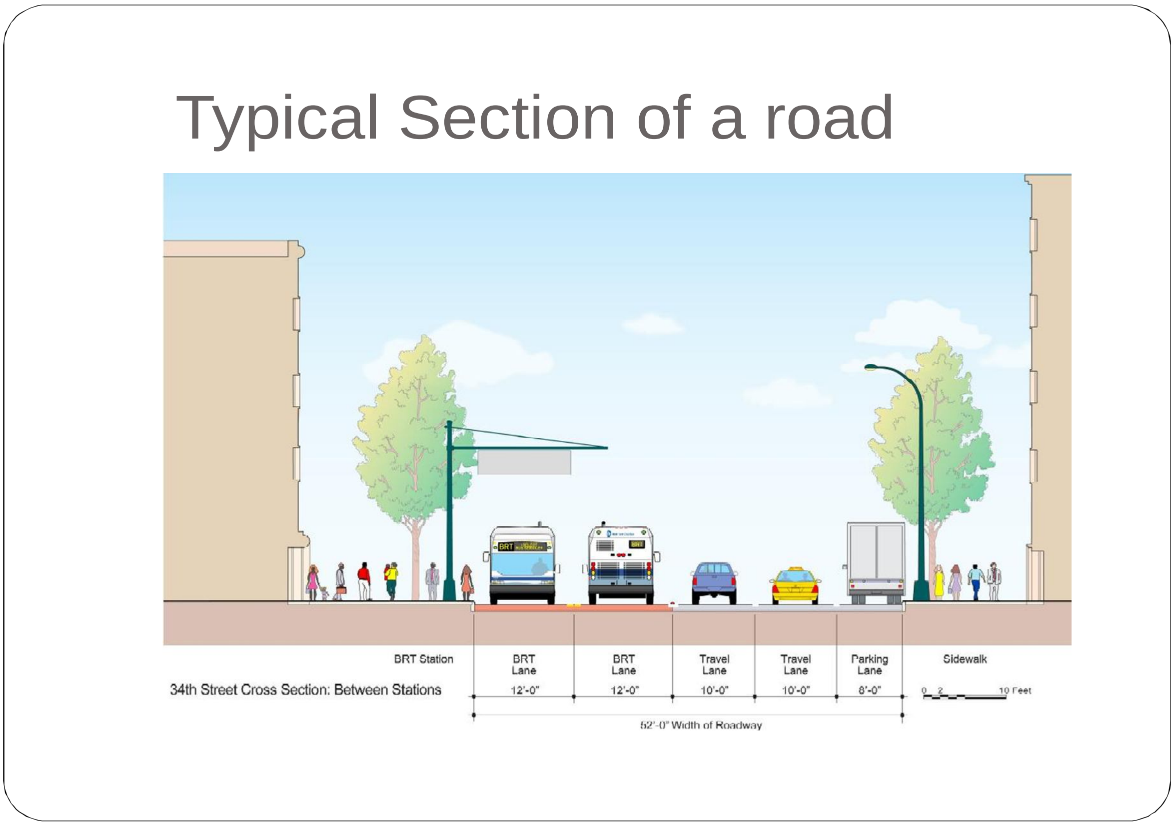


Figure 2.5: Cross-section of BRT system road with other modes

According to Transport Research Laboratory (2004) and Bus Rapid Transit Guideline (2005), the advantages and disadvantages can be identified as follows:

Advantages of BRT:

1. Lower capital cost.
2. Lower operational cost.
3. Short construction period.
4. Higher speed than normal buses.
5. Save time and reduce travel time.

6. Infrastructure cost and operation and maintenance costs of the rail systems cause serious financial burdens for governments than other systems.

7. High capacity that can reach to the level of light rail transit, and less fuel consumption and air pollution than the traditional bus transit.

8. BRT system is environmentally sustainable (reduce emission), financially sustainable and socially sustainable with a view point of sustainable transportation.

9. Although BRT has many advantages than other public transit systems, its fairness and reasonableness have not been analyzed.

10. Reduce accident and illness, reduce costs of delivering services such as electricity, sanitation, and water.

Disadvantages of BRT:

1. Two additional lanes required for the BRT system on existing roads.

2. Difficulties encountered for road extension for another two lanes due to services and other obstructions.

3. Land acquisition difficulties.

4. Need to buy new busses for BTR system with better facilities and ability of articulate.

5. Solutions for existing buses at road.

6. Required to install new traffic control systems for different mode of transports.

2.8. Monorail System

Monorail system is an elevated and dedicated road for the monorail coaches. It is not possible to use any other modes. Special elevated entrance point is essential to construct at each access points. Following pictures provide a clear idea of cross section of the monorail and normal traffic system.

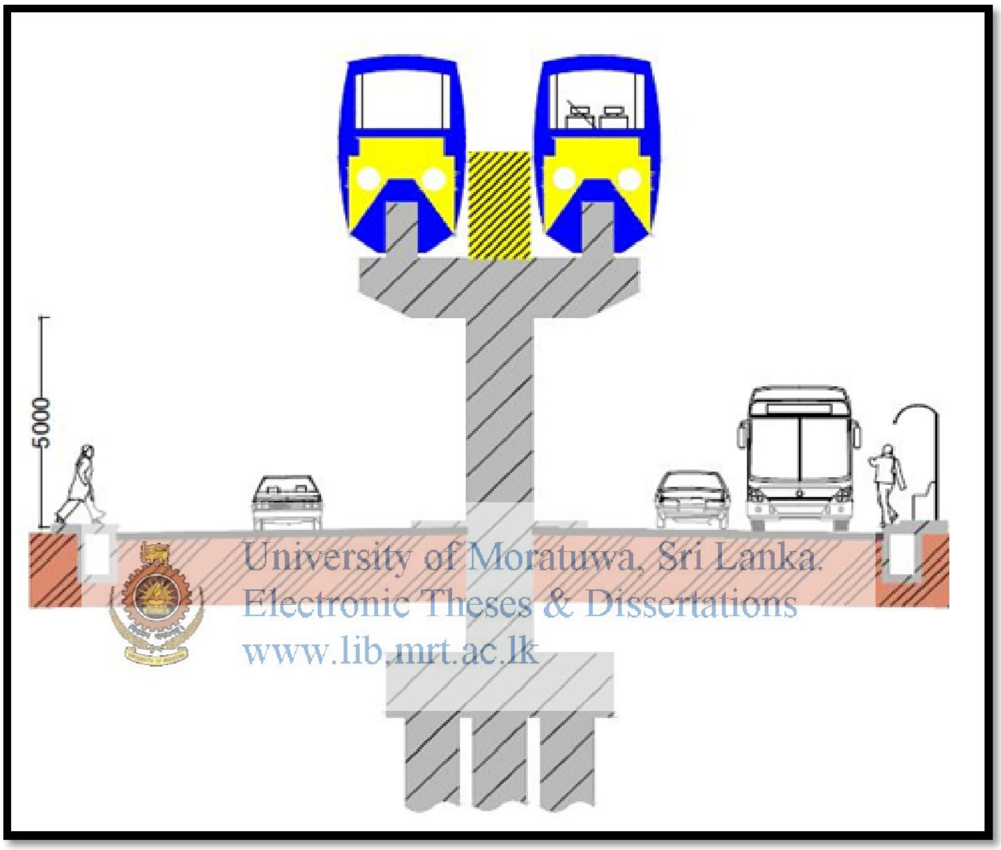


Figure 2.6: Typical cross section of Monorail system

Figure 2.7: Tokyo Monorail system (Takahashi, 2014, http://www.akihabaranews.com), (Original in Colour)

Figure 2.8: Mumbai monorails system (Najeem, 2014, http://www .themetrognome.in) (Original in Colour)

Advantages of Mono rail system:

1. Require less space.
2. High capacity than normal buses.
3. Passenger attractive system than other transport modes.
4. Eco friendly system.
5. Safer than ground transport.
6. Can create many job opportunities.

Disadvantages of Mono rail system:

1. High capital cost for system installation.
2. System can operate only on a special track line.
3. Track line cannot use for any other transportation mode.
4. Repair works are difficult and may completely cease the service until completion of repair works.
5. Mono Rail maintenance requires special workers.
6. Construction time is more than normal bus routes and hence a burden for the government.

CHAPTER 3

3. Methodology

3.1. Selection of corridor

For the research, Jayawardenapura corridor was selected as case study. This is a heavy traffic section during peak time.

Selection this corridor depends on following reasons:

Road section is Fort to Battaramulla. The selected passengers use this route partly or to a certain extent to access other towns.

This route has high traffic congestion during peak time and it will increase drastically in future due to establishment of government offices at Battaramulla (it will act as an administrative city).

It is possible to access many cities through this route without travelling to the Colombo city.

It provide easy access to Southern Express way entrances at Kottawa or Kaduwela and other express ways by Outer Circular Highway.

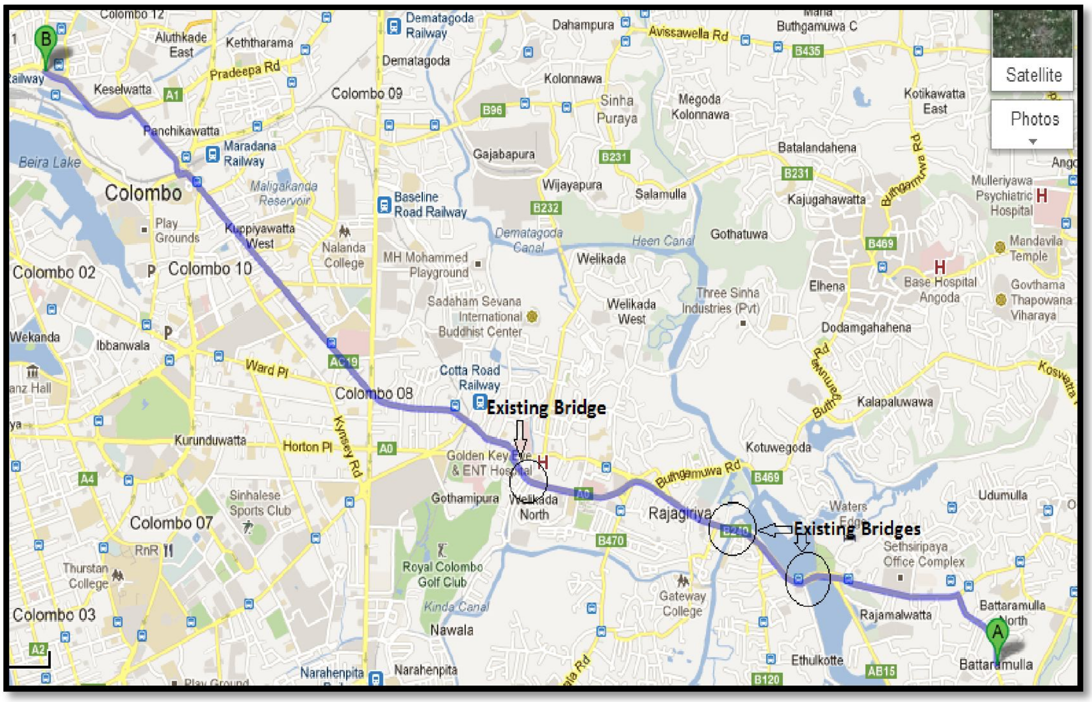


Figure 3.1: Case study trace

The literature identify Common Rapid transit types as follows:

Mass rapid transit (MRT)

Light rapid transit (LRT)

Bus rapid transit (BRT)

Mono rails system

3.2. The important parameters

Selection of new Rapid Transit should consider following important parameters:

- Passenger preference
- Environmental friendliness
- Constructability
- Cost parameters
- Future extendibility of new system
- Connection with other transport modes

Comparison of above parameters can be discussed with weight age.

3.3. Preparation of the questionaire

This reserarch is based on data collected by a questionaire. Format of the questionaire is constructed with the most important questions. It is experienced that large questionaires are not practical and receive negaive responses by passengers. Passnegers will not spend time with large questionaire with their other works, and hence, this questionaire consisted only important data.

Questionaire was completed by the commuters who travel from Fort to Battaramulla road section, fully or partially.

Major factors were concerned during preparation of the questionnaire:

- Income level of passengers
- Purpose of the trip at the specified time
- Present transport mode they are using and the difficulties encounterd
- Requriement and difficulties on parking facilities
- Cost per trip for the passenger
- Reason for the using present transport mode
- Preferred new transit systems
- Expecting facilities of new transport system
- Frequency of new transport system

The specimen questionaire is attached in Annexture 01.

With the questionaire results, cost calculation for each mode, benefits of each new rapid systems, details available were tabulated in Tables 3.1 and 3.2:

Table 3.1 Passenger preference parameters

Parameters	MRT	BRT	LRT	Monorail
Construction Cost ($)				
Preference of Level of passenger income				
Preference of Purpose of the passenger trip				
Preference of Preference of Daily travel passenger				
Preference of Non-Daily travel passenger				
Preference of Hire car users at present				
Preference of Public mode users at present				
Preference of private vehicle users at present				
Preference of working passengers				
Preference travel for other purpose passengers				

Table 3.2 Additional parameters

Parameters	MRT	BRT	LRT	Monorail
Connect with other modes				
Extendibility in future				
Environmental friendliness				
Constructability				

CHAPTER 4

4. Data Collection and Data Analysis

Data were collected by the questionnaire and data sample was 140. With the data collection, the graphs plotted with various combinations to analyse data set. Data combinations were as follows and results of the plot are presented in the Discussion chapter.

4.1. Preferred new transit vs. passenger (%)

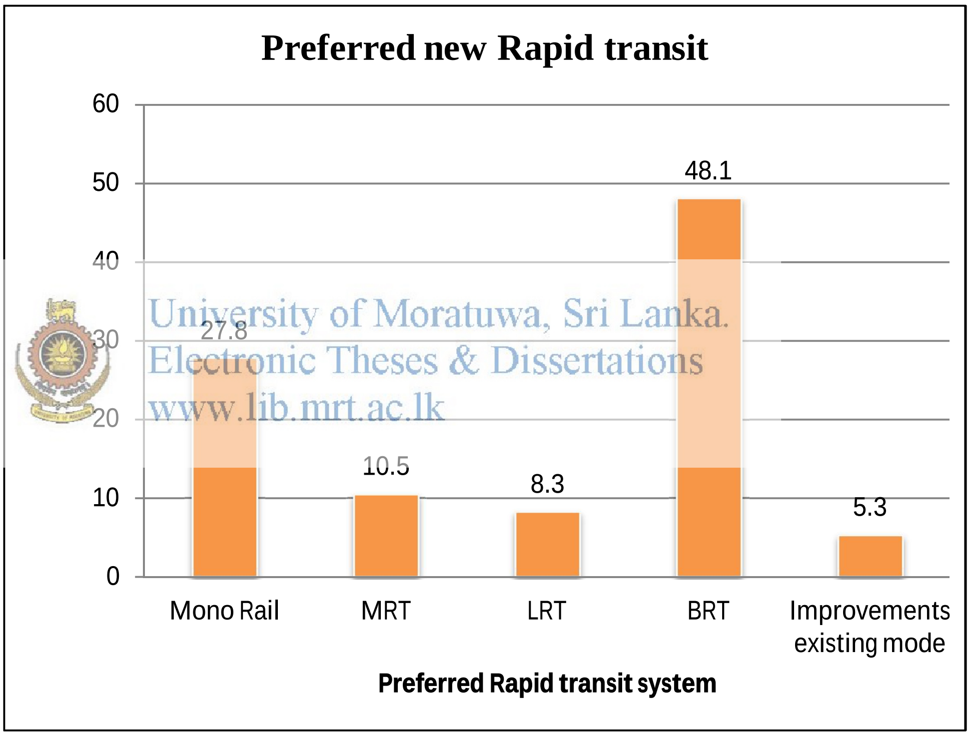


Figure 4.1: Preferred new Rapid Transit System

According to data collection, graph plotted the passenger percentage with preferred new rapid transit system. It illustrates that BRT is preferred by 48.1% of all passengers, which is the heighst value depicted among all rapid transits. According to the graph, Monorail system and MRT take second the third places respectively .

4.2. Daily travel vs. new transit mode

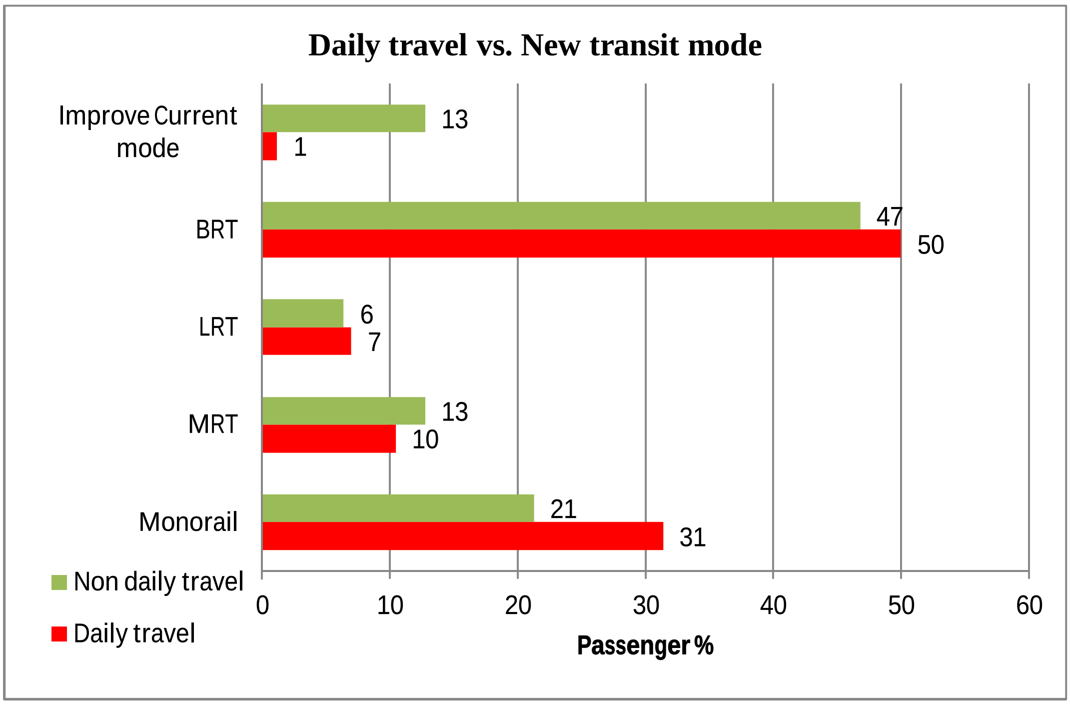


Figure 4.2: Daily travel vs. New transit mode

According to Figure 4.2, more passengers belonging to daily travel and non daily travel prefer Bus Rapid Transit system.

Daily travellers were less interested on improving the existing mode as well as the LRT system.

Daily travelers selected Monorail as their second choice for rapid transit.

Comparison of daily travel passengers vs. new transit mode, mostly prefer to Bus Rapid Transit.

4.3. Income vs. New transit mode

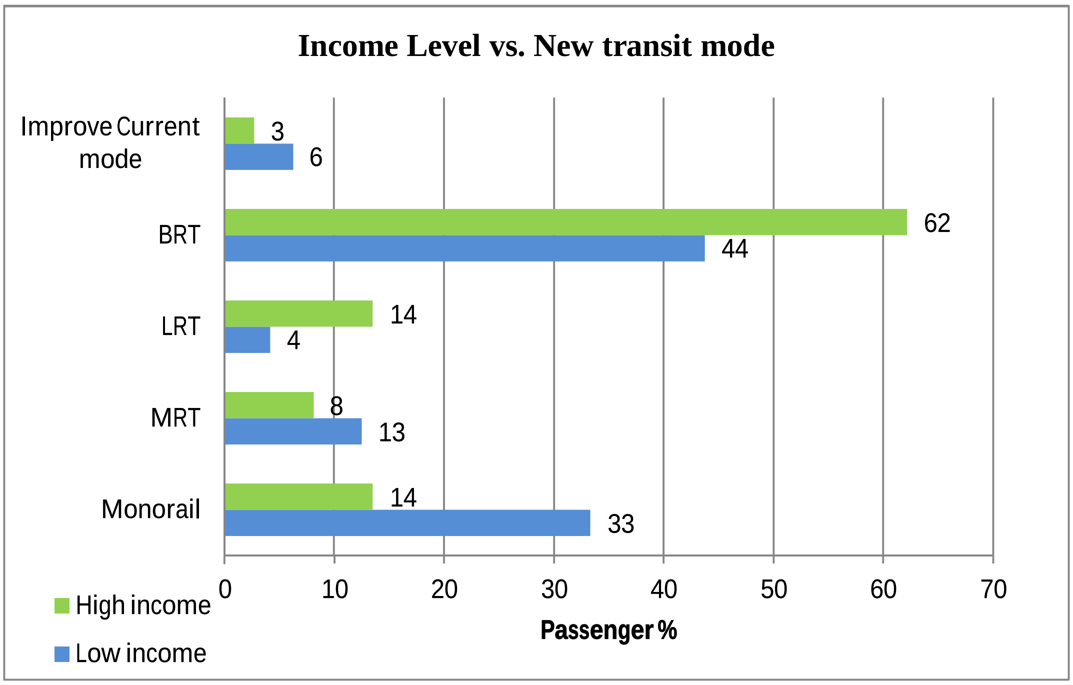


Figure 4.3: Income vs. New transit mode

Both low and high income (monthly income more than Rs. 50,000) passengers mostly preferred the BRT system.

The second choice of both income levels were the monorail system.

High income passengers' interest of MRT was just below than Monorail and it is a considerable amount.

Comparison to the income of passenger and new transit mode, it shows the preferred new transit mode is the Bus Rapid Transit.

4.4. Purpose of the trip vs. new transit mode

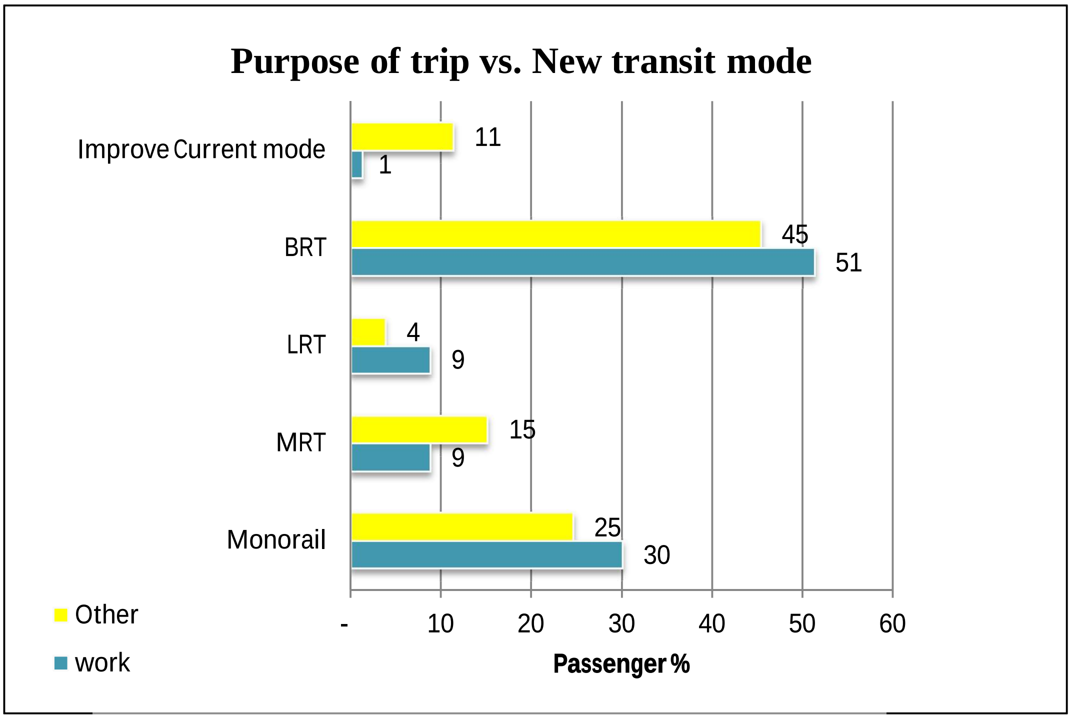


Figure 4.4: Purpose of trip vs. New transit mode

Passengers who travel for work and other purposes were mostly interested on BRT system and secondly, on Monorail system.

Travel for other purposes were interested on improving the current system than LRT.

Passengers travelled for work were not interested on improving current mode; they may have understood that there are no practical ways to imporve present mode with other factors.

Both parties were less interested on LRT system as a new transit mode.

Comparison with the purpose of trip and new transit mode, Bus Rapid Transit is preferred.

4.5. Present transport mode vs. New transit mode

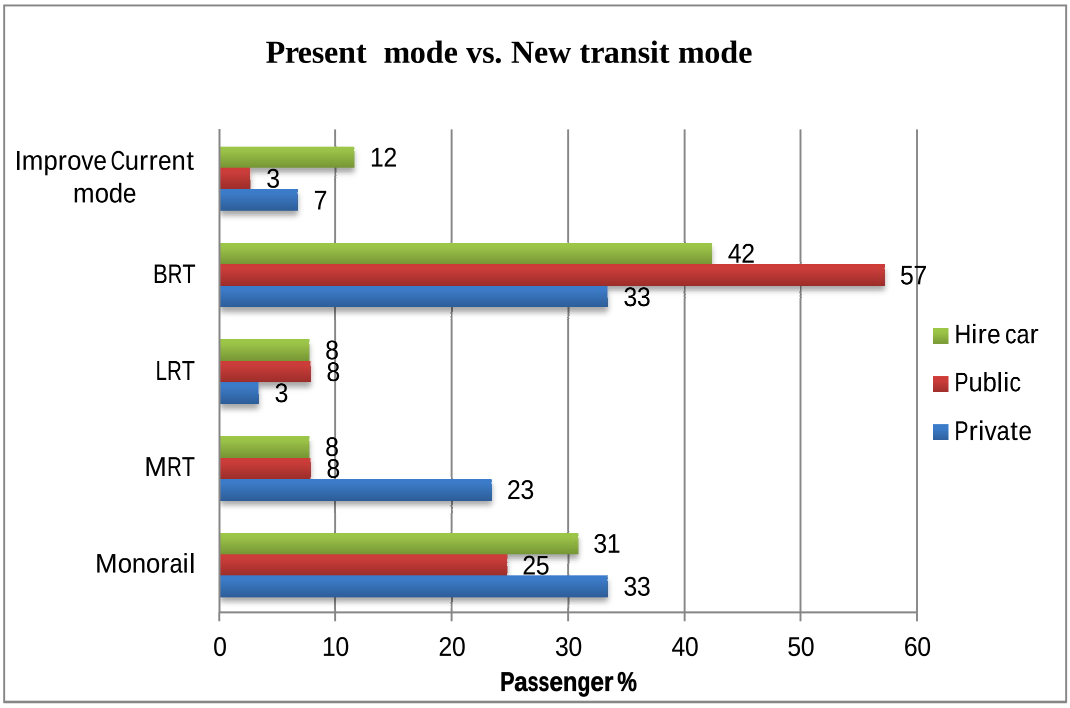


Figure 4.5: Present transport mode vs. New transit mode

Passengers who used Public modes prefered BRT system.

Passengers who hire cars mostly prefered BRT system.

Passengers with private cars prefered BRT system.

Comparison of present transport mode and new transit mode revealed, Bus Rapid transit was prefferred over all types of present transport modes.

4.6. Problems of existing transport mode

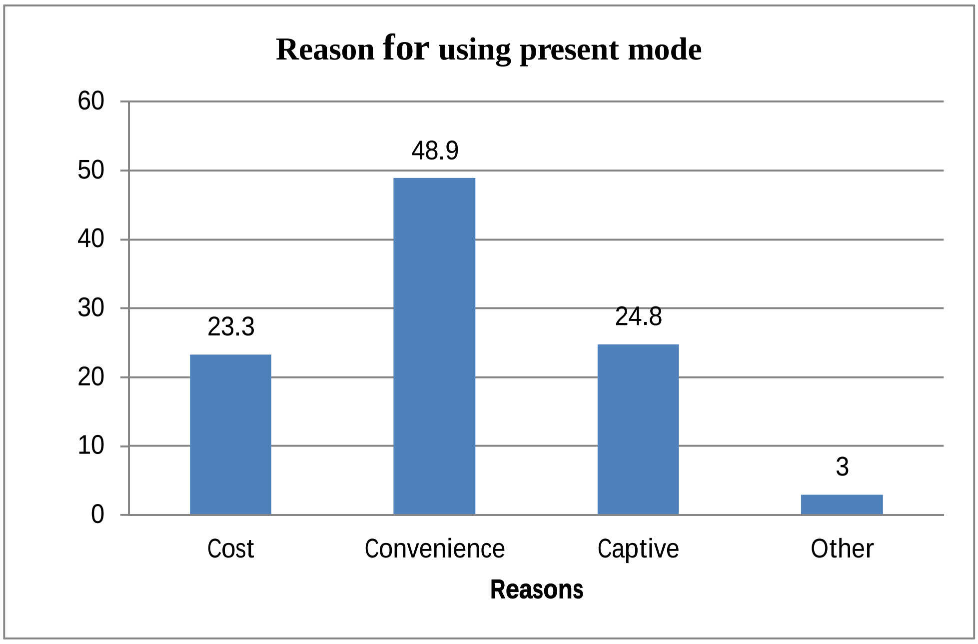
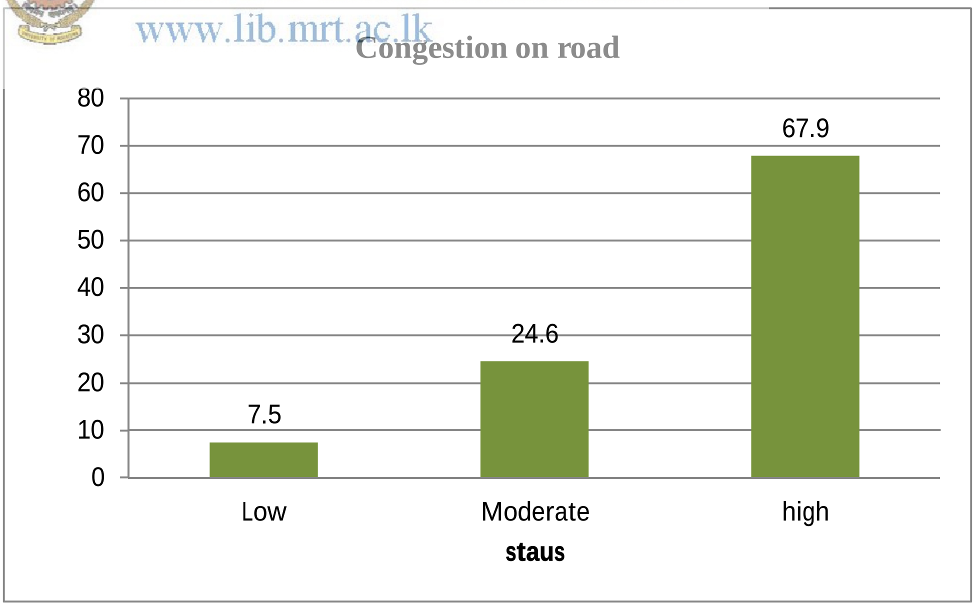


Figure 4.6: Reason for using present mode

According to Figure 4.6, most commuters use exsising trasnport mode, firstly due to the convenience and secondly because its captive.



Figue 4.7: Congestion on road

Congestion of road was considered as the most inconvenient issue for the exisiting modes by 68% of commuters.

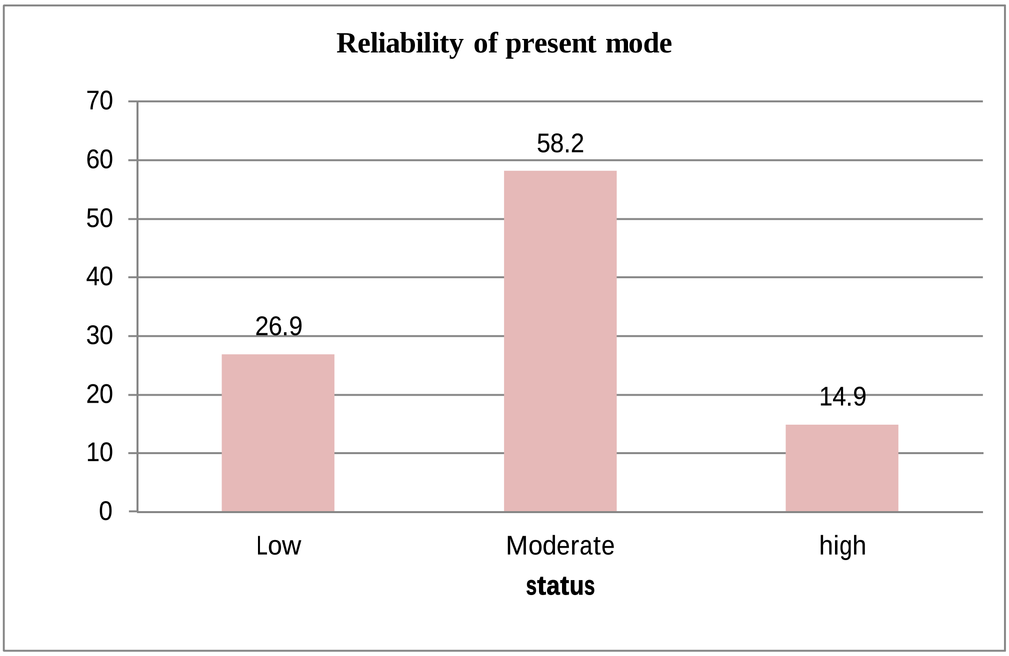


Figure 4.8: Reliablity of present mode

The commuters did not consider much on reliability of the present mode and treated it as moderate.

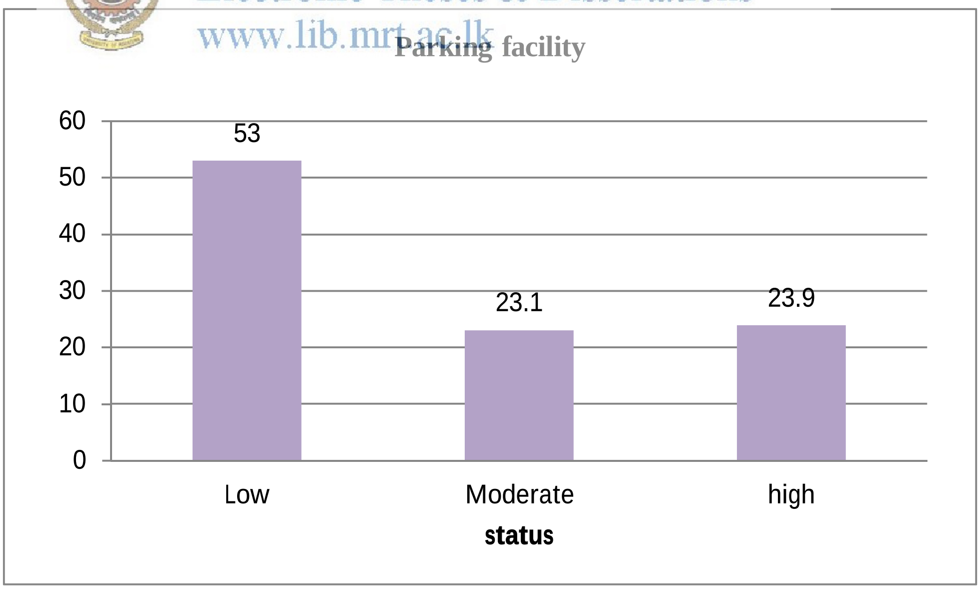


Figure 4.9: Parking facility

Since most commuters travel by public modes, parking facility was not prominent. But is may be a critical issue when considering hire and private vehicle users.

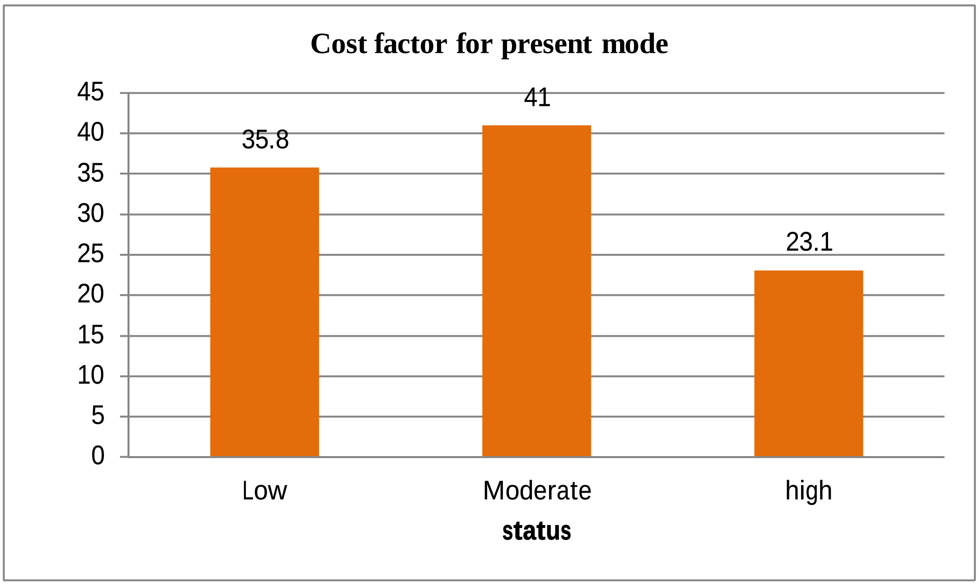


Figure 4.10: Cost for present mode

Cost for the present tramsport mode is not critical according to the questionaire data.

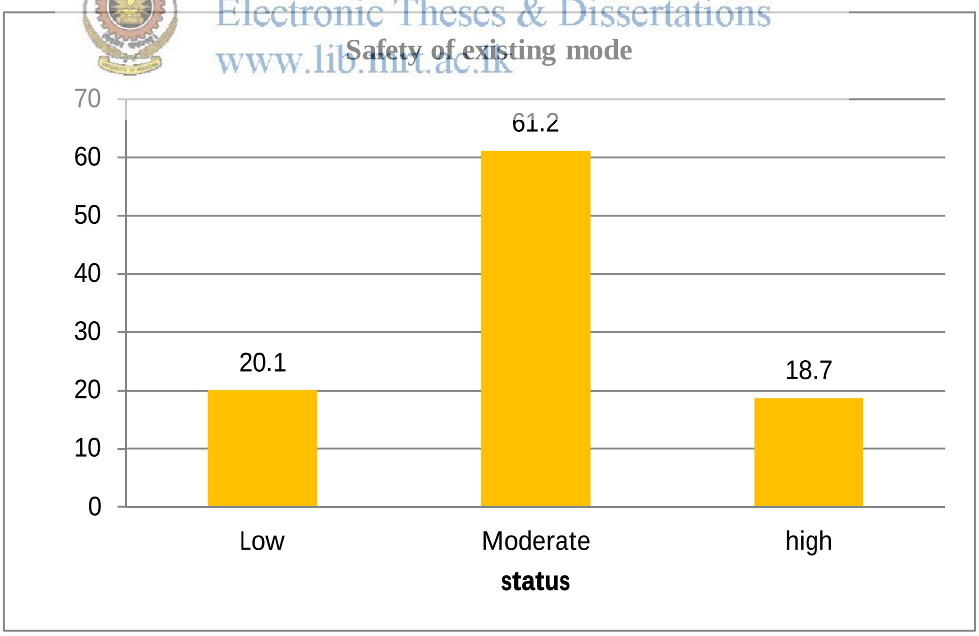


Figure 4.11: Safety of existing mode

Safety of the existing mode was accepted by the commuter and they consider it moderately, at a value of 61.2%.

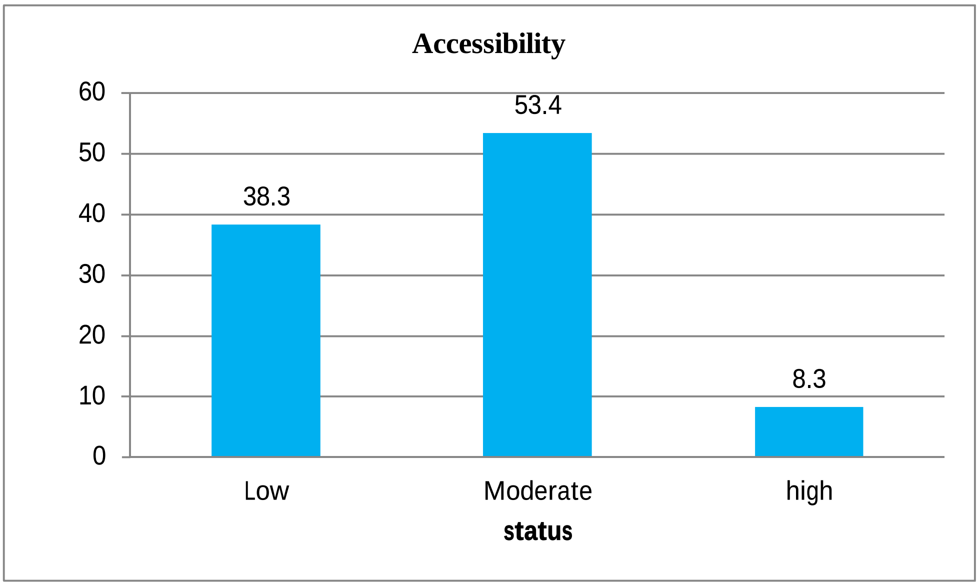


Figure 4.12: Accessibility for existing mode

Accessibility is not a critical issue for commuters who paticipated in this survey.

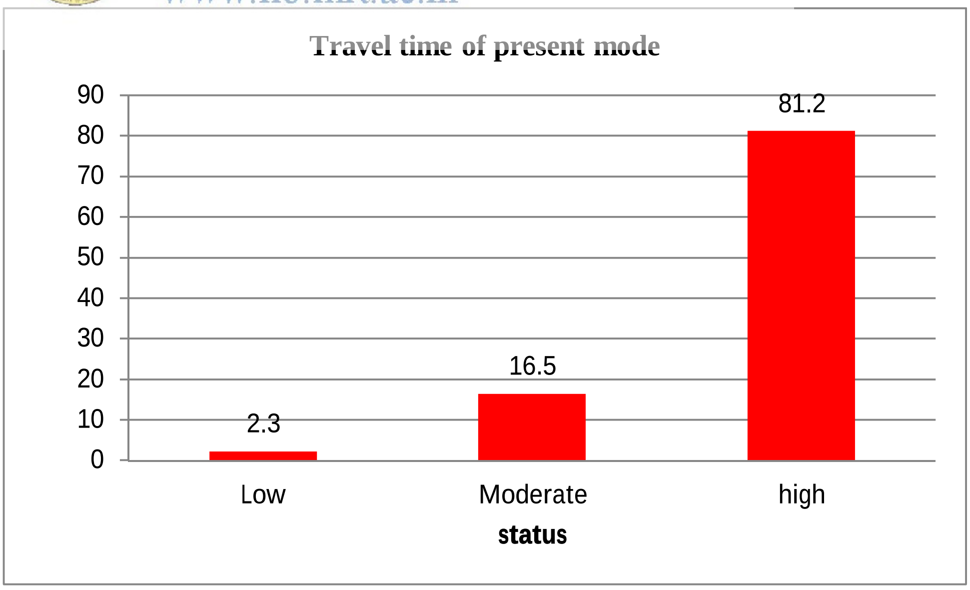


Figure 4.13: Travel time of present mode

Travel time is the most critical and cause high inconvenience to the commuters and at a value of 81.2%. Travel time increae due to congestion of the roads lead to wasting fuel and money.

4.7. Expected facilities of new Rapid transit systems

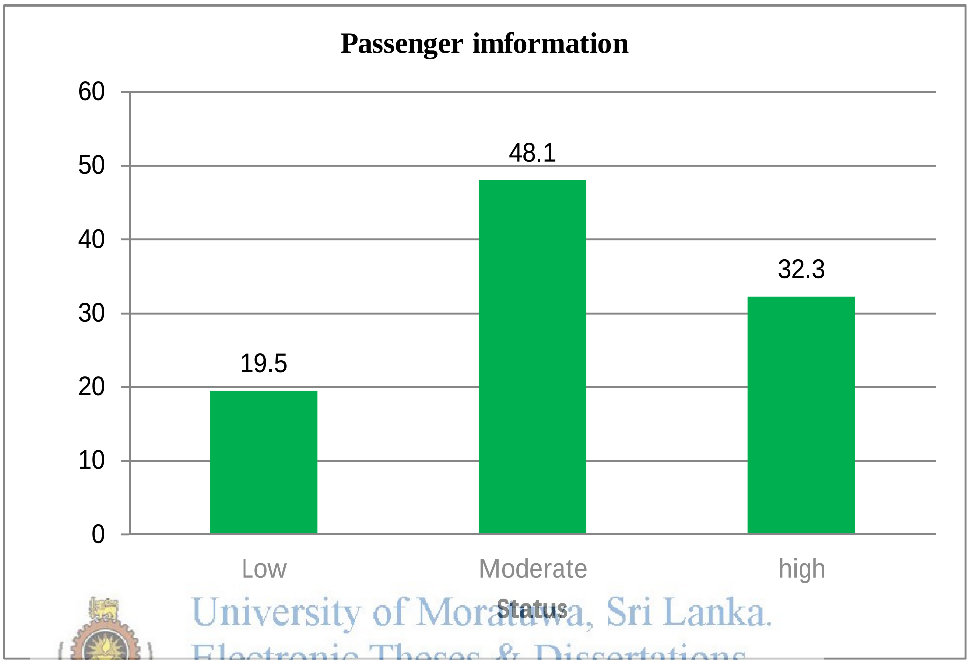


Figure 4.14: Passenger information for new transit mode

Passenger information was treated as a moderate impact by the commuters.

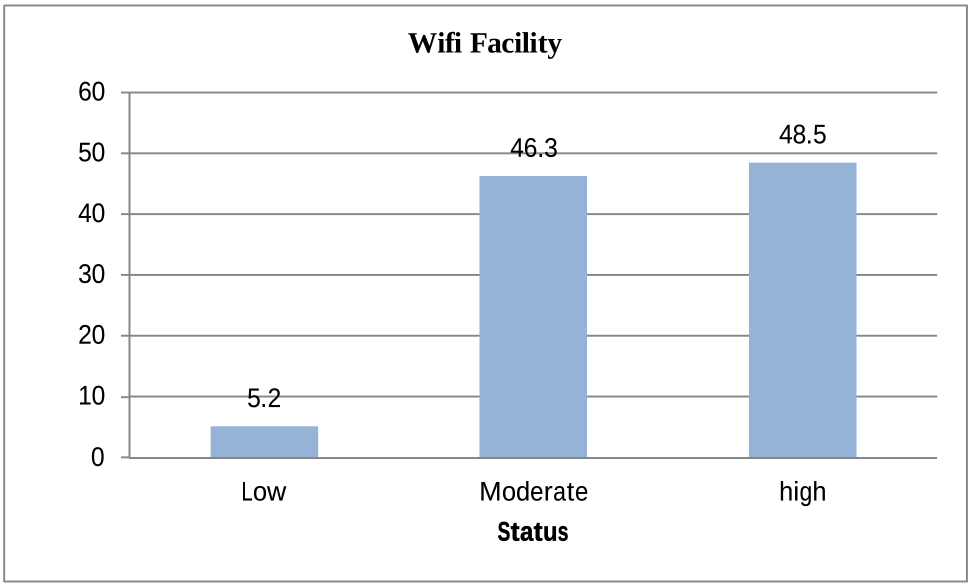


Figure 4.15: Passenger information for new transit mode

Wifi Facilty is in high demand for the new rapid transit and 49% commuters treated it as critical for the new rapid transit.

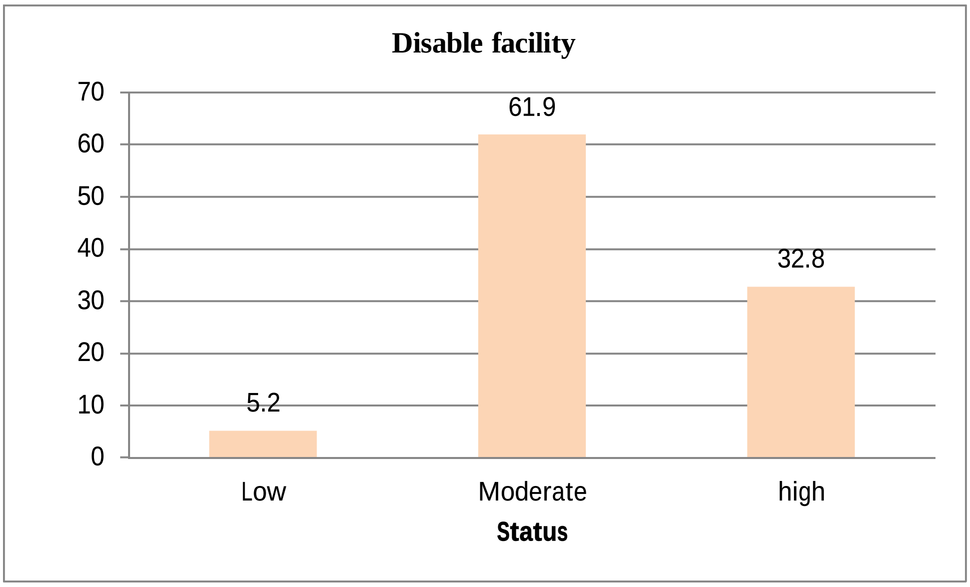


Figure 4.16: Disable facilty for new transit mode

Disable facility is considered as a moderate interest by 62% of commuters whereas 33% commuters considered disable facility as highly demanding.

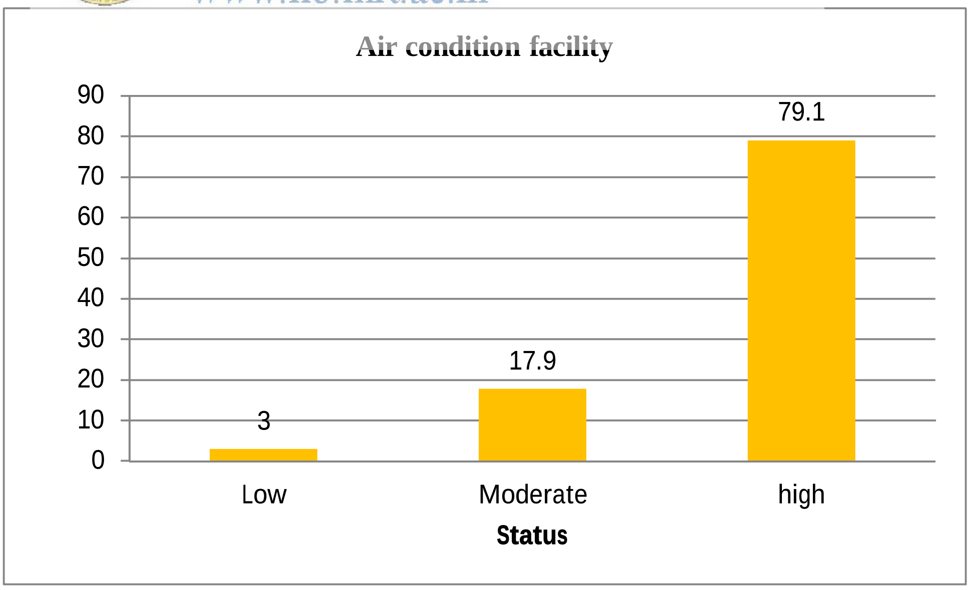


Figure 4.17: Air condition facilty for new transit mode

Commuters were higly interested on airconditioning facility provided with new rapid transit system and 80% of total passengers request this facility.

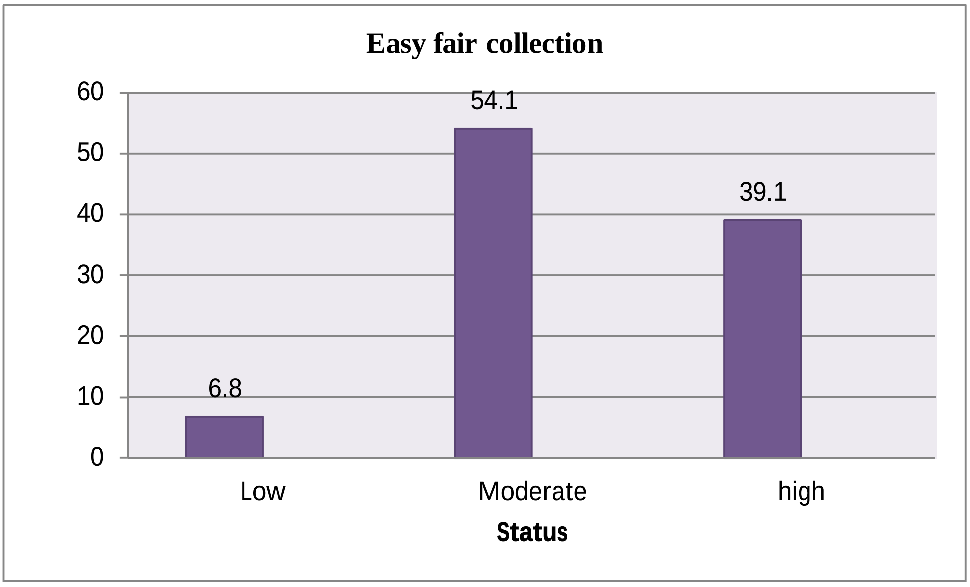


Figure 4.18: Easy fair collection facilty for new transit mode

Easy fair collection facility was considered as moderate type facility by 54% of commuters while 40% commuters were highly interested on this facility to be available in new rapid transit system.

Economic feasibility of new system

Econmic feasibility study should be conducted for certain new projects to find out the economical status during and after completion of the project. Conducting an economic feasibility study is needed for each type of new transit mode, intended to introduce in this study.

Economic Feasiblity study is used as the main evaluation method on the investment of Social Overhead Capital (SOC), whose ripple effect applies nationwide. Along with such economic feasibility study, financial feasibility study conducted from the perspective of concrete parties of the business project is conducted as a secondary evaluation method. Financial feasibility study is conducted on the project, which is proven to be economically feasible to evaluate its financial profitability. Though it is not simple to analyze preliminary the business prospect of the project, performing financail feasibility study roughly based on genaral assumption at the preliminay feasibility study stage is considerd. The employee forcast data will help to calculate the ecomical data in future years as necessary calculations.

Table 4.1: D.S. Division Employee Forecast (Colombo Monrail syestem joint development project, 2011)

D.S. Division	2016	2020	2025	2030	2035	2040	2045
Colombo	175,104	184,162	194,705	205,777	217,557	230,017	243,186
Thimbirigasyaya	147,989	158,259	170,435	183,451	197,565	212,764	229,133
Dehiwala	55,763	59,632	64,220	69,125	74,444	80,171	86,337
Rathmalana	63,307	67,702	72,911	78,479	84,516	91,018	98,021
Sri Jayawardenapura	69,465	76,572	85,275	94,894	105,675	117,678	131,050
Kaduwela	107,018	114,447	123,249	132,659	142,866	153,858	165,696
Moratuwa	101,713	110,910	122,045	134,214	147,689	162,511	178,828
Hanwella	48,399	51,833	55,909	60,276	65,017	70,130	75,646
Maharagama	116,313	128,211	142,779	158,885	176,935	197,035	219,418
Padukka	27,981	29,924	32,225	34,687	37,355	40,229	43,324
Kesbewa	107,803	115,286	124,154	133,637	143,918	154,989	166,912
Kolonnawa	76,435	81,268	86,960	93,009	99,525	106,497	113,958
Homagama	120,068	133,975	151,226	170,557	192,513	217,295	245,265
SUM	**1,217,358**	**1,312,181**	**1,426,093**	**1,549,650**	**1,685,575**	**1,834,192**	**1,996,774**

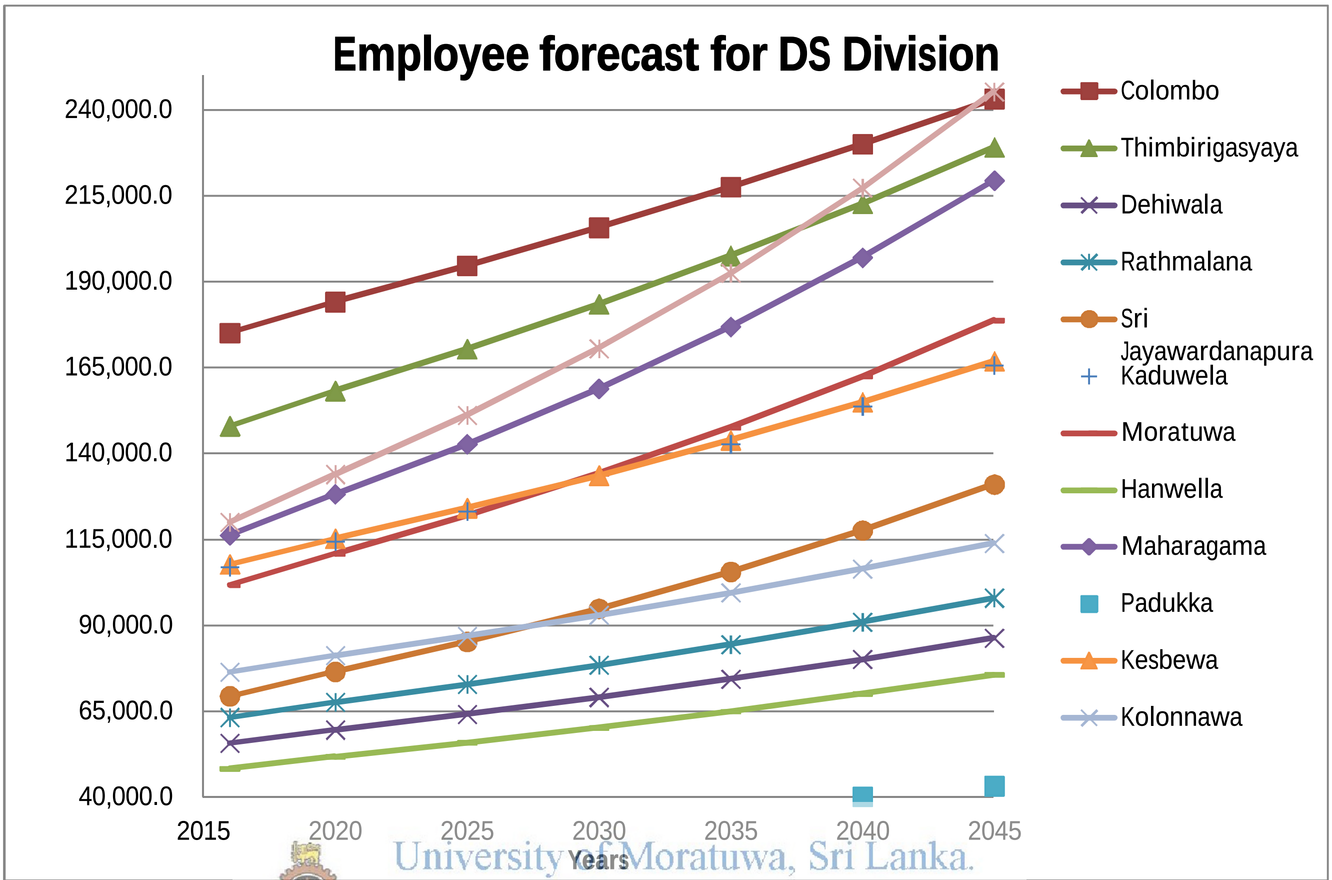


Figure 4.5: Emplyoee forecast for DS division

It shows the employee continue to increase drastcally in each Grama Niladari divison, which provide evidence for the increase of number of commuters in future.

4.8. Cost estimate and comparison

Cost Estimation of Alternatives

In a developing country like Sri Lanka, the most crucial fact to be considered when initiating a certain project is the initial cost, which is known as the capital cost. If the initial cost is lower, the practicability would be higher. Same way, the recurrence cost also affect the topic. Therefore, it is of much importance to be aware of the associated costs when considering the feasibility of any project. Here an estimation of initial and recurrent cost for every alternative is developed for the maximum possible accuracy, with the available information sources.

Cost allocation and estimations for overseas projects are as follows:

Table 4.2: Capital costs for differnet mass rapid transit (Wright, 2007)

City	Type of system	Kilometres of segregated lines (km)	Cost per kilometre (US$ million/km)
Taipei	Bus rapid transit	57.0	0.5
Quito (Ecovía Line)	Bus rapid transit	10.0	0.6
Porto Alegre	Bus rapid transit	27.0	1.0
Las Vegas (Max)	Bus rapid transit	11.2	1.7
Curitiba	Bus rapid transit	57.0	2.5
São Paulo	Bus rapid transit	114.0	3.0
Bogotá (Phase I)	Bus rapid transit	40.0	5.3
Tunis	Tram	30.0	13.3
San Diego	Rail trolley	75.0	17.2
Lyon	Light rail transit	18.0	18.9
Bordeaux	Light rail transit	23.0	20.5
Zurich tram	Tram	NA	29.2
Portland	Light rail transit	28.0	35.2
Los Angeles (Gold Line)	Light rail transit	23.0	37.8
Kuala Lumpur (PUTRA)	Elevated rail	29.0	50.0
Bangkok (BTS)	Elevated rail	23.7	72.5
Kuala Lumpur Monorail	Monorail	8.6	38.1
Las Vegas	Monorail	6.4	101.6
Mexico City (Line B)	Metro rail	24.0	40.9
Madrid (1999 extension)	Metro rail	38.0	42.8
Beijing Metro	Metro rail	113.0	62.0
Shanghai Metro	Metro rail	87.2	62.0
Caracas (Line 4)	Metro rail	12.0	90.3
Bangkok MRTA	Metro rail	20.0	142.9
Hong Kong subway	Metro rail	82.0	220.0
London (Jubilee Line ext.)	Metro rail	16.0	350.0

4.8.1. Widening the existing 4-lane road to a 6-lane road

<u>Assumptions</u>

Width of a new lane would be 3m.

1. 1 perch = 25 m^2
2. Total length of proposed road widening = 9.4 km
3. Earthwork requirements will occur only along 30% of the existing road length (9.4 km x 30% = 2.8 km)

Additional land requirement = 9400 x 3/ 25 x 2

= 2256 perch

Estimation of Cost of Widening the Road to a Six-Lane Highway

		Rs. (million)
Average price of land (per perch/25 m^2)	Rs. 1.5 million	
Total Cost of land acquisition	2256 perch	3,384
Average cost of earthwork (per km)	Rs. 8 million	
Total cost of earthwork		**22**
Cost of surfacing (per km)	Rs. 10 million	
Total cost of surfacing		**94**
Cost of drainage (per km)	Rs. 1 million	
Total cost of drainage		**9**
Total estimated cost for widening the road		**3509**
Total estimated cost for widening the road (US$ million)	**25.8**	

In addition to these costs, there will be an increase in the cost of commuting between these two locations as widening of the existing road would disturb the current usage of the road. Detours may have to be considered. This will increase the mileage of the vehicles and fuel consumption, and will increase the time spent on road during the construction period. Therefore, it will affect other economic activities in a negative manner.

The benefits will come in the form of reduction of travel time between the two locations after completing the project, until the end of the design lifetime. Measure of the benefit could be the number of human hours saved in this manner and the associated valued created from these additional hours.

4.8.2. Bus Rapid Transit System (BRT)

<u>Assumptions</u>

1. Width of a new lane = 3.4m.
2. 1 perch = 25 m^2
3. Total length of the proposed road widening = 9.4 km
4. Earthwork requirements will occur only along 30% of the existing road length (9.4 km x 30% = 2.8 km)
5. Traffic signal changing cost not considered

Additional land requirement = 9400 x 3.4 x 2/25

= 2556.8 perch

Estimation of cost of introducing a BRT System is as follows

(Assume US$ 1= LKR 136)

	Per km cost	Total Rs (million)
Average price of land (per perch/ 25 m^2)	Rs 1.5 million	
Total Cost of land acquisition	**2556 perch**	3,384
Average cost of road construction with overlay (per km)	Rs 40 million	
Total cost of road construction		**376**
Average cost of earthwork (per km)	Rs. 2.5 million	
Total cost of earthwork		**23.5**
Cost of drainage (per km)	Rs. 1 million	
Total cost of drainage		**9.4**
Total estimated cost for road widening (Rs. million)		**4292.9**
Total estimated cost for road widening (US$ million)		**31.56**

Cost for a BRT specialized bus = 7 million

Number of buses required = 5

Total cost for buses = 35 million

Cost for a BRT station = 1 million

Number of stations = 10

Total cost for stations = 10 million

Therefore, total final cost for installing a BRT system = 4292.9 + 10 + 144

= Rs. 4446.9 million

Cost for BRT installing (US$ million) = 32.7

Bus priority lanes

The system will function by using prevailing buses and stations, and with the help of law enforcement authorities, the public will be made aware of the new rules and prevent private vehicles from using the Bus Priority Lane. Hence, the costs will be low for the installation and at least for the commencement of the project. The three modes of costs incurred in this system are road demarcating cost, cost for improvement of bus stations, and the cost associated with traffic signal alterations.

- Cost for road demarcating = Rs. 3200.00 / m^2

Approximately, 200 m^2 per km required for road demarcating, lane dividing, and guiding signs.

Therefore, the Total Cost of demarcating = 3200 * 200 * 9.4 * 2 = Rs. 12.032 million

Cost for traffic alterations = Rs. 25 million

Cost for improvement of a bus station (bus bay and station) = Rs. 2.5 million

Number of bus stations = 12

Cost for the station improvement = Rs. 30 million

Total final cost for installing and implementing this system = Rs. 67.032 million

Therefore, cost wise, this system is extremely beneficial and easy to implement, and if the expected outcomes can be achieved, this is very much feasible. However, with the above mentioned barriers and practical issues, the feasibility of this system is questionable.

4.8.3. Monorail system

Estimated cost of monorail system	= US$ 20/km
Estimated total cost of monorail system (US$20mn x 10)	= US$ 200 million
	= Rs. 26400 Million
Estimated cost of a stations construction	= Rs. 10 million
Estimated total cost of stations (LKR 10mn x 6)	= Rs. 60 million
Estimated total cost capital of the system	= Rs. 26460 million
Estimated total cost capital of the system (US$ million)	= 134.55

Apart from the above two categories of population, an extensive quantity of commuter population from all over the country travel in this Sri Jayawardenapura Corridor.

Table 4.3: Type of BRT facilities with level of access control

Facility Type	Access Control	Examples
Busways		
Bus tunnel	Uninterrupted flow—full control of access	Boston, Seattle
Grade-separated busway	Uninterrupted flow—full control of access	Ottawa, Pittsburgh
At-grade busway	Partial control of access	Miami, Hartford, Los Angeles
Freeway lanes		
Concurrent flow lanes	Uninterrupted flow—full control of access	Ottawa, Phoenix
Contraflow lanes	Uninterrupted flow—full control of access	New Jersey approach to Lincoln Tunnel
Bus-only or bus priority ramps	Uninterrupted flow—full control of access	Los Angeles
Arterial streets		
Arterial median busway	Physically separated lanes w/in street ROW	Curitiba, Vancouver, Cleveland
Curb bus lane	Exclusive/semi-exclusive lanes	Rouen (France), Vancouver, Las Vegas
Dual curb lanes	Exclusive/semi-exclusive lanes	New York City (Madison Ave)
Interior bus lanes	Exclusive/semi-exclusive lanes	Boston
Median bus lane	Exclusive/semi-exclusive lanes	Cleveland
Contraflow bus lane	Exclusive/semi-exclusive lanes	Los Angeles, Pittsburgh
Bus-only street	Exclusive/semi-exclusive lanes	Portland (OR)
Queue jump/bypass lane	Mixed traffic operations	Leeds (UK), Vancouver
Transit signal priority	Mixed traffic operations	Los Angeles, Oakland

Source: *TCRP Report 118: Bus Rapid Transit Practitioner's Guide*, Transportation Research Board of the National Academies, 2007

CHAPTER 5

5. Discussion

5.1. Daily travel vs. new transit mode

The analysis revealed 50% of daily travel passengers preferred BRT as the new transit mode, while only 47% of non-daily travelers liked BRT. A 33% of daily travelers and 15% non-daily travelers liked the Monorail system. Other new transit modes did not exceeded 15% for both daily- and non-daily travelers.

5.2. Income of passenger vs. new transit mode

A 62% of passengers identified to be in the high income categary (monthly income exceed Rs. 50,000), and a 44% of passengers identified to be in the lower income category, prefers BRT system as the new transit mode. Further, a 14% of high income category passengers and a 33% of low income passengers regard Monrail system as the new transit mode.

5.3.Purpose of the trip vs. new transit mode

According to the graph in Fig. 4.4, 51% of passengers travel for the work and 45% of other trips on this corridor, like BRT system as new the transit system. On this corridor, a 30% of passengers traveling to work and a 25% of other purposes trip passengers favour Monorail system.

5.4. Present transport mode vs. new transit mode

The BRT system is favoured as new transit mode by 57% of passengers travel with a hired car, 42% passengers travel with public transport mode, and 33% of private car users.

All combination of the results reveales, BRT system is much preferred by the passenger.

Results of the questionaires were utilised to plot data in different combinations of graphs to analyse data in various way and present the results in a table format.

Parameters	MRT	BRT	LRT	Monorail
Cost (US$ Million per Km)	>75	0.5-5	5-20	20-120
Level of passenger income-Low	13%	44%	4%	33%
Level of passenger income-High	8%	62%	14%	14%
Purpose of the trip for work	9%	51%	4%	30%
Purpose of the trip for other purpose	15%	51%	5%	21%
Preference of Daily travel passenger	13%	49%	4%	33%
Preference of Non-Daily travel passenger	12%	56%	9%	15%
Preference of Hire car users at present	20%	50%	0%	30%
Preference of private vehicle users at present	19%	35%	4%	35%
Preference of Public mode users at present	9%	57%	7%	24%

Eventhough the results indicate the Bus Rapid Transit is the best mode to introduce for Sri Jayawardenapura corridor, it needs to check and comply with other factors given below:

5.5. Connect with other modes

Possibility of connctivity with other existing modes with new modes such as Public bus routes and existing rail tracks is very important. Commuters travel with Buses, cars, rails or other modes and they should connect with new transit system without traveling in another intermediate mode. There should be a convenient way of connecting. If the connectivity of both modes make a considerable distance to travel, or difficult to climb, commuters will not be attracted to the new transit system.

Connect with other modes with Monorail is possible easily due to less space requirment.

It is possible for LRT system to connect with other modes by constructing new track lines touching bus stations at cities.

5.6. Extendability of new transit system

New system can be extendable with the time to suit the passenger demand. In a developing country like Sri Lanka, incurring heavy costs for the tranport section is difficult, in addition to other important and major costs as education, health, and economy. However, it is possible through investing on proper things, with only a sufficient amount. It is advisable to introduce a new transit system in sufficient capacity, but not target for the total capcity in future. It should be possible to extend the rapid transit system to suit future demand if the commuter attract more in future. It helps to avoid unncessary costs for the government investing at one time for the new transit system.

Within this context, articulated systems are more effective to extend the system. Monorail system and LRT system are possible to extend. BRT system also can articulate with certain restrictions since operating BRT on road base need restrictions with the road terrain and curves. MRT system is difficult to extend with their designs.

5.7. Environmental friendliness

New mode should be an eco-friendly system and with less emmision since environment emmision at present situation is very important. Many aspects emit to environment and pollute air. Especially, the transport systems add more polluted air that cause harmfull hazards to human body.

Presently, the entire country should experience zero emmition transport sysetem or use hybrid vehicles to prevent air pollution.

BRT system use fuel as diesel or petrol, which result in emition to environment. However, due the articulate BRT reduce air pollution to a certain extent than traditional systems.

MRT system may cause air pollution and noice pollution due to high speed.

Monorail system and LRT system operate with electricity, which cause no air pollution; hence favourable for the environment.

5.8. Constructability

Constructability of a new transit system is a vital factor. It is very difficult to land acquisition for new constructions. Land value is comparatively high in Sri Jayawardenapura corridor than other places.

BRT system is difficult due to land unavailablity and acqusition problems. There are many large buildings and other structures near the exsting roads obstructing lane expansions. Once it allocate middle two lanes for BRT, vehicles face difficulties to right turn, and thus, a special system is required to introduce particular traffic signals.

Monorail system has a good opportunity to be introduced since it requre lesser space. It can be provided at the centre median of the road and overhead trace can be constructed with the available space.

Construction of MRT system is difficult due to unavailablity of bare land and it needs special methods since most of systems are under ground. Water table of this corridor is high due to water bodies and marshy area, and it is difficult to operate the system with water. To prevent water seeping into the tunnel, a special water-proofing system and many precaution works are essential for the MRT. It will encount additional costs to system installation.

Parameters	MRT	BRT	LRT	Monorail
Connect with other modes	Poor	Moderate	Good	Good
Extendibility in future	Poor	Moderate	Good	Good
Environmental friendliness	Poor	Moderate	Good	Good
Constructability	Poor	Moderate	Good	Good

New mode should be economically feasible (Cost Benefit Ratio, Net percent value, IRR).

CHAPTER 6

6. Conclusion and Recommendations

Information obtained using the questionnaire prepared by the Author for the Jayawardenapura corridor and their data graphs indicate that the most prefered new transit mode by commuters is the Bus Rapid Transit system whereas the secondary prefered transport mode is Monorail system. Light Rapid Transit is thirdly prefered by the commuters as per data.

Evidence from cost calculations suggest lesser cost requirement to implement Bus Rapid Transit system than the Monorail transit system and according to calculations, it involves lower initial cost and less operational cost. However, the BRT system requires a considerable amount of land acquisition than the Monorail system. Hence, with the restrictions on road widening, Monorail system has better constructability than BRT system. With the advantages of the BRT system, it provides good support to mitigate pollution than the present condition, yet the Monorail system is more environment friendly than the BRT system.

Within this context, and considering extendibility in future, Monorail system appeared to be better than the BRT system. Also, need to have coordinated traffic signal system, for the difficulty that will encounter for turning vehicle across the BRT lanes as well.

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