MINISTRY OF MEGAPOLIS AND WESTERN DEVELOPMENT
DEMOCRACTIC SOCIALIST REPUBLIC OF SRI LANKA

PREPARATORY SURVEY ON THE PROJECT FOR ESTABLISHMENT OF NEW LIGHT RAIL TRANSIT SYSTEM IN COLOMBO

FINAL REPORT

MAIN REPORT

MAY 2018

JAPAN INTERNATIONAL COOPERATION AGENCY

Oriental Consultants Global Co., Ltd.
Japan International Consultants for Transportation Co., Ltd.
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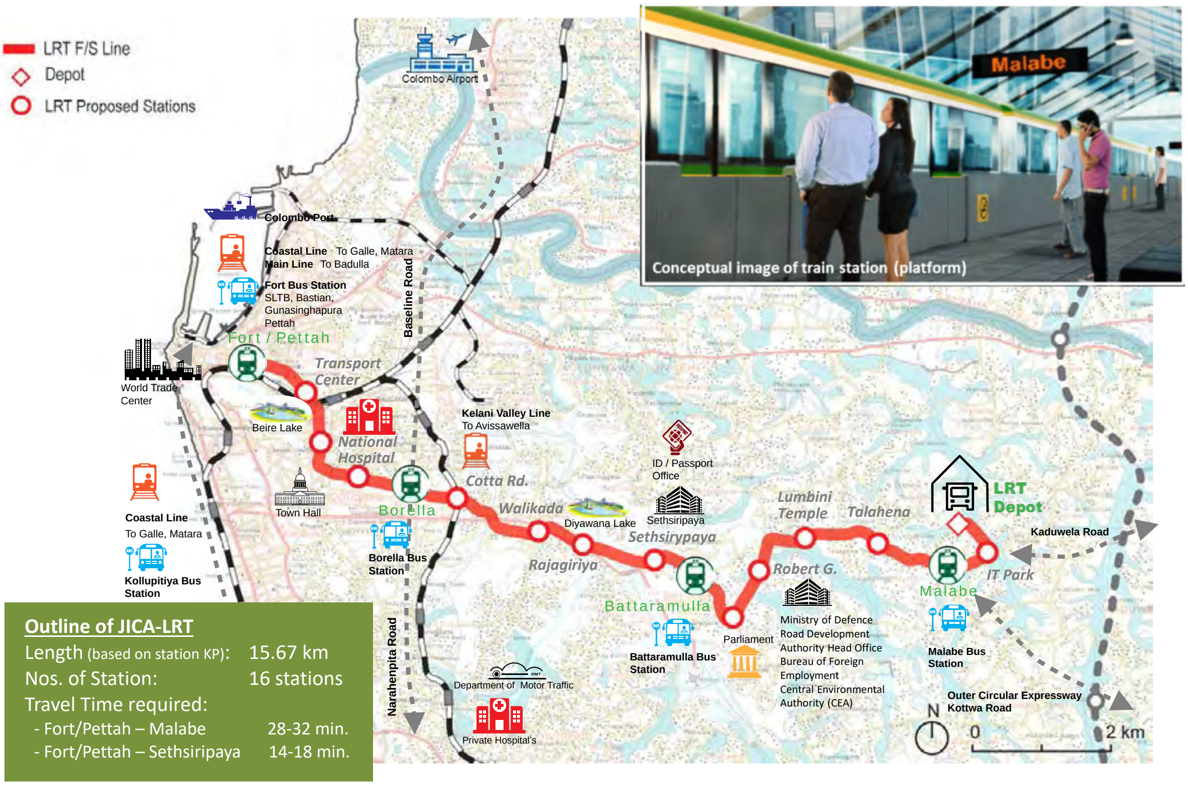
US$ 1.00 = LKR 153
US$ 1.00 = JPY 113

(Exchange rate of January 2018)

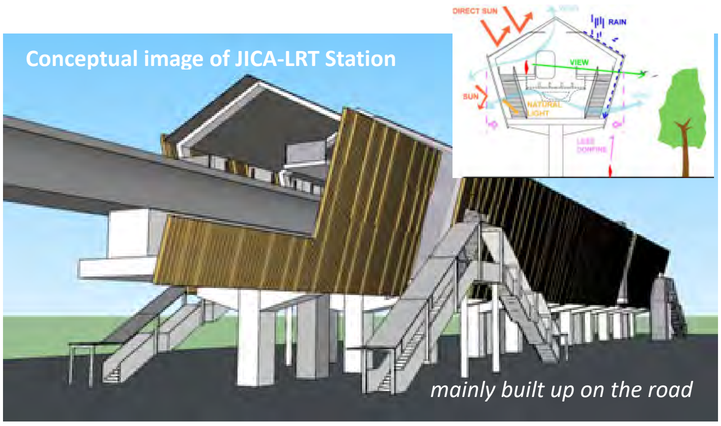
Conceptual Image of JICA-LRT System in Colombo



Outline of JICA-LRT

Length (based on station KP): 15.67 km
Nos. of Station: 16 stations
Travel Time required:
- Fort/Pettah – Malabe 28-32 min.
- Fort/Pettah – Sethsiripaya 14-18 min.

Route and Connectivity of JICA-LRT system in Colombo (Fort/Petth – National Hospital – Borella – Battaramulla – Malabe)



JICA-LRT Facilities (Station, Depot)

Outline of the Project

1.	**Country: The Democratic Socialist Republic of Sri Lanka**
2.	**Project Name:** **Preparatory Survey on The Project for Establishment of New Rail Transit System in Colombo**
3.	**Executing Agency: Ministry of Megapolis and Western Development (MMWD)**
4.	**Survey Background:** Due to severe traffic congestion in the Colombo Metropolitan Area caused by the increasing number of traffic modes utilizing road network, introduction of a public transportation system has become urgently necessary. The Ministry of Megapolis and Western Development has formulated the "Western Region Master Plan - 2030" and identified the seven Rapid Transit System (RTS) networks for public transport modes. The Government of Sri Lanka requested to introduce Light Rail Transit (LRT) to the Japanese government due to its versatility, which means the ability to run in all possible types of alignment of RTS-1 and 4. This Study, therefore, examines feasibility of the JICA-LRT from technical, economical, financial, institutional and environmental aspects.
5.	**Survey Contents:** Government of Sri Lanka and JICA agreed the survey which will study feasibility of the Project will cover the following routes utilizing data and information already available from previous studies conducted by JICA (RTS-1: Fort - Kollupitiya - Borella - Union Place - Maradana, RTS-4: Borella - Rajagiriya - Battaramulla - Malabe). The Survey covers the following components. • Preliminary Design (Route/Alignment Plan, Rolling Stock Plan, Demand Forecast, Structure Design, Signal & Telecommunication, Electrical and Mechanical, Station Development) • Construction Plan, Operation and Maintenance (O&M) Plan and Cost Estimation • Evaluation of the Project (Economic Analysis, Financial Analysis) • Project Implementation Plan (Procurement Packaging, Implementation Schedule) • Environmental and Social Consideration Survey (Environmental Impact Assessment (EIA)/Resettlement Action Plan (RAP))
6.	**Conclusions and Recommendations:** **(1) Conclusions** • The JICA-LRT system was designed as a technically, economically suitable, and effective solution for the Colombo Metropolitan Area for alleviating traffic congestion. • The project costs for the implementation of the JICA-LRT system will be economically covered by the large amount of benefits from the JICA-LRT system showing economic feasibility. • The JICA-LRT O&M company has possibility to be financially profitable and sustainable when the JICA-LRT fare is set at affordable level (less than 100 LKR between Fort and Malabe). • The EIA study revealed that the potential impacts of the proposed project take place mainly during the construction stage, and impact during operational stage is minimal. • The social study revealed that a certain area of agricultural land and paddy field is necessary as construction of the depot, however, the number of houses and commercial establishments to be relocated due to the project is relatively low. **(2) Recommendations** 1) Towards Smooth Implementation of the Project - Capacity development for PMU in project implementation and branding is recommended. - Proper understanding of utilities and preparation of its diversion/ relocation is crucial. - Minimization of social and environmental impacts due to the Project is essential. - Establishment of O&M business company is expected. - Improved coordination with relevant stakeholders is highly important. 2) To Further Increase the Effectiveness of the Project - Introduction of Japanese technologies through the STEP by securing bidding competitiveness is recommended. - Study on station area development linked to JICA-LRT and introduction of feeder bus service is necessary to add value to the JICA-LRT. - Technical assistance from the experience of Japanese railway operation can be expected. - Developing a new urban life with JICA-LRT (education and promotion programme) is recommended.

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LIST OF ABBREVIATIONS

Abbreviation	Name
°C	Celsius
A/C	Air Conditioning
ABL	Assessment Background Level
ABT	Account Based Ticketing
AC	Alternating Current
ADSCR	Average Debt Service Coverage Ratio
AFC	Automatic Fare Collection
ADB	Asian Development Bank
ARPA	Agriculture Research and Production Assistant
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
AWLR	Average Weighted Lending Rate
BAU	Business-As-Usual
BIQ	Basic Information Questionnaire
BOD	Biochemical Oxygen Demand
BOT	Build-Operate-Transfer
BRT	Bus Rapid Transit
BTC	Beginning of Transition Curve
BTO	Build-Transfer-Operate
CAD	Computer Aided Design
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CBD	Central Business District
CBT	Card Based Ticketing
CBTC	Communications-Based Train Control
CCEM	The Cabinet Committee on Economics Management
CCTV	Closed Circuit Television
CEA	Central Environment Authority
CEB	Ceylon Electricity Board
CEO	Chief Executive Officer
CESMA	CESMA: International company who helped Government of Sri Lanka update a plan for building “Megapolis” Western Province
CFO	Chief Financial Officer
CIM	Centralised Information Monitoring
CIS	Centralized Interlocking System
cm	Centimetre
CMA	Colombo Metropolitan Area
CMC	Colombo Municipal Council

Abbreviation	Name
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
COO	Chief Operating Officer
CP	Packages
CPI	Consumer Price Index
CRRC	Chinese Railway Rolling Stock Corporation
CSC	Construction Supervision Consultant
CSRP	Colombo Suburban Railway Project
CTC	Centralised Traffic Control
CV	Chief Valuer
DAISY	Digital Accessible Information System
DC	Direct Current
DFR	Draft Final Report
DGM	Deputy General Manager
DMU	Diesel Multiple Unit
DO	Dissolved Oxygen
DS	Divisional Secretariat
DTO	Driverless Train Operation
DWC	Department of Wildlife Conservation
E&M	Electrical & Mechanical
EA	Environmental Assessment
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EMC	Electromagnetic Compatibility
EMMP	Environmental Management and Monitoring Plan
EMU	Electric Multiple Unit
EN	Globally and Nationally Endangered
ENL	Equivalent Noise Level
ENPV	Economics Net Present Value
EPA	Environmental Protection Area
EPC	Engineering, Procurement, and Construction
ERD	Department of External Resources
ETC	End of Transition Curve
F/S	Feasibility Study
FGD	Focus Group Discussion
FIDIC	International Federation of Consulting Engineers
FIRR	Financial Internal Rate of Return
FQS	Fuel Quality Standards
GDP	Gross Domestic Product
GHG	Greenhouse Gas

Abbreviation	Name
GIS	Geographic Information System
GOA	Grade of Automation
GoSL	Government of Sri Lanka
GRC	Grievance Redress Committee
GRDP	Gross Regional Domestic Product
GRM	Grievance Redress Mechanism
GSS	Grid Substation
H&S	Health and Safety
ha	Hectare
HDI	Human Development Index
HHWL	Highest High Water Level
HOV	High Occupancy Vehicle
HQ	Headquarters
HSCB	High Speed Circuit Breaker
HVS	Home Visit Survey
I/O	Input and Out
IC	Integrated-Circuit
ICB	International Competitive Bidding
ICR	Inception Report
IEC	International Electrotechnical Commission
IEE	Initial Environmental Examination
IGBT	Insulated Gate Bipolar Transistor
IHDI	Inequality-adjusted HDI
IMF	International Monetary Fund
IOL	Inventory of Lost Assets
ITI	Industrial Technology Institute
ITR	Interim Report
IWT	Inland Water Transport
JCT	Junction
JICA	Japan International Cooperation Agency
JOCV	Japan Overseas Cooperation Volunteers
JPY	Japanese Yen
km	Kilometre
km/h	Kilometre Per Hour
kN	Kilonewton
KPIs	Key Performance Indices
kV	Kilovolt
KV	Kelani Valley
kW	Kilowatt
LAA	Land Acquisition Act

Abbreviation	Name
LAeq	Equivalent noise level
LAmax	Peak noise level
LARC	Land Acquisition and Resettlement Committee
LCB	Local Competitive Bidding
LCD	Liquid-Crystal Display
LECO	Lanka Electricity Company
LED	Light Emitting Diode
LKR	Sri Lankan Rupee
LRT	Light Rail Transit
LTA	Land Transport Authority
m	Metre
MC	Motor Car
MDB	Multilateral Development Bank
MDB	Multilateral Development Bank
min	Minute
MLLD	Ministry of Land and Land Development
MLPR	Ministry of Lands and Parliamentary Reforms
mm	Millimetre
MMC	Multi Modal Centres
MMS	Mobile Mapping System
MmTH	Multimodal Transport Hub
MMWD	Ministry of Megapolis and Western Development
MoT	Ministry of Transportation
MRV	Monitoring, Reporting, and Verification
MSL	Mean Sea Level
MST	Minimum Spacing Tree
MVA	Megavolt-ampere
NDC	Nationally Determined Contribution
NEA	National Environmental Act
NFC	Near Field Construction
NGO	Non-governmental Organization
NIRP	National Involuntary Resettlement Policy
NO_2	Nitrogen Dioxide
NPD	National Planning Department
NPOs	Non-Profit Organizations
NPV	Net Present Value
NSPD	National Secretariat for Persons with Disabilities
NWS&DB	National Water Supply & Drainage Board
O&M	Operation & Maintenance
OCC	Operation Control Centre

Abbreviation	Name
OCH	Outer Circular Highway
OD	Origin-Destination
ODA	Official Development Assistance
OPEX	Operational Expenditure
PA	Public Address
PAA	Project Approving Agency
PAP	Project Affected People
Pax.	Passengers
PC	Pre-stressed Concrete
PCU	Passenger Car Unit
PD	Project Director
PDA	Pile Dynamic Analysis
PDCA	Plan–Do–Check–Act
pH	Potential of Hydrogen
PHC	High Strength Concrete
PID	Passenger Information Display
PIP	Project Implementation Plan
PIWQS	Proposed Inland Water Quality Standards
PM_{10}	Particulate Matter 10 micrometers and smaller
PMU	Project Management Unit
PPHPD	Passenger Per Hour Per Direction
PPP	Public Private Partnership
PRC	Programmed Route Control
PSD	Platform Screen Door
PwD	Persons with Disabilities
QR	Quick Response
R	Radius
RAP	Resettlement Action Plan
RBL	Rating Background Level
RC	Reinforced Concrete
RCS	Replacement Cost Survey
RDA	Road Department Authority
ROW	Right of Way
RP	Revealed Preference
RSS	Receiving Substation
RTS	Rapid Transit System
RTU	Remote Terminal Unit
RU	Resettlement Unit
S&T	Signalling and Telecommunications
S/C	Steering Committee

Abbreviation	Name
SAM	Security Application Module
SBD	Standard Bidding Document
SCADA	Supervisory Control and Data Acquisition
SCF	Standard Conversion Factor
SES	Socioeconomic Survey
SGBV	Sexual and Gender-based Violence
SKYTRAIN	Integrated Transport System with Monorail
SLFD	Sri Lanka Foundation for Disabled
SLLRDC	Land Reclamation and Development Corporation
SLPA	Sri Lanka Port Authority
SLR	Sri Lanka Railways
SLT	Sri Lanka Telecom
SO_2	Sulfur Dioxide
SP	Stated Preference
SPT	Standard Penetration Test
SSS	Service Substation
STEP	Special Term for Economic Partnership
STO	Semi-automatic Train Operation
TAC	Technical Advisory Committee
TAZ	Traffic Analysis Zone
TDM	Transport Demand Management
TDRS	Director Engineers
TOD	Transit Oriented Development
TOR	Terms of Reference
TOT	Training of Trainers
TRC	Telecommunication Regulatory Committee
TSS	Traction Substation
TTC	Travel Time Cost
UDA	Urban Development Authority
UITP	International Association of Public Transport
UN	United Nations
UNDP	United Nations Development Programme
UNESCAP	United Nations Economic and Social Council for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
UTO	Unattended Train Operation
V	Volt
VA	Volt Ampere
VGF	Viability Gap Funding
VOC	Vehicle Operating Cost

Abbreviation	Name
VVVF	Variable-Voltage/Variable-Frequency
WG	Working Group
WHO	World Health Organization
WRMPP	Western Region Megapolis Planning Project
WS	Workshop
WTP	Water Treatment Plant

Executive Summary

EXECUTIVE SUMMARY

1. Introduction

1.1 Background

In Sri Lanka, over 90% of people and cargo transport depends on road networks. Around 42% of GDP and 29% of the population are concentrated in the capital Colombo, especially in the Western province that has achieved solid economic growth since the end of civil war. The number of traffic modes utilizing road networks such as automobiles, buses and motorcycles has been rapidly increasing. It is said that about 1 million people are flowing into the centre of Colombo every day, resulting in severe traffic congestion in the city and its surroundings. During the morning and evening peak times, travel speed is observed to be less than 20 km/h, which is defined as traffic congestion. In fact, there are roads with less than 10 km/h travel speed, which infers that the current urban transport network is reaching its limits. Such decline in traffic mobility will adversely affect the economic activity of the Colombo metropolitan area, and will negatively impact the national economy.

Based on the current saturated traffic condition at major roads in Colombo, from the viewpoint of an efficient public transport mode compared with private vehicles, the improvement of current public transportation system is urgently necessary. The Urban Transport System Development Project for Colombo Metropolitan Region and Suburbs (CoMTrans), which was supported by the Japan International Cooperation Agency (JICA) and implemented by the Ministry of Transportation (MoT) of Sri Lanka from 2012 to 2014, found that out of seven major corridors heading towards the centre of Colombo, the Malabe Corridor was observed to have the most serious congestion with the largest number of private cars and the lowest travel speed at peak hours. Therefore, the new public transport system named Integrated Transport System with Monorail (SKYTRAIN) along the Malabe Corridor was proposed and studied, which was identified as a high priority project by CoMTrans.

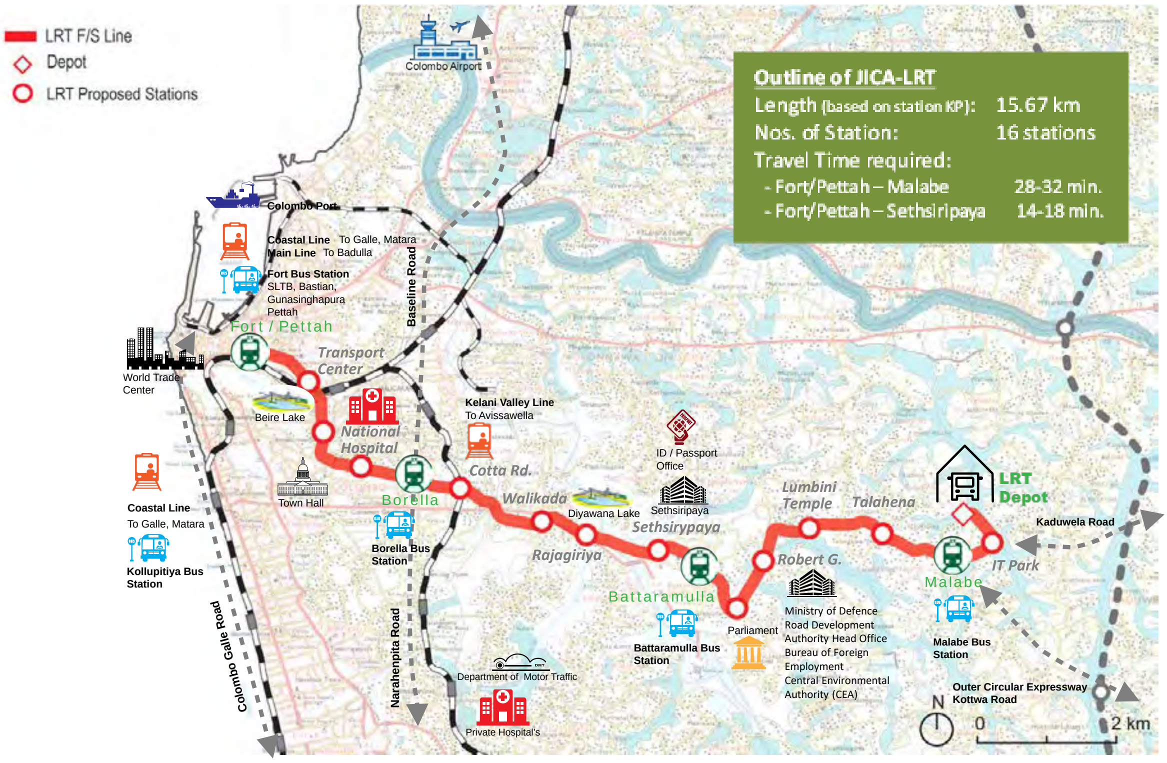
Since the establishment of the new government of Sri Lanka (GoSL) in January 2015, the Ministry of Megapolis and Western Development (MMWD), which is responsible for planning the urban development in the Colombo metropolitan area, has prepared the "Western Region Master Plan - 2030". A priority concern of this master plan is to solve traffic congestion in the Colombo Metropolitan Area (CMA) by introducing a public transport system. Therefore, the GoSL officially requested to introduce the proposed Light Rail Transit (LRT) system RTS-1 and RTS-4 to the government of Japan under the Special Term for Economic Partnership (STEP).

After the official request for LRT to the Japanese government, JICA Headquarters sent a mission on September 2016 to discuss the scope of the Preparatory Survey with GoSL. As the result of the discussion, both the JICA mission and the GoSL agreed that the Preparatory Survey (F/S) will cover the following routes, utilizing data and information already available from previous studies conducted by JICA.

- Rapid Transit System (RTS) 1: Fort - Kollupitiya - Borella - Union Place - Maradana
- RTS 4: Borella - Rajagiriya - Battaramulla - Malabe

Both sides also agreed that the portions of the northern part of RTS-1, which are different to the SKYTRAIN trace, will be examined in the Preparatory Survey to determine the optimum alignment for the Project.

This Study aims to conduct the Preparatory Survey for targeted routes in order to examine the necessity and feasibility of the Project for Establishing the New Light Rail Transit System under the Western Region Megapolis Development. It also aims to collect the necessary information for appraisal of the project as a candidate Japanese ODA Loan Project.



Source: Survey Team

Figure 1.1.1 Route with Connectivity of JICA-LRT

1.2 Scope of the Preparatory Survey

As described above, the Survey aims to study feasibility for the JICA-LRT system in Colombo, as officially requested by the GoSL under the Japanese ODA Loan Project.

The Survey includes the following scope of work:

- Outline of the Project and Preliminary Design (Route/Alignment Plan, Rolling Stock Plan, Demand Forecast, Structure Design, Operation Plan, Signal & Telecommunication, Electrical and Mechanical, Depot, Station Development)
- Construction Plan
- Operation and Maintenance (O&M) Plan
- Cost Estimation
- Evaluation of the Project (Economic Internal Rate of Return (EIRR), Financial Internal Rate of Return (FIRR))
- Project Implementation Plan (Procurement Packaging, Implementation Schedule)
- Discussion on Project Implementation Organization, O&M Organization

- Environmental and Social Consideration Survey (Environmental Impact Assessment (EIA)/Resettlement Action Plan (RAP))

2. Outline of the JICA-LRT System

2.1 Target Corridor under RTS network

The CoMTrans study was supported by JICA and implemented by the MoT of Sri Lanka from 2012 to 2014. The objective of the study was summarised as follows:

- To prepare reliable transport data that can be utilised to evaluate and formulate transport development plans in a scientific manner by conducting an area-wide transport survey.
- To formulate a comprehensive Urban Transport Master Plan for the Colombo Metropolitan Area, including the seven transport corridors prioritised with the justification of selected priority/leading projects for short-term, mid-term, and long-term implementation.
- To conduct a feasibility study on the prioritised project under the comprehensive urban transport master plan.

In the CoMTrans study, a series of transport surveys were conducted including the Home Visit Survey (HVS) to 35,850 households. Based on the survey results and the results of the transport demand forecast, the comprehensive Urban Transport Master Plan was formulated for a target year of 2035.

Out of seven major corridors, the Malabe Corridor was observed to have the most serious congestion, with the largest number of private cars and the lowest average travel speed at peak hours. Based on this, implementation of the new public transport system was proposed between Fort and Malabe as one of the major and high priority projects. Following CoMTrans, the Feasibility Study of Integrated Transport System with Monorail (SKYTRAIN) was conducted in 2014.

In 2015, MoT with the University of Moratuwa prepared the Strategic Plan for Traffic Management in Colombo Metropolitan Region, by conducting a review of the CoMTrans master plan.

After the establishment of MMWD in January 2016, the Megapolis Master Plan and the Megapolis Transport Master Plan were formulated. In the Megapolis Transport Master Plan, the RTS implementation projects were proposed including the line between Fort and Malabe, and LRT was selected for the RTS project. The LRT lines that were proposed by the Megapolis Transport Master Plan are listed in Table 2.1.1.

Table 2.1.1 Rapid Transit System Network Proposed in Megapolis Transport Master Plan

Line Name	Length	Major Sections	Elevated/at Grade
Green Line (RTS1)	15km	Fort - Kollupitiya - Bambalapitiya - Borella - Union Place - Maradana	Elevated
Yellow Line (RTS2)	11.5km	Fort - Maradana - Mattakkuliya - Peliyagoda	Elevated
Red Line (RTS3)	10km	Dematagoda - Borella - Narahenpita - Kirulapone - Havelock City - Bambalapitiya	Elevated
Purple Line (RTS4)	10km	Borella - Rajagiriya - Battramulla - Malabe	Elevated/at Grade
Pink Line (RTS5)	9.6km	Malabe - Kottawa	Elevated/at Grade
Olive Line (RTS6)	6km	Malabe - Kaduwela	Elevated/at Grade
Ash Line (RTS7)	13km	Peliyagoda - Kadawatha	Elevated/at Grade

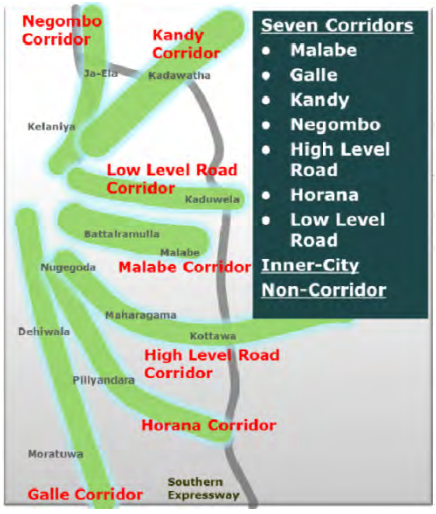
Source: Megapolis Transport Master Plan (Table made by Survey Team)

Among the 7 lines, RTS 1 and RTS 4 were identified as the priority lines in the master plan to connect the city centre, Sethsiripaya and Malabe areas, which runs along the Malabe Corridor. This conclusion was the same as the concept of the monorail project in the CoMTrans and SKYTRAIN project, which was derived from the corridor analysis based on a series of transport surveys.

Why Malabe Corridor?

Malabe Corridor is one of the 7 major corridors which connect the city centre and the suburban areas (Figure 2.1.1). In the CoMTrans study, a corridor analysis was conducted for the 7 corridors. From the result of the corridor analysis, Malabe Corridor was identified as the highest priority corridor for the installation of a mid-sized elevated train system in the CoMTrans study. In the Megapolis Transport Master Plan, the route connecting Fort and Malabe (RTS 1 and 4) was prioritised in the implementation plan for RTS.

In the corridor analysis, the characteristics of Malabe Corridor are recognised as follows.

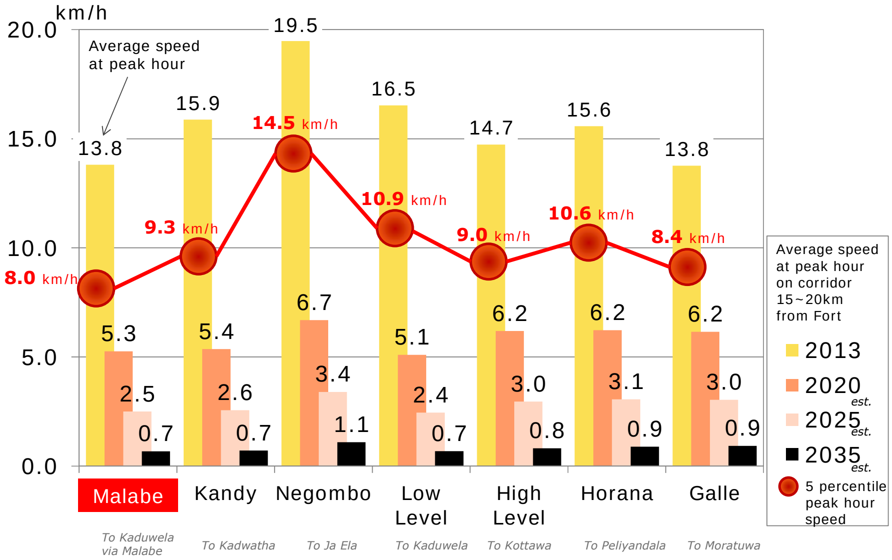


Source: CoMTrans Screen Line Survey, 2013

Figure 2.1.1 Major 7 Corridors Analysed in CoMTrans Study

1. Highest Demand/ Lowest Travel Speed

Malabe Corridor has the traffic highest volume, 121,400 passenger car unit (pcu)/day/direction, followed by Kandy Corridor and Galle Corridor. In peak hour, a traffic volume of 5,100 pcu/hour is loaded to the capacity of 4,400 at the Colombo Municipal Council (CMC) boundary on Malabe Corridor. As a result, travel speed on the corridor is 13.8 kilometres per hour during the peak period at the CMC boundary. If no solution is implemented, the travel speed is expected to be decreased to 5.3 km/h in 2020 as shown in Figure 2.1.2.



Source: CoMTrans Travel Speed Survey for 2013 and CoMTrans estimates for 2020, 2025 and 2035 (Do Nothing Scenario).

Figure 2.1.2 Peak Hour Travel Speed of Major Transport Corridors

2. Corridor without a Transit System with Urban Development Projects

The corridor is also without a rail based public transport system. Moreover, the current transport system is unable to handle the increasing passenger demand due to the relocation of government offices to the Battaramulla area, which includes the Defence complex in Akuregoda. Therefore, in the CoMTrans master plan, the Fort-Malabe corridor has been identified as requiring urgent policy intervention to shift private mode users to public transport.

Light Rail Transit (LRT)

Since CoMTrans/SKYTRAIN proposed a Monorail System as the new transit system on the Malabe Corridor based on the multi-criteria comparison with other transport mode such as bus priority lanes, Bus Rapid Transit (BRT), LRT (Elevated/Street), Monorail, and MRT (underground), MMWD selected the LRT for their following reasons:

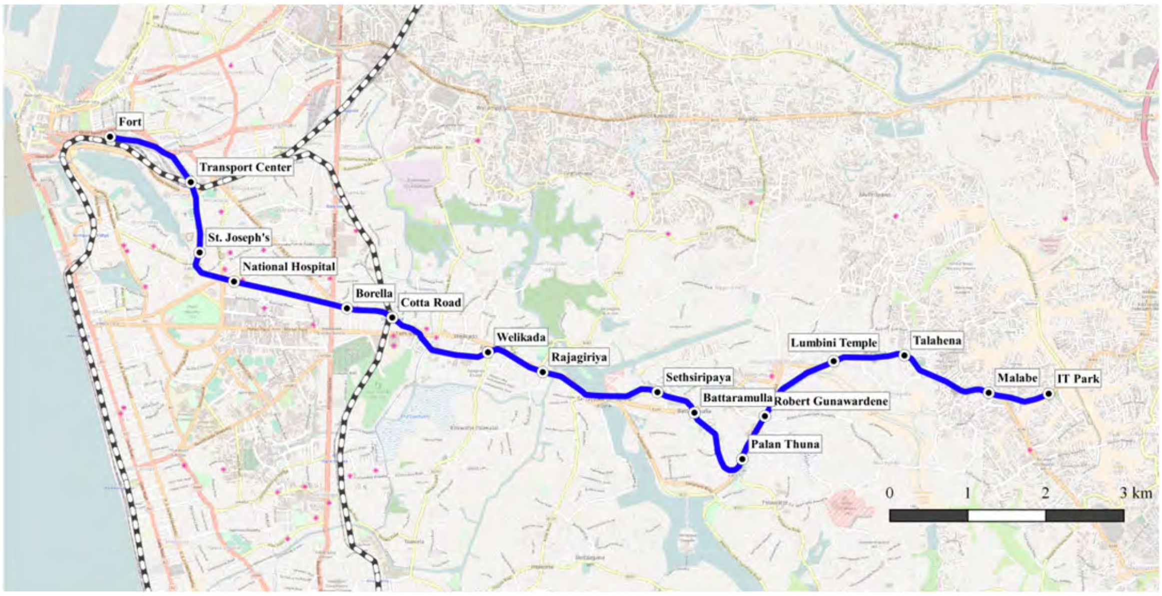
- There are only a limited number of monorail manufacturers worldwide, which constrains the competitiveness of the bidding process.
- With the monorail, it is difficult to expand the lines in the future because other MMWD's proposed RTS lines are LRT, and it is also difficult to increase the number of cars for the monorail due to the difficulty of technical configuration.
- Certain sections of MMWD's other RTS lines in the suburban area will operate at-grade, which is impossible to introduce the monorail.
- Unfamiliarity of maintenance and inspection works of a monorail system in Sri Lanka.

Based on the official request, which MMWD made to the Government of Japan under the STEP loan, the targeted LRT system to be considered has the following characteristics:

- Medium passenger capacity urban transport mode with rail-based system (therefore not the so-called tram/streetcar).
- Completely elevated structure over the road due to limited space along the LRT route within the urban area.

2.2 Route and Passenger Demand

Figure 2.2.1 shows the proposed JICA-LRT route and station locations in the demand forecast model. The total length is 17 km, with 16 stations located roughly every 1 km from Fort to IT Park. The JICA-LRT line has strong connections with other transport modes at the east-end, west-end and middle of the network (Fort, Transport Centre, Borella, Cotta Road and Malabe). The line also covers the area that has current transport demand in the city centre, and the area that has potential transport demand around Sethsiripaya and Battaramulla.



Basemap: OpenStreetMap
Source: Survey Team

Figure 2.2.1 Proposed Route of JICA-LRT

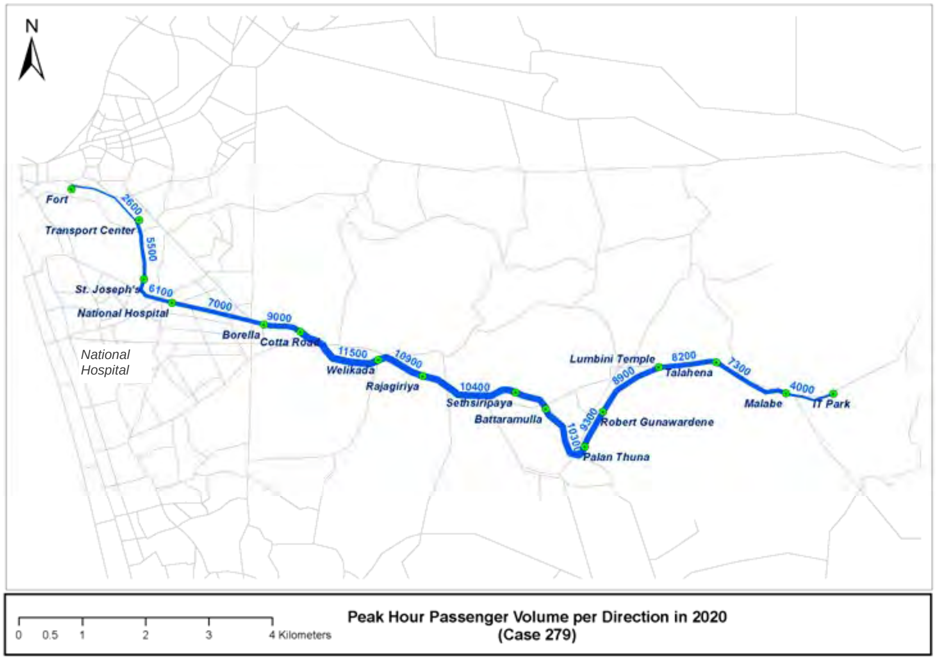
Table 2.2.1 shows the summary of demand forecast of JICA-LRT in 2020, 2025 and 2035. Daily passenger volume is expected to be increased to 498,000 passengers (pax)/day in 2035. The Passenger per Hour per Direction (PPHPD) is calculated from the maximum daily section volume per direction multiplied by the peak ratio of 13%.

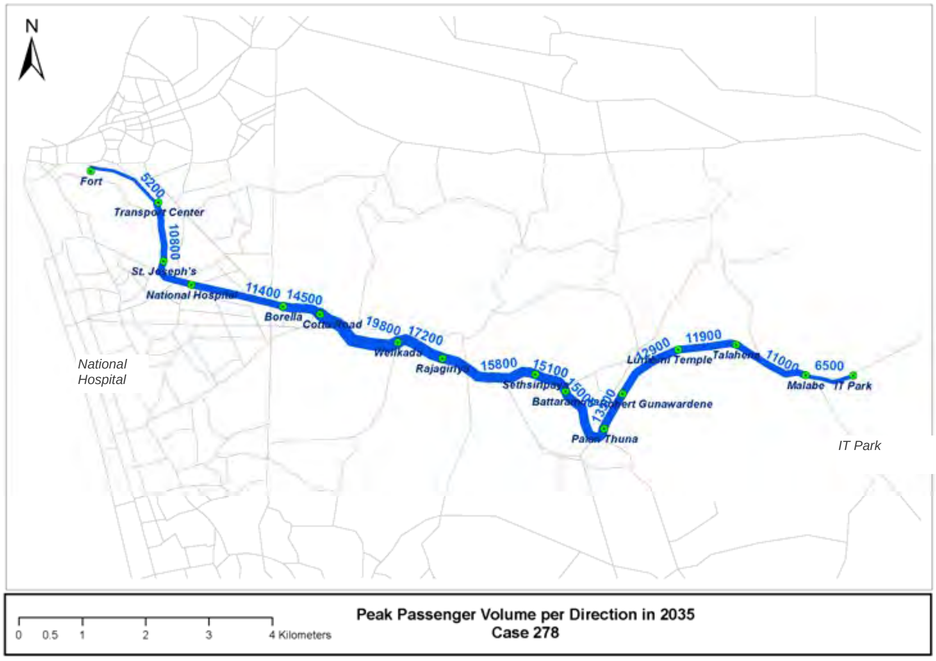
Table 2.2.1 Summary of Demand Forecast Result

Indicator	2020	2025*	2035
PPHPD	11,500	14,300	19,800
Max Section	Cotta Rd. - Walikada	Cotta Rd. - Walikada	Cotta Rd. - Walikada
Daily Passengers	295,000	363,000	498,000
Daily Passenger-km	1,736,000	2,087,000	2,787,000

Note: Fare Level “Normal×2.3”
*: The demand of 2025 was calculated by linear interpolation of demand in 2020 and 2035.
Source: Survey Team

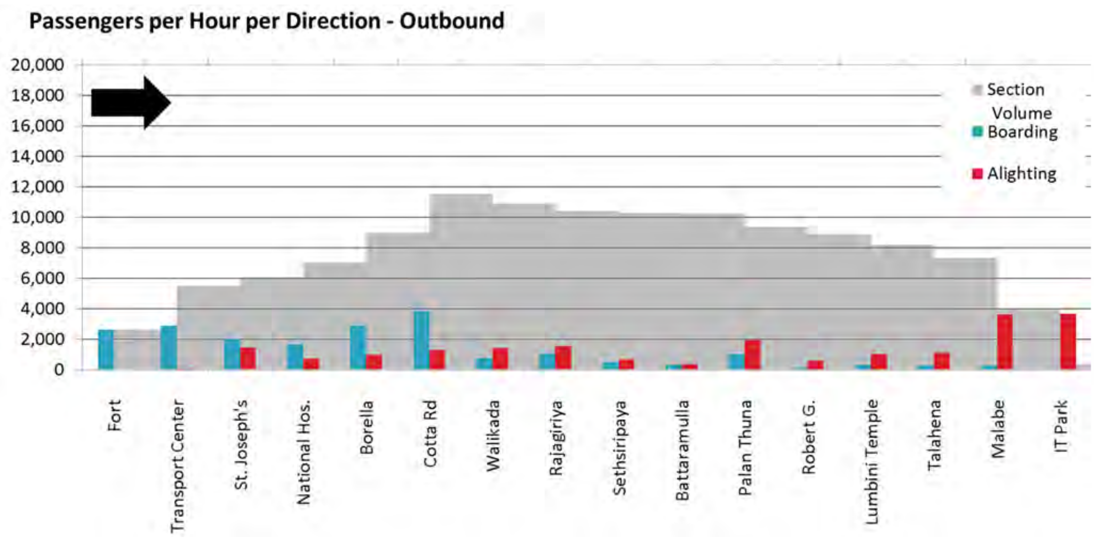
Peak hour traffic volumes in 2020 and 2035 are shown in Figure 2.2.2, and boarding and alighting passenger volumes by station and sectional passenger volumes during peak hour in 2020 is shown in Figure 2.2.3.





Source: Survey Team

Figure 2.2.2 Peak Hour Section Volume of JICA-LRT in 2020/2035



Source: Survey Team

Figure 2.2.3 Peak Hour Passenger Loading by Station in 2020

2.3 JICA-LRT System and Structure

Based on a series of discussions with MMWD officials for this Study, the service level (design principle) of the JICA-LRT in Colombo will be selected as follows:

- Develop a User-Friendly LRT System

This implies that the JICA-LRT should highly consider the principle of "think first for the JICA-LRT users". There are three important considerations for JICA-LRT users that should be incorporated in the planning and design stages:

- Comfort
- Safety
- Reliability

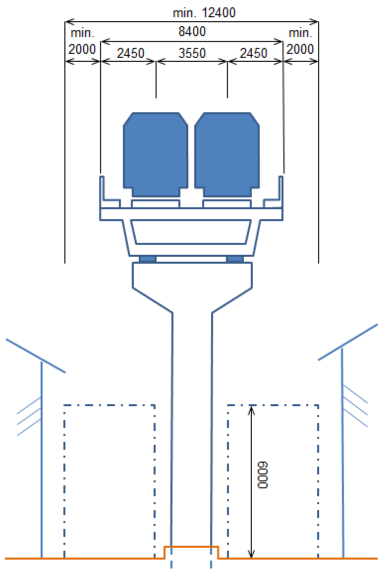
Comfort for users aims to provide enough "space in a car" for not only seating and but also standing during operation as well as boarding/alighting at the stations. The "comfortable seat" provision is another point of consideration. Materials and cleanliness is an important issue for users including disabled people. "Smooth ride" is ensured by engineering challenges to set the proper horizontal and vertical alignment without any occurrence of sudden vibrations and gallops. Enough space in a car helps the users to ride on/off with ease even during congested periods.

Safety is also an important issue, without any doubt. It is highly necessary to manage "train operation" not only for normal operation but also special events such as emergencies and evacuations. "Security" in the train and/or station is also an important point to be prepared. Note that access for medical treatment and firefighting are also considered during station development.

Reliability is the crucial point to be ensured for encouraging users. As the JICA-LRT is running in an urban area, time conscious people including businesspeople are potential users. Therefore, "shortening travel time" as well as "punctuality" are key points when designing the alignment, selecting rolling stock, and planning of signalling and telecommunication.

In addition, the aforementioned principles cannot be applied without consideration of minimizing and avoiding negative impacts for both environmental and social aspects. The items that should be minimized and avoided as negative impacts for LRT in Colombo are described as follows:

- Environmental Aspects: Construction impacts, vibration, noise
- Social Aspects: Land acquisition, livelihood impacts



Source: Survey Team

Figure 2.3.1 Typical Layout and Size of JICA-LRT Structure

To meet the above considerations, the JICA-LRT is proposed as an elevated structure with minimum width for safety operation of rolling stock, and with appropriate passenger capacity as the urban railway for Colombo. Figure 2.3.1 indicates the typical layout and size of the JICA-LRT structure.

As for the type of rolling stock, it is crucial to ensure competitiveness at the bidding stage with considerable cost. Since JICA-LRT is planned to be implemented as the Project by Japanese ODA Loan under STEP, it is to be considered that Japanese products and systems are applied to the rolling stock as well. In addition, GoSL needs to ensure the competitiveness at the bidding stage and to save on the price of rolling stock, so it is recommended that currently operated rolling stock that are standard commuter rolling stocks in metropolitan areas is to be applied.

A series of discussion were made with the Project Management Unit (PMU) of MMWD for the applicability of this specification, together with the design principle (comfort, safety, reliability), estimated passenger demand, route plan, and natural and cultural conditions in Colombo. In addition, through the opportunities for GoSL officials to ride various types of rolling stock in the Tokyo and Osaka areas during the invitation program in Japan on September 2017, the proposed specifications were confirmed with the actual size and riding comfort. Table 2.3.1 and Table 2.3.2 show the recommended specifications for JICA-LRT to become Sri Lanka's first urban railway.

Table 2.3.1 JICA-LRT System

Technical Parameters	Specifications
Gauge	1,435mm (Standard gauge)
Traction Power	3rd rail, DC750V
Max. Train Operation Speed	80km/h
Max. Train Operation Speed on the section of tight curve radius 100 m	30km/h ~ 40km/h
Min. Distance between Tracks	3.55 m
Min. Width of Viaduct and ROW	8.4m, 12.4m (2.0m margin from each side of Viaduct)
Min. horizontal curve radius	Main line: 100m Main line along platform: 300m Depot 100m
Min. Circular Curve Length	20m
Min. Tangent Length	20m
Type of Transition Curve	Cubic Parabola
Max. Gradient	Main line: 35/1,000 Station: 5/1,000 Depot or train stabling area: Level
Min. Vertical Curve Radius	Gradient change of more than 10/1,000 : 3,000 m Unavoidable cases : 2,000 m
Turnout/Switch (decree of branching)	Main line: 1:10 Depot: 1:8
Clearance from the surface of the road	6.0m
Platform Length	120m for 6 cars
Min. Width of Platform	Island Type: 6.0m Siding Type: 4.0m

Source: Survey Team

Table 2.3.2 Specifications of Rolling Stock

Technical Parameters		Specification		
Maximum Speed		80km/h		
Gauge		1,435mm (Standard gauge)		
Traction Power Supply		Third Rail System		
Train Formation *Tc: Trailer Car with driver's cab,* *M: Motor car*		2M2T (Tc+M+M+Tc)		
Standard Passenger Capacity		Seated	Standing (3.3 persons/m²)	Total
	Lead Car	42	86	128
	Intermediate Car	52	84	136
Capacity of a Train (4 car-sets)		Per Car	Nos. of cars	Total
	Lead Car	128	2	256
	Intermediate Car	136	2	272
	Total Passengers (3.3 persons/m²) Including Seated passenger			528 (seated : 188)
	Total Passengers in different AW (Added Weight due to standing passenger)			
	AW-4: stand (4persons/m²) + seat	600		
	AW-6: stand (6persons/m²) + seat	806		
Major Dimension				
	Leading Car Length	18,000mm		
	Intermediate Car Length	18,000mm		
	Body Width	2,650~2,850mm		
Weight per Train (tare)		120t		
Body Materials		Light weight stainless steel or Aluminium		
Saloon Design				
	Door Ways	3 doorways each side of car		
	Door Type	Double slide doors 1,300 ~ 1,400mm width		
	Seat type	Longitudinal seat type		
Special Facilities				
	Wheel Chair Space	Equipped		
	Baggage Space	Not Equipped		
	Toilet	Not Equipped		
Traffic performance				
	Acceleration	3.2 km/h/s (0~30km/h)		
	Deceleration	Service 4.0 km/h/s Emergency 5.0 km/h/s		
Propulsion System				
	Power Collection System	DC 750 V, Collector shoe, (2 set / 1 Bogie)		
	Control System	Variable-Voltage/Variable-Frequency (VVVF) inverter with Insulated Gate Bipolar Transistor (IGBT), (1 unit / M car)		
	Brake Control System	All electric command electro-pneumatic brake		
Bogies		Bolster-less type (air suspension)		
Air Conditioning Equipment		Roof top type		
Auxiliary Power Supply Equipment		SIV: 3-phase inverter with IGBT		
Inter communication system		Communication system between front and rear cabin		
Passenger Information System		Public address system via loudspeaker Visual information system via Liquid-Crystal Display (LCD) screens		
Security camera		Several security cameras are installed in each Rolling Stock.		
Signal System		ATP, Centralised Traffic Control (CTC), Automatic Train Operation (ATO) CBTC or Track Circuit System		

Source: Survey Team

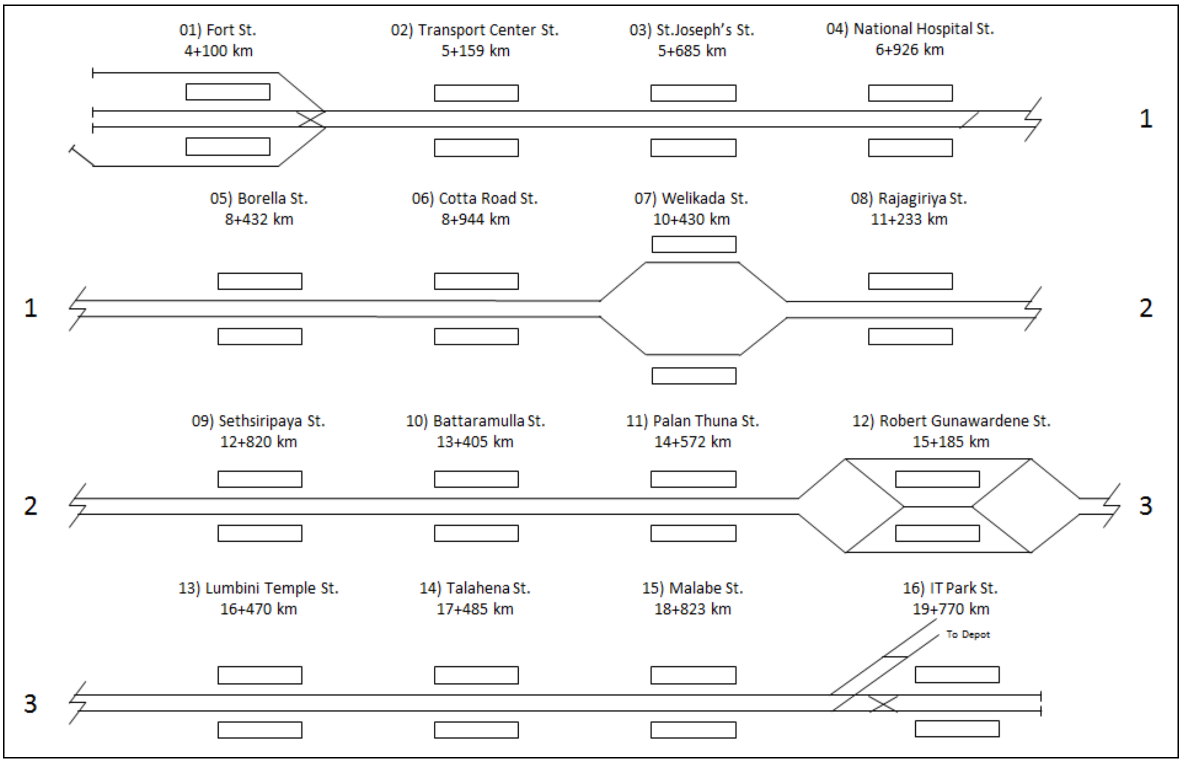
Conceptual images for rolling stock, typical station and depot (stabling yards and maintenance workshop facilities together with administration/train operation control centre) are depicted in Figure 2.3.2.

Source: Survey Team

Figure 2.3.2 Conceptual Images of JICA-LRT

2.4 Train Operation Plan

For the operation route of Fort - National Hospital - Borella - Sethsiripaya – Malabe - Depot, the train operation is planned with consideration of several speed restrictions, due to steep curvatures on the alignment designed for structures on existing roads. Figure 2.4.1 shows the train operation diagram with stations of JICA-LRT.



Source: Survey Team

Figure 2.4.1 Track Layout of JICA-LRT

Based on the demand forecast and transportation capacity described above, the required headway at peak hour for each milestone year was estimated, and the required number of rolling stock based on the train diagram in peak hour is calculated. Table 2.4.1 shows the operation plan with planned headway and required number of trains.

Table 2.4.1 Results of Train Operation Plan

No.	Key Factor for Operation Plan	Indicators
1	Number of cars in a train	4 cars (2025) , 6 cars (2035)
2	Number of operation trains in peak hour per direction from Fort to Robert Gunawadena MW (based on passenger demand data)	18 trains (2025 and 2035)
3	Regular train set for daily operation (trains)	22 train sets (plus 3 reserved train sets)
4	Total train km (km)/day	6,245.40 km/day
5	Total train operation hours (hh:mm:ss)	228:24:50
6	Total number of trains in service in a day in one direction between Fort St. and Robert Gunawadena MW St.	222 trains
	Total number of trains in service per direction per day from Robert Gunawadena MW St. to IT Park St.	147 trains
7	Transport capability at peak hour from Fort St. to Robert Gunawadena MW St.	In 2025 (4car:806 persons) 14,508 (pax./direction) In 2035 (6car:1,209 persons) 21,762 (pax./direction)

Source: Survey Team

2.5 Cost Estimation and Implementation Schedule

[Classified]

2.6 Institutional Arrangement and Operation & Maintenance

Concepts of Operation & Maintenance (O&M)

The O&M working group was established during the F/S, and the important concept/schemes for realizing JICA-LRT O&M activities were discussed. The following points were understood to be important considerations and actions that GoSL should take:

- **Autonomous body for O&M:** The O&M business body should have management autonomy for providing good quality of service and profitable railway business.
- **Ensuring governmental financial support:** The government should provide financial support program until the breakeven point for sustainable railway business.
- **Establishment of legislative system:** Based on the O&M scheme, the legislative system should be essential to control the O&M business body.

Proposal for O&M Business Scheme

Many members in the O&M Working Group stated that the organization body for O&M of JICA-LRT should be formed as a joint-stock company with a governmental share of less than 50%, because a company with a governmental share of more than 50% should be established by the special act. Considering similar O&M organizations such as Sri Lankan Railways (SLR), it is envisioned that SLR employees feel much different than the LRT Company if the LRT Company is formed by a governmental company with flexible employment conditions. In addition, according to major opinions of O&M Working Group members, it is preferred that the private sector have more than 50% of the company shareholding rate, to secure the autonomy of company management if the government can provide a VGF scheme for the O&M company. Further discussion will be done by the O&M Working Group to finalize the preferred O&M scheme to meet the situation of GoSL's context.

Scheme of O&M Activities

For conducting O&M activities, there are three different types of schemes in general.

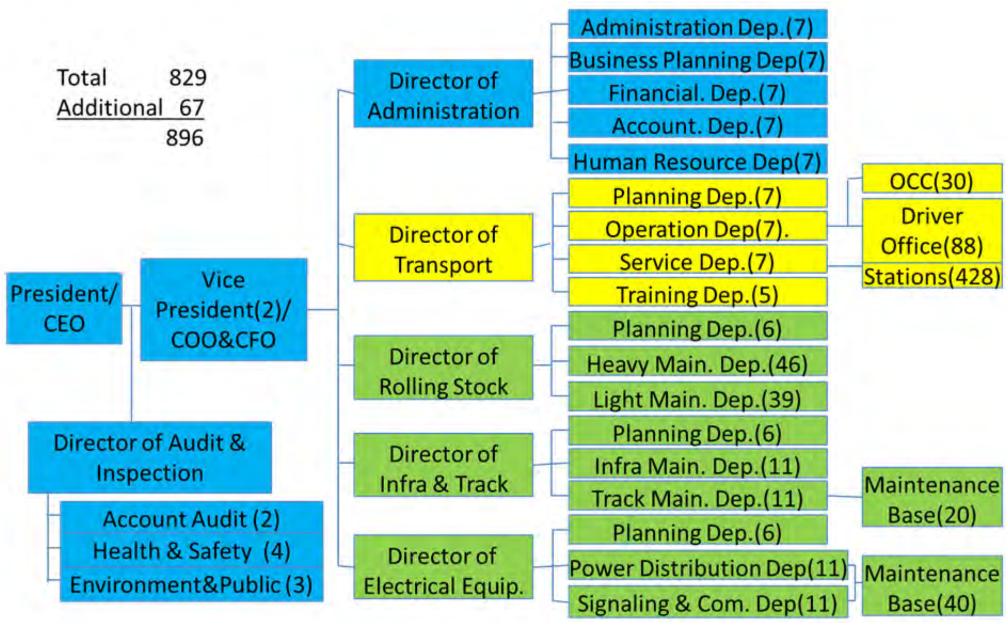
- Type-A: The O&M business company conducts both O&M tasks by themselves
- Type-B: The O&M business company conducts the operation tasks by themselves, but let maintenance tasks be conducted by another company through outsourcing
- Type-C: A full outsourcing contract of both O&M tasks by another company

Although each scheme is possible for the railway O&M business, the difference is how the O&M business company takes risks of O&M activities, and how much the O&M business company should pay to the contractor.

It is recommended that 'Type-A", with the conditions that the O&M company is able to receive full support for training of O&M skills before commercial operation, be considered from the perspective of sustainability and creating the industry related to LRT O&M in Sri Lanka. The members of the O&M Working Group acknowledged the importance of this recommendation. Therefore, it is important to prepare the contents of supporting program for the training of O&M skills.

<u>Propose Organization Structure for Operation and Maintenance</u>

Figure 2.6.1 shows the total required number of staff and divisional/departmental structure of the O&M Company for the JICA-LRT based on the train operation plan.



Source: Survey Team

Figure 2.6.1 Total Number of Staff and Whole Structure of O&M Company

<u>Operation and Maintenance Cost</u>

The O&M costs in 2025 and 2035 are estimated as shown in Table 2.6.1 based on the unit prices of salary, costs of maintenance and consumable goods, as well as power costs.

Table 2.6.1 Estimated O&M Cost (2017 price)

Description		Cost (1,000 LKR/year, 2017 Price)	
		2025	2035
Direct Labour Cost		953,940	953,940
Outsourcing & Spare Parts Cost	Operation	629,451	944,176
	Maintenance of Rolling Stock	399,594	599,391
	Maintenance of Infrastructure & Track	410,857	410,857
	Maintenance of Electrical Equipment	493,028	493,028
Power Cost		573,641	860,461
Administration Cost		95,394	95,394
Total		**3,555,905**	**4,357,248**

Source: Survey Team

Legislative System for Urban Railway or LRT

It is recommended that the urban railway be managed by another legislative system from the national railway in Sri Lanka, because the operation and maintenance of LRT or urban railway are much different from that of the national railway. A new act for urban railway should be established.

The following items are essential in the new Urban Railway (or LRT) Act:

a. Planning and construction
b. Operation program: licensing, fare, reporting etc.
c. Regulation and commission to the operator
d. Duties and penalties of the operator and passengers

It will be ideal to establish the new act before starting the construction of the JICA-LRT. In reality, this ideal is difficult because of time consuming to establish the new act. Three items from “b.” to “d.” are essential before starting construction of the project if the construction is to be executed by a private sector company. In the case of JICA-LRT, construction will be implemented by GoSL, therefore, at least one item (“d.”) should be set before starting operation.

3. Project Evaluation (Economic/ Financial Analysis)

3.1 Economic Analysis

The economic analysis was conducted aiming to ensure that the resources are allocated efficiently, and that investment brings benefits to the country and raises the welfare of its citizens. By establishing the “With Project” and “Without Project” scenarios, economic benefits and costs associated with the Project were estimated. The economic cost benefit analysis was conducted, and the economic internal rate of return (EIRR) and economic net present value (ENPV) were calculated as parameters to measure the economic return on investment.

Economic Evaluation

- Cost Benefit Analysis: The EIRR shows 20.18% and the ENPV shows 174.3 billion LKR. Since the EIRR exceeds the discount rate of 12% with a positive ENPV, the project implementation is assessed as having economic validity from the viewpoint of the national economy.
- Sensitivity Analysis: The sensitivity analyses of three cases; i) 10% decrease in economic benefit, ii) 10% increase in economic cost, and iii) 10% decrease in economic benefit, 10% increase in economic cost, were conducted. The results of the sensitivity analyses indicated economic feasibility in all cases. The EIRR applied by 50% decrease in economic benefit or 210% increase in economic cost fulfils the discount rate (cut off rate) of 12%.

3.2 Financial Analysis

Financial Analysis of “O&M Company”

The financial analysis for establishing a JICA-LRT O&M Company was conducted based on the revenues, operation and maintenance costs, replacement costs, depreciation costs and finance costs generated by operating the JICA-LRT line with four cases, and the Financial Internal Rate of

Return (FIRR), Net Present Value (NPV) and Average Debt Service Coverage Ratio (ADSCR) were calculated as indicators, to measure the financial return on investment as well as the ability to repay debt service.

Evaluation Cases

The following four cases were evaluated to analyse the feasibility of an O&M Company by different base bus fare assumptions and types of replacement cost coverage (Table 3.2.1).

Table 3.2.1 Evaluation Cases

Item	Case 1	Case 2	Case 3	Case 4
Base bus fare	1.2 times of Normal Bus (15 LKR)	1.5 times of Normal Bus (18 LKR)	1.5 times of Normal Bus (18 LKR)	2.3 times of Normal Bus (27 LKR)
Replacement Cost (rolling stocks, service facilities, information system, power system distribution, etc.)	Not Included[1]	Partial Replacement (Only rolling stocks and service facilities)	Full replacement	Full replacement
Depreciation of Replacement Cost	Not Included[2]	Depreciation Coverage	Depreciation Coverage	Depreciation Coverage

Source: Survey Team

Results of Financial Analysis

The results of the financial analysis are summarized in the following Table 3.2.2. The equity of 1.08 million LKR with the loan of 2.52 billion LKR (repayment for five years) at the establishment of a company is not included in the calculation.

Table 3.2.2 Result of Financial Analysis

Item	Case 1	Case 2	Case 3	Case 4
Number of years after operation achieving positive net profit after tax	29 years	1 year	1 year	1 year
Number of years after operation achieving positive cumulative net profit after tax	Negative value for the whole evaluation period	12 years	13 years	3 years
Short-term loan for working capital	For 28 years (814 bil. LKR in total)	For 9 years (2.7 bil. LKR in total)	For 6 years (0.6 bil. LKR in total)	Not required, self-finance is possible
Long-term loan for replacement cost	Not required, due to no replacement coverage	30, 40, 60 years after operation	10, 15, 20, 30, 40, 60 years after operation	30 years after operation
Government assistance by equity or subsidy	Not required, due to no replacement coverage	Not required, due to partial replacement coverage	15, 20, 30, 40, 60 years after operation (58.1 bil. LKR in total)	Not required, self-finance is possible

[1] Replacement cost and its depreciation cost will not be covered by an O&M Company and will be covered by the government subsidy.
[2] Ditto

Item	Case 1	Case 2	Case 3	Case 4
Number of years after operation to start paying dividends to the investors (20% of equity; 216 million LKR)	29 years	11 years	41 years	1 year
FIRR (>8.87%) NPV (>0) Minimum ADSCR (>1.2)	Negative ▲148 bil. LKR ▲1.40	9% ▲0.2 bil. LKR 0.02	Negative ▲7.4 bil. LKR ▲0.99	27% 8.5 bil. LKR 2.00

Source: Survey Team

The evaluation results show that only Case 2 and Case 4 recorded positive FIRR, which exceeds the opportunity cost of capital of 8.87%. The minimum ADSCR, the parameter to measure the ability to repay debt services, and generally higher than 1.2[3], shows that only Case 4 exceeds 1.2.

Financial Analysis of "the Project"

The financial analysis for the JICA-LRT Project was conducted based on the construction costs, revenues, operation and maintenance costs, replacement costs, depreciation costs and finance costs. The FIRR and NPV were calculated as indicators to measure the financial return on investment.

Results of Financial Analysis

The result of the financial analysis of the Project shows the FIRR of ▲5.17% with negative value of NPV at 190 billion LKR. The net cash flow did not turn to positive value during the project period.

For achieving positive FIRR, increasing other revenues can be considered. Achieving 110% of JICA-LRT fare revenue as other revenue, currently only 7%, is required for reaching positive FIRR; for achieving FIRR of more than 8.87%, the opportunity cost of capital, reaching 490% of JICA-LRT fare revenue as other revenue is required.

4. Findings and Recommendations

Findings of the Survey on JICA-LRT Project

The following points summarize the findings of the JICA-LRT Project F/S:

- The JICA-LRT system, which includes civil structures, a depot, electrical and mechanical systems, and a signal and telecommunication system, was designed as a technically, economically suitable and effective solution for the introduction of a new transit system, as proposed by the Megapolis Urban Transport Master Plan for the Colombo Metropolitan Area. The route and stations were selected to capture increasing passenger demand under the constraints within the urban area of Colombo. The JICA-LRT can help to alleviate traffic congestion, considering the social environment of the urban area.
- The project cost for the implementation of the JICA-LRT system will be economically covered by the large amount of benefits from the JICA-LRT system. This means the Project is the economical viable one.

3 Cesar Queiroz, Financial Assessment of PPP Projects

- In terms of financial sustainability, the JICA-LRT O&M Company has the possibility to be financially profitable and sustainable when the JICA-LRT fare is set at an affordable level (less than 100 SLR between Fort and Malabe).
- In terms of environmental and social aspects, the EIA study revealed that the potential impacts of the proposed project take place mainly during the construction stage, and that impacts during operational stage are minimal. Although impacts from the project during construction stage could be significant, particularly for noise/vibration, traffic and social infrastructure, the impact could be minimised and mitigated to a great extent if appropriate mitigation measures are implemented as suggested in the EIA study. Also, the latest technical solutions for the construction method proposed by the Survey Team will help to mitigate these impacts.
- The social study revealed that a certain area of agricultural land and paddy field is necessary for construction of the depot. However, the number of houses and commercial establishments to be relocated due to the project is relatively low, since the JICA-LRT route traverses mainly through the already existing road network.

Therefore, the project is expected to be implemented as the introduction of the new transit system, not only for public transport users but for all residents of Colombo and its surroundings.

Recommendations on the JICA-LRT Project

There are several recommendations are to be considered during the implementation stage for smooth implementation and for further increase of effectiveness of the Project.

A) Toward Smooth Implementation of the Project

Capacity Development for PMU in Project Implementation: Since a dedicated PMU was established during the F/S, it is highly recommended that the number of staff for each field is maintained towards the implementation. For the implementation stage, environmental and social safeguards need to be implemented, and the capacity of the PMU to do this becomes crucial. The PMU must be able to address the environmental and social impacts, including the land acquisition process to meet the timeline of the planned implementation schedule before starting the construction work. Therefore, it is recommended to set up the PMU with experienced staff, and to seek opportunities to improve the capacity through assistance from other experienced agencies (e.g. Road Department Authority (RDA)).

Branding: With this JICA-LRT being the first urban railway system in Sri Lanka, the "Branding of the LRT Project" to support the Colombo people in understanding this public transport mode correctly is an essential activity to be done by the PMU. This effort also helps encourage people to become a "Supporter" who can then accelerate the project implementation to realize the JICA-LRT as soon as possible.

Proper Understanding of Utilities and Preparation of its Diversion/ Relocation: In order to comply with the scheduled construction work, it is crucial to obtain the precise location of underground and overhead utilities along the alignment of the JICA-LRT. Since the Mobile Mapping System (MMS) was developed and each utility location was digitised, it is recommended that this information be utilized during the detailed design for the location of the piers/foundations, as well as for the diversion/relocation plan.

Minimization of Social and Environmental Impacts due to the Project: It is essential to avoid and minimize social and environmental impacts caused by JCIA-LRT construction to the public. During the detailed design stage, it is recommended to consider the following:

- reduction of the construction area occupied on the road, and of the construction period;
- design of the station to minimize required land acquisition;
- selection of an appropriate construction method to minimize environmental and social impacts;
- development of a comprehensive traffic management plan; and
- implementation of measures to minimize air pollution, noise and vibration due to the construction work.

Establishment of an O&M Business Company: During the F/S, as mentioned in Chapter 5, the discussion on the O&M scheme and organization have been started within GoSL, and will be continued from the standpoint of an autonomous O&M business company that can be financially and technically sustainable. The proactive specific procedures toward the establishment of the O&M Company are expected within the GoSL. In addition, it is expected that the fare collection method and fare level/types be discussed and arranged, and that the legislative system for the LRT system will be developed for both this JICA-LRT and extension, and for other RTS lines.

Improved Coordination with Relevant Stakeholders: It is highly important to further improve coordination among relevant stakeholders, particularly with relevant government agencies and the project affected persons, to be able to obtain full support to implement the Project regardless of the political uncertainties. This can be done through transparency, and continuous and open communication. Gathering support from relevant stakeholders is particularly important for land acquisition/resettlement, relocation of utilities, and road traffic configuration and control.

B) To Further Increase the Effectiveness of the Project

Introduction of Japanese Technologies through the STEP for Bidding Competitiveness: Since it is crucial to apply the construction method within a narrow section, for a more efficient railway system and equipment to meet the conditions in Colombo similar to Japan, it is an optimal opportunity to use the latest Japanese technologies for the first LRT system in Colombo by applying the STEP condition. In order to call for bidders with reasonable bidding prices and the latest technologies, the specifications should be further studied to make it clear and attractive to the bidders.

Study on Station Area Development linked to JICA-LRT Project: This F/S only covers the necessary infrastructure for the JICA-LRT system; it is not a comprehensive study to create an urban development plan around the stations.

Since JICA-LRT will be a good opportunity to impact the public transport network and its connectivity in Colombo, especially along the Malabe Corridor, the urban development around public transport, such as Transit Oriented Development (TOD), is recommended to be studied at the next stage with close collaboration with the Urban Development Authority (UDA). This would include: a) development of public services/buildings for education, health, cultural and local/governmental administration offices, as well as large-sized commercial facilities and working offices to be located around the JICA-LRT stations; and b) improvement of accessibility to each JICA-LRT station by foot, para-transit and feeder bus services by means of station plaza (bus and para-transit stand, kiss & ride area), MMC (multi-modal centre that links to other public transport modes smoothly), pedestrian bridges with elevators and direct connection to adjustment buildings, which are designed as barrier-free and with universal design principles for all kinds of public transport users.

At the same time, the strategical stations to provide car parking facilities, namely P&R stations, should also be examined and selected. In the view of urban transport planning, private cars are to be reduced by providing good public transport services for the whole trip from their home, meaning that P&R stations are basically located outside of the CBD. Currently, potential P&R stations to be considered are IT-Park Station and Robert Gunawardena Station.

Furthermore, since the feasibility study on MmTH is envisioned at Fort/Pettah, it is recommended that JICA-LRT will take close communication with MmTH development team to show our design and discuss on smooth connections with other transport modes and urban development around the MmTH.

With consideration of all of above, LRT could be a more attractive public transport mode, and play a fundamental role in urban development.

Introduction of Feeder Bus Service: There is potential for current bus users to shift to the LRT mode because several bus routes are on the same alignment as the route of JICA-LRT. Actually, the bus mode provides much closer service to each residence, so it will be an opportunity to change their current long distance bus route to a shorter route that connects to JICA-LRT station such as "Feeder Bus Service", to provide more service within the residential areas. This would operate more efficiently (reducing the operation cost) and gain more passengers (increasing the fare revenue), which will encourage people to use more public transport.

In the detailed design stage, it is recommended to implement this feeder bus service route and for the operation to be well coordinated at the JICA-LRT stations with bus stands.

Technical Assistance from the Experience of Japanese Railway Operation: Since the LRT system is new for Colombo, the LRT business company needs training for its operation and maintenance, as described in Chapter 5.

With the perspective of technical sustainability and creating new industry/employment related to LRT, it is recommended to acquire the knowledge and techniques for operation and maintenance from experienced engineers and managers in railway operators of similar size to the JICA-LRT in Colombo. The technical assistance provided should be programmed not only for training the staff of the LRT Company after its establishment, but also for inputting their ideas for improvement of the design with the operational perspectives at even the detailed design stage.

Shaping the New Urban Life with LRT (Education and Promotion Programme): Before starting a new public transport system, it is difficult to imagine the LRT's uses and benefits for commuting and weekend activities by the Colombo people. As the result, there are many cases observed in various countries and urban areas where the people needed time to understand how to use and what the benefits are of a new public transport system. In order to fully enjoy the benefit of JICA-LRT by the people of Colombo as soon as possible, the education and promotion programmes should be well-prepared and conducted before starting operation, which includes proposals of using LRT in daily life.

In addition, the policies and measures used to promote public transport in Japan should be studied, such as the special company tax exemption system applied only for commuting allowance by public transport. A mechanism to integrate the parking fee at P&R, JICA-LRT fare and commercial coupon can be studied before starting operation, to promote more LRT users and reduce private vehicles for urban trips.

Main Report

Chapter 1 Introduction

1.1 Background

In Sri Lanka, over 90% of people and cargo transport depends on road networks. Around 42% of Gross Domestic Product (GDP) and 29% of the population are concentrated in the capital Colombo, especially in the Western province which has achieved solid economic growth since the end of civil war. The number of traffic modes utilizing road networks such as automobiles, buses and motorcycles has been rapidly increasing. It is said that about 1 million people are flowing into the centre of Colombo every day, resulting in severe traffic congestion in the city and its surroundings. During the morning and evening peak times, travel speed is observed less than 20 km/h, which is defined as traffic congestion. In fact, there are roads with less than 10 km/h travel speed, which infers that current urban transport network is reaching its limits. Such decline in traffic mobility will adversely affect the economic activity of the Colombo metropolitan area, and will negatively impact on the national economy.

Based on the current saturated traffic condition at major roads in Colombo, from the viewpoint of efficient public transport mode compared with the private vehicles, the improvement of current public transportation system is urgently necessary. The Urban Transport System Development Project for Colombo Metropolitan Region and Suburbs (CoMTrans) which was supported by the Japan International Cooperation Agency (JICA) and implemented by the Ministry of Transportation of Sri Lanka from 2012 to 2014 found that out of seven major corridors heading towards the centre of Colombo, the Malabe Corridor was observed to have the most serious congestion with the largest number of private cars and the lowest travel speed at peak hours. Therefore, the new public transport system named Integrated Transport System with Monorail (SKYTRAIN) along the Malabe Corridor was proposed and studied, that was identified as high priority project by CoMTrans.

Since the establishment of the new government of Sri Lanka (GoSL) in January 2015, the Ministry of Megapolis and Western Development (MMWD) which is responsible for planning the urban development in the Colombo metropolitan area, has prepared the "Western Region Master Plan - 2030". A priority concern of this master plan is to solve traffic congestion in the Colombo Metropolitan Area by introducing a public transport system. Therefore, the GoSL officially requested to introduce the proposed Light Rail Transit (LRT) system RTS-1 and RTS-4 to the government of Japan under the Special Term for Economic Partnership (STEP).

After the official request for LRT to Japanese government, JICA Headquarters sent a mission September 2016 to discuss the scope of the Preparatory Survey with GoSL. As the result of the discussion, both the JICA mission and GoSL agreed the Preparatory Survey (F/S) will cover the following routes utilizing data and information already available from previous studies conducted by JICA.

- RTS-1: Fort - Kollupitiya - Borella - Union Place - Maradana
- RTS-4: Borella - Rajagiriya - Battaramulla - Malabe

Both sides also agree that the portions of the northern part of RTS-1 which are different to the SKYTRAIN trace will be examined in the Preparatory Survey to determine the optimum alignment for the Project.

This Survey aims to conduct the preparatory survey for targeted routes in order to examine the necessity and feasibility of the Project for Establishing the New Rail Transit System in Colombo. It also aims to collect the necessary information for appraisal of the Project as a candidate of Japanese Official Development Assistance (ODA) Loan Project.

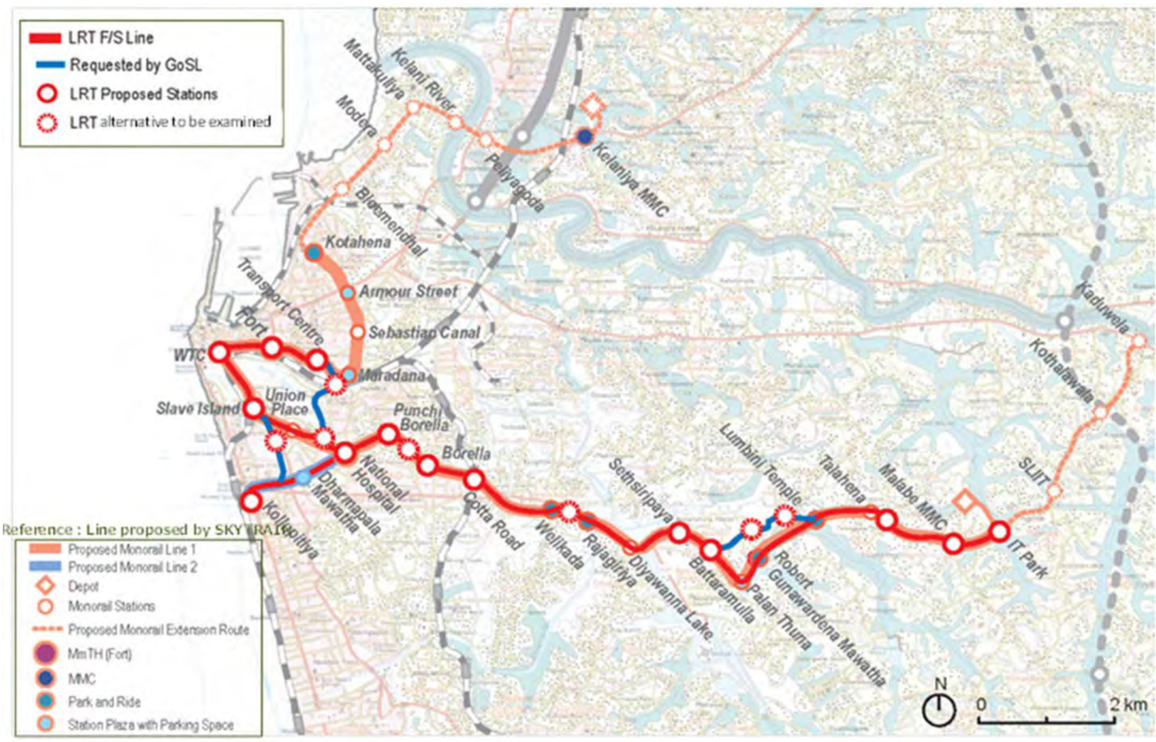
1.2 Scope of the Preparatory Survey

As described above, the Survey aims to study feasibility for the JICA-LRT system in Colombo as officially requested by the GoSL under the Japanese ODA Loan Project.

The Survey includes the following scope of work:

- Outline of the Project and Preliminary Design (Route/Alignment Plan, Rolling Stock Plan, Demand Forecast, Structure Design, Operation Plan, Signal & Telecommunication, Electrical and Mechanical, Depot, Station Development)
- Construction Plan
- Operation and Maintenance (O&M) Plan
- Cost Estimation
- Evaluation of the Project (Economic Internal Rate of Return (EIRR), Financial Internal Rate of Return (FIRR))
- Project Implementation Plan (Procurement Packaging, Implementation Schedule)
- Discussion on Project Implementation Organization, O&M Organization
- Environmental and Social Consideration Survey (Environmental Impact Assessment (EIA)/Resettlement Action Plan (RAP))

In the beginning of the survey, the Proposed Route for the Preparatory Survey was set in accordance with the discussion between the JICA mission and GoSL in September 2016.



Source: Survey Team: Inception Report (ICR), February 2017

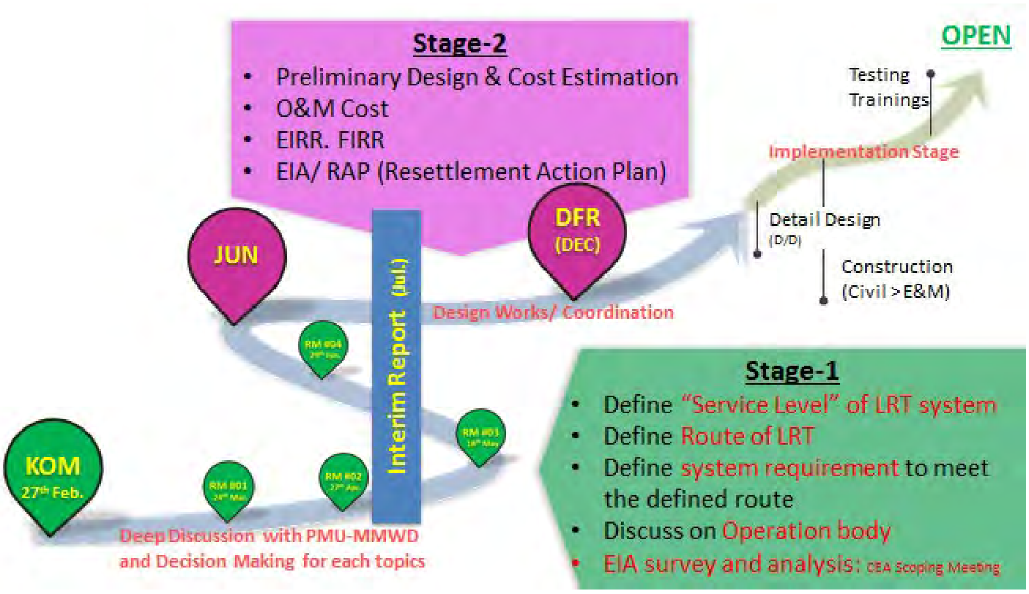
Figure 1.2.1 Survey Route described in ICR

In order to achieve the Project, Stage-1 of the F/S shall cover the following components based on the Aide-Memorie of the F/S on 1st of March 2017:

- Service of JICA-LRT
- Route of JICA-LRT
- System requirement to meet the defined route
- Operation & Maintenance body
- EIA preparation

1.3 Schedule and Tasks

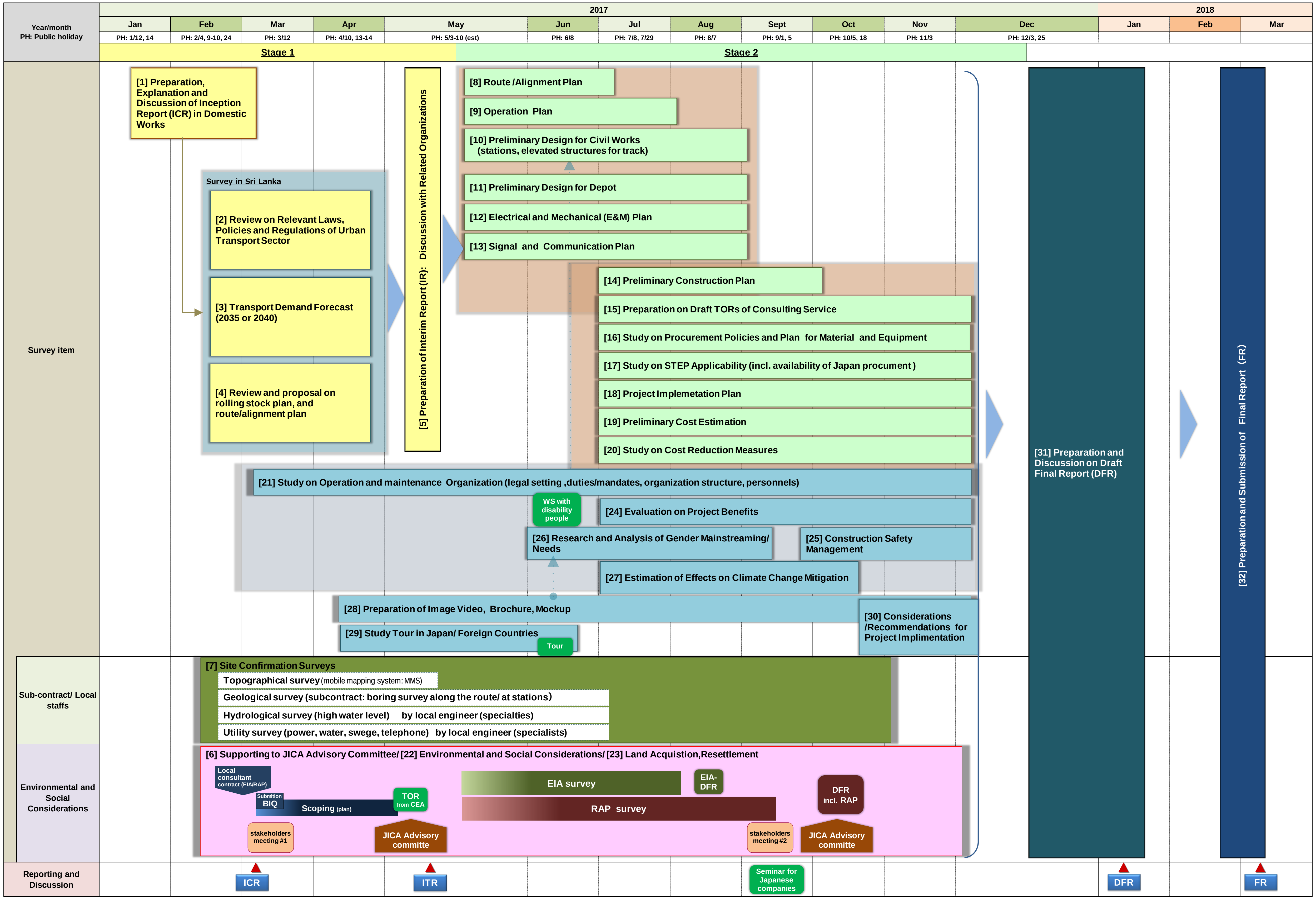
In order to visualize the roadmap of the Project, the Survey Team presented the overall picture of the Project implementation at the kick-off meeting chaired by the Advisor to the Prime Minister on 28 February 2017 as shown in Figure 1.3.1. It divides the schedule into two stages before entering further preliminary design and cost estimation. Items in Stage-1 highlight the importance of establishing the operation body. The entire schedule of the F/S is depicted in Figure 1.3.2.



Source: Survey Team, ICR, February 2017

Figure 1.3.1 Overall Schedule of the JICA-LRT Implementation

As shown in the schedule, the Draft Final Report (DFR) is submitted in December 2017, which covers all activities in the Stage-1 and Stage-2.



Source: Survey Team: ICR, February 2017

Figure 1.3.2 Flowchart of the Survey

Based on the task items shown in the ICR, the topics/items to be decided and discussed during Stage-1 and Stage-2 of the F/S are summarised below:

Topics/items to be determined in Stage- 1:

- Definition of service level of JICA-LRT system
- Definition of JICA-LRT route: detail of station locations and alignments
- Definition of system requirement to meet the defined route
- Definition of Operation/Institutional Arrangement for JICA-LRT system
- EIA survey and analysis

Items to be finalized in Stage-2:

- Preliminary Design & Cost Estimation
- O&M Scheme and Cost
- EIRR/FIRR
- Project Implementation Plan (PIP)
- EIA/RAP
- Approval of ITR by Steering committee
- Study tour in Japan

1.4 Institutional Arrangement

1.4.1 Project Management Unit

MMWD formulated the Project Management Unit (PMU) only for the Project of JICA-LRT on May 2017 after commencement of the Survey, and appointed the dedicated Project Director (PD).

The members of PMU are employed during the Survey. As of January 2018, there are 25 positions in total 34 staff in PMU. Table 1.4.1 shows the members of PMU-MMWD for the Project of JICA-LRT.

Table 1.4.1 Members of Project Management Unit

No.	Designation	Number	Note
1	Project Director	1	Recruited
2	Deputy Project Director	1	Recruited
3	Finance Manager	1	Recruited
4	Procurement/ Contract Specialist	1	Recruited
5	Environmental Specialist	1	Recruited
6	Social Specialist	1	Recruited
7	Urban Transport Specialist (Consultant)	1	Recruited
8	Signaling and Telecommunication Specialist (Consultant)	1	Recruited
9	Electrical Engineering Specialist	1	Recruited
10	Senior Engineer (Operation and Maintenance)	1	Recruited
11	Senior Engineer (Infrastructure)	1	Recruited
12	Senior Engineer (Electrical Installation)	1	Recruited
13	Senior Engineer (Electrical)	2	Recruited on acting basis from CEB
14	Transport Engineer (Operations)	1	Recruited
15	Engineer (Signaling and Telecommunication)	1	Recruited
16	Electro Mechanical Engineer (Rolling Stock)	1	Recruited

No.	Designation	Number	Note
17	Engineer (Electrical)	3	Recruited on acting basis from CEB
18	Senior Land Acquisition. & Resettlement Officer	1	Recruited
19	Senior Environmental Officer	1	Recruited
20	Administrative Officer	1	Recruited
21	Accounts Assistant	1	Recruited on acting basis
22	Project Secretary	1	Recruited
23	Management Assistant	4	Recruited
24	Office Assistant	4	Recruited
25	Driver	2	Recruited

Source: Survey Team

1.4.2 Steering Committee

The Survey Team received the lists for appointment of the Steering Committee (S/C) (LRT/JICA/ADM/01, 26th May 2017), and member of PMU-MMWD with aim to discuss the Project contents and implement the decision making.

The first Steering Committee Meeting was held in July 18th, and the second was held in December 21st 2017. The members of steering committee are shown below as Table 1.4.2.

Table 1.4.2 Members of Steering Committee

No.	Institute	Designation
1	Ministry of Megapolis and Western Development	Secretary
2	JICA Sri Lanka Office	Chief Representative
3	Urban Development Authority (UDA)	Chairman
4	Ministry of Transport and Civil Aviation (MOT)	Additional Secretary (Planning)
5	Light Rail Transit JICA Project	Project Director
6	Ministry of Megapolis and Western Development	Chief Accountant
7	Ministry of Mahaweli Development & Environment	Secretary
8	Ceylon Electricity Board (CEB)	DGM (WPS 2)
9	Sri Lanka Telecom (SLT)	General Manager (Enterprise & Government Business)
10	Ministry of Lands and Parliamentary Reforms	Assistant Secretary (Bim Saviya)
11	Ministry of Highway & Higher Education	Senior Programme Director
12	Sri Lanka Land Reclamation & Development Corporation (SLLRDC)	Deputy General Manager (R&D)
13	National Transport Commission	Deputy Director Planning
14	Sri Lanka Transport Board	To be nominated
15	Western Province Transport Authority	Deputy General Manager (Operation)
16	Road Development Authority (RDA)	Deputy Director (Planning)
17	Sri Lanka Railway (SLR)	Deputy Chief Engineer (Bridges)
18	Kaduwela Municipal Council	To be nominated
19	Colombo Municipal Council (CMC)	Director Engineer (TDRS)
20	Sri Jayawardenepura Kotte Municipal Council	Municipal Engineer
21	Sri Lanka Police	To be nominated
22	Central Environmental Authority (CEA)	Assistant Director (Environmental Impact Assessment)
23	National Water Supply & Drainage Board (NWS&DR)	Additional General Manager (Western)

No.	Institute	Designation
24	Department of National Budget	Assistant Director
25	Department of External Resources	Director
26	Department of National Planning	Director
27	Department of Agrarian Service	Senior Engineer
28	Department of Irrigation	Director of Irrigation
29	Department of Valuation	Deputy Chief valour
30	Department of Wild Life	To be nominated
31	Department of Archaeology	To be nominated
32	Survey Department	Additional Secretary (Field)
33	District Secretariat, Colombo	District of District Planning Secretariat
34	Sri Lanka Ports Authority (SLPA)	Engineer (Civil)

Source: Survey Team

1.4.3 O&M Working Group

The O&M working group (WG) meeting was held on 1st November 2017, with the purpose of discussing the regulatory body and operation mechanism for the LRT system.

The nominated members for the WG are listed in Table 1.4.3.

Table 1.4.3 Members of O&M Working Group

No.	Institute	Designation
1	Ministry of Megapolis and Western Development	Secretary
2	National Agency for Public Private Partnership (PPP), Ministry of Finance and Mass Media	Chairman
3	PMU-MMWD, JICA-LRT Project	Project Director
4	Department of Public Finance, Ministry of Finance and Mass Media	Director
5	Ministry of Public Enterprises Development	State Secretary
6	Ministry of National Policies and Economic Affairs	Additional Secretary
7	Department of National Planning (NPD), Ministry of National Policies and Economic Affairs	Director
8	Department of External Resources (ERD), Ministry of National Policies and Economic Affairs	Director
9	Department of Project Monitoring, Ministry of National Policies and Economic Affairs	Director General
10	Urban Development Authority, MMWD	Director General
11	Ministry of Transport and Civil Aviation	Additional Secretary

Source: Survey Team

Records of major meetings, which are review Meetings chaired by the Advisor to the Prime Minister, technical meeting within the MMWD (PMU for Megapolis Transport Projects and designated PMU (LRT-JICA)), meetings regarding environmental and social safeguards, working group for O&M, workshop on accessible station for disabled people, and meeting with CEB, are described in Appendix 1.

In addition, the brief explanation for several activities related to the JICA-LRT (mobile mapping, short-video and invitation program in Japan) is also included in Appendix 1.

Chapter 2 Reviews of Updated Policy and Planning

2.1 Introduction

As mentioned in Chapter 1, CoMTrans study was supported by JICA and implemented by the MoT of Sri Lanka from 2012 to 2014. The objective of the study was summarised as follows.

- To prepare reliable transport data that can be utilised to evaluate and formulate transport development plans in a scientific manner by conducting an area-wide transport survey.
- To formulate a comprehensive Urban Transport Master Plan for the Colombo Metropolitan Area including the seven transport corridors prioritised with the justification of selected priority/leading projects for short-term, mid-term, and long-term implementation.
- To conduct a feasibility study on the prioritised project under the comprehensive urban transport master plan.

In CoMTrans study, series of transport survey[1] was conducted including the Home Visit Survey (HVS) to 35,850 households. Based on the survey results and results of transport demand forecast, the comprehensive Urban Transport Master Plan was formulated for target year 2035.

Out of seven major corridors, the Malabe Corridor was observed to have the most serious congestion with the largest number of private cars and the lowest average travel speed at peak hours. Based on this, implementation of the new public transport system was proposed between Fort and Malabe as one of the major and high priority projects. Following CoMTrans, the Feasibility Study of Integrated Transport System with Monorail was conducted in 2014.

In 2015, MoT with the University of Moratuwa prepared "the Strategic Plan for Traffic Management in Colombo Metroplitan Region", by conducting a review of the CoMTrans master plan.

After the establishment of MMWD in January 2016, Megapolis Master Plan and Megapolis Transport Master Plan were formulated. In the Megapolis Transport Master Plan, the RTS implementation projects were proposed including the line between Fort and Malabe, and LRT was decided as the mode by GoSL for the RTS project. In this chapter, these two Plans are reviewed, and their policy and planning are confirmed.

2.2 Reviewed Reports

2.2.1 Megapolis Master Plan

As per the decision made by the Cabinet of Ministers on 22nd April 2015, the Western Region Megapolis Planning Project (WRMPP) was established. Accordingly, this Project commenced its work from 5th May 2015 for the development of the Western Region Megapolis Master Plan, referred to as the Megapolis Master Plan. The master plan lays out redevelopment of the country's capital and its surrounding districts within a 15 year time frame. The Megapolis Master Plan has three broad goals: 1) to alleviate congestion pressures of urbanization; 2) to

[1] Home Visit Survey, Cordon Line Survey, Screen Line Survey, Trip Generation Survey, Truck Origin-Destination (OD) Interview Survey, Directional Traffic Count Survey, Bus Passenger Interview Survey, Stated Preference Survey, Travel Speed Survey, etc.

create a grand strategy to become a developed nation; and 3) to leverage the current global techno economic environment for national development. The project for the Megapolis Master Plan was completed in January 2016.

Under the Megapolis Master Plan, over 150 different development projects were identified and grouped into ten mega projects:

- Transport, energy and water
- Housing and relocation of administration
- Environment and waste management
- The aero-maritime trade hub
- "The High Rise" – central business district
- Industrial and tourists cities – Mirigaman, Horana, Negombo and Aluthgama
- Science and technology city
- "Eco Habitat" and plantation city
- "Smart Nation" – the smart city development project
- "Tranquillity" – the spiritual development facilitation

2.2.2 Megapolis Transport Master Plan

(1) Brief Summary

The Megapolis Transport Master Plan was developed considering the proposals by the previous masterplans and incorporating them as suitable. Necessary revision/intervention was made to fit the higher population projection and spatial distribution resulting from a new structure plan, through continuous consultations with stakeholders and necessary analyses by a core team.

The transport proposals outlined in the Megapolis Transport Master Plan include:

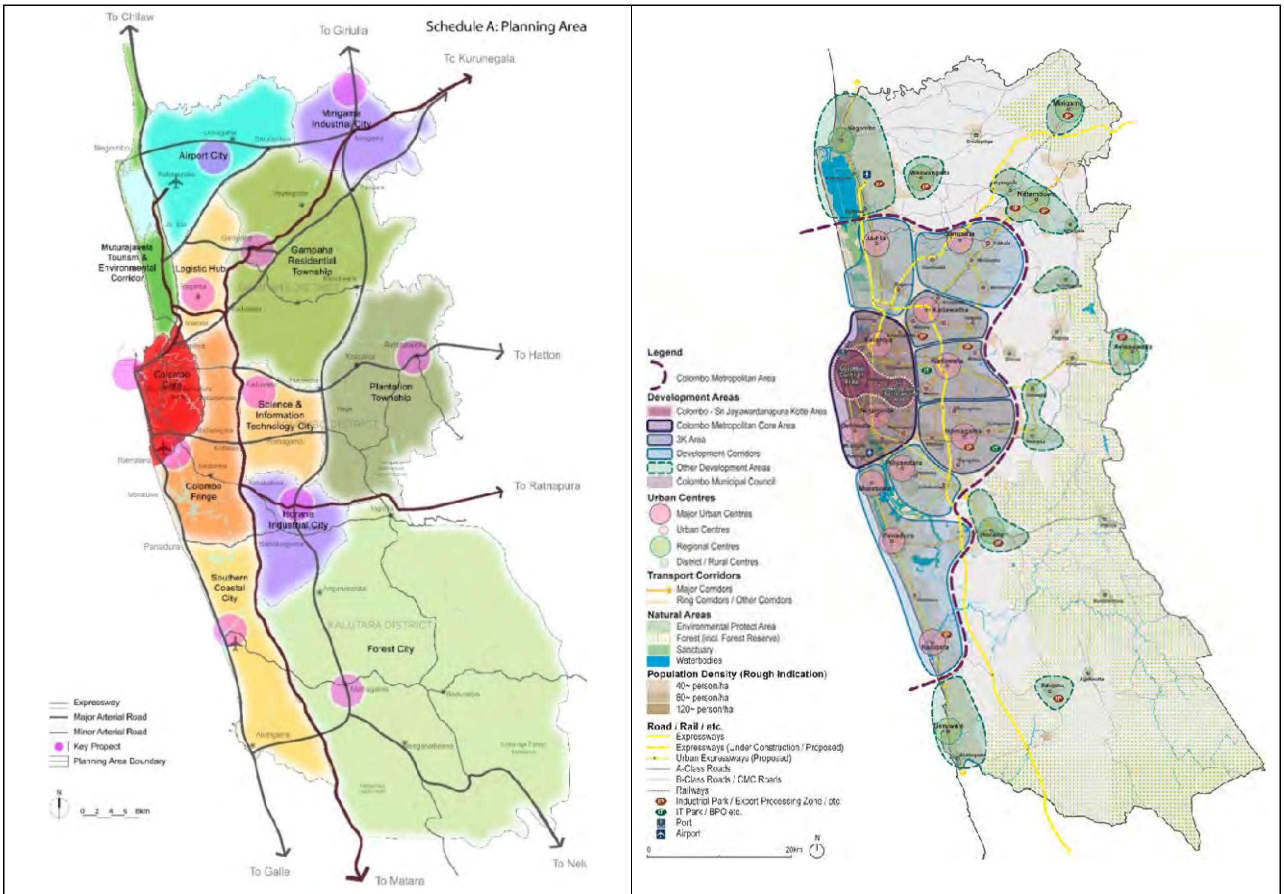
- Public transport improvements (railway electrification, rapid transit system, inland waterways, bus modernization, multimodal facilities, school bus/taxi regulation)
- Road infrastructure improvements (national and urban expressway, improvements of existing and missing links)
- Transport demand management (TDM)
- Environmentally Sustainable Transport

(2) Differences from CoMTrans

One of the major differences between Megapolis Transport Master Plan and CoMTrans is derived from their structure plans. The difference in their structure plan results in differences of future total population, population distribution, and hence their respective transport demand forecast. Each of the aforementioned transport master plans is prepared in response to their respective demand forecasted. Based on Figure 2.2.1 below, major differences are pointed as follows:

- In the Megapolis structure plan, major growth areas (under which the key projects are described in later sub-section) are planned all over the territory of Western Province including the present rural parts of the province. However, major development areas and urban centres under CoMTrans are planned mainly within the premise of the determined Colombo Metropolitan Area.
- Megapolis structure plan clusters the planning areas into different economic sub-sectors and functions, including a precise extent of planning area and allocated population as depicted in Figure 2.2.1. On the other hand, CoMTrans does not segregate planning area by nature of

their functions. Therefore, spatial distributions of future job and population change from those of CoMTrans to Megapolis.



Megapolis **CoMTrans**

Figure 2.2.1 Structure Plans of Megapolis Master Plan and CoMTrans

(3) Process of Megapolis Transport Master Plan Formulation

During the preparation of the Transport Master Plan, MMWD established a Transport Sub-committee[2] in which the core team members and members from all key stakeholder organizations actively took part in planned weekly meetings. Suggestions, comments, and proposals of each organizations were given due consideration during the formulation of the Megapolis Transport Master Plan.

The Megapolis Transport Master Plan was officially approved on 2nd December 2016 by the committee, comprised of 3 secretaries from MMWD; Ministry of Transport and Civil Aviation; and Ministry of Higher Education and Highways appointed by the Cabinet Paper No. 16/0774/724/036 dated April 5th 2016. On March 31st 2017, the meeting chaired by the Hon. Minister, MMWD with the participation of the heads of all stake holder organizations and the members of the coordinating committee was held to officially release the Megapolis Transport Master Plan.

2 Refer to Megapolis Transport Master Plan – Final Report 2016, Pages 40-41

2.3 Structure Plan

2.3.1 Concept of the Structure Plan

The structure plan, which forms the basis and framework for detailed planning, was prepared under four planning options outlining the possible solution for the year 2030: 1) polycentric urban development; 2) peripheral townships development; 3) CESMA plan prepared in 2003; and 4) functional zoning of the region with specialised activities.

Option 4, which was selected for Megapolis Master Plan, is based on the concept that cities in adjacent regions work together to create a new urban form that promotes economic opportunity and global competitiveness for each individual city and for the whole nation.

This selection was the evaluation outcome by four (4) working groups of WRMPP to address current issues and anticipated development objectives of Western Region. Inputs from experts and resource persons from relevant institutions were then integrated to improve the regional structure plan option 4 in consideration of demographic/socio-economic framework and development visions. After finalising the structure plan, detail planning works including the Megapolis Transport Master Plan were prepared and submitted to the committee appointed by the abovementioned Cabinet Paper No. 16/0774/724/036 dated April 5th 2016. Therefore, based on the procedure taken by the WRMPP, option 4 was evaluated as a realistic and valid structure plan that suits with Western Region.

With a vision to transform the Western province as the most vibrant, liveable, and cosmopolitan Smart City Region in South Asia having Colombo as the core, the Megapolis Master Plan promotes specialized polycentric and multi-centric spatial structure economic clusters towards the Eastern, Southern, and Northern parts of Western province, spreading the development away from the Colombo core area. This makes the Megapolis structure plan significantly different from the structure plan proposed during CoMTrans.

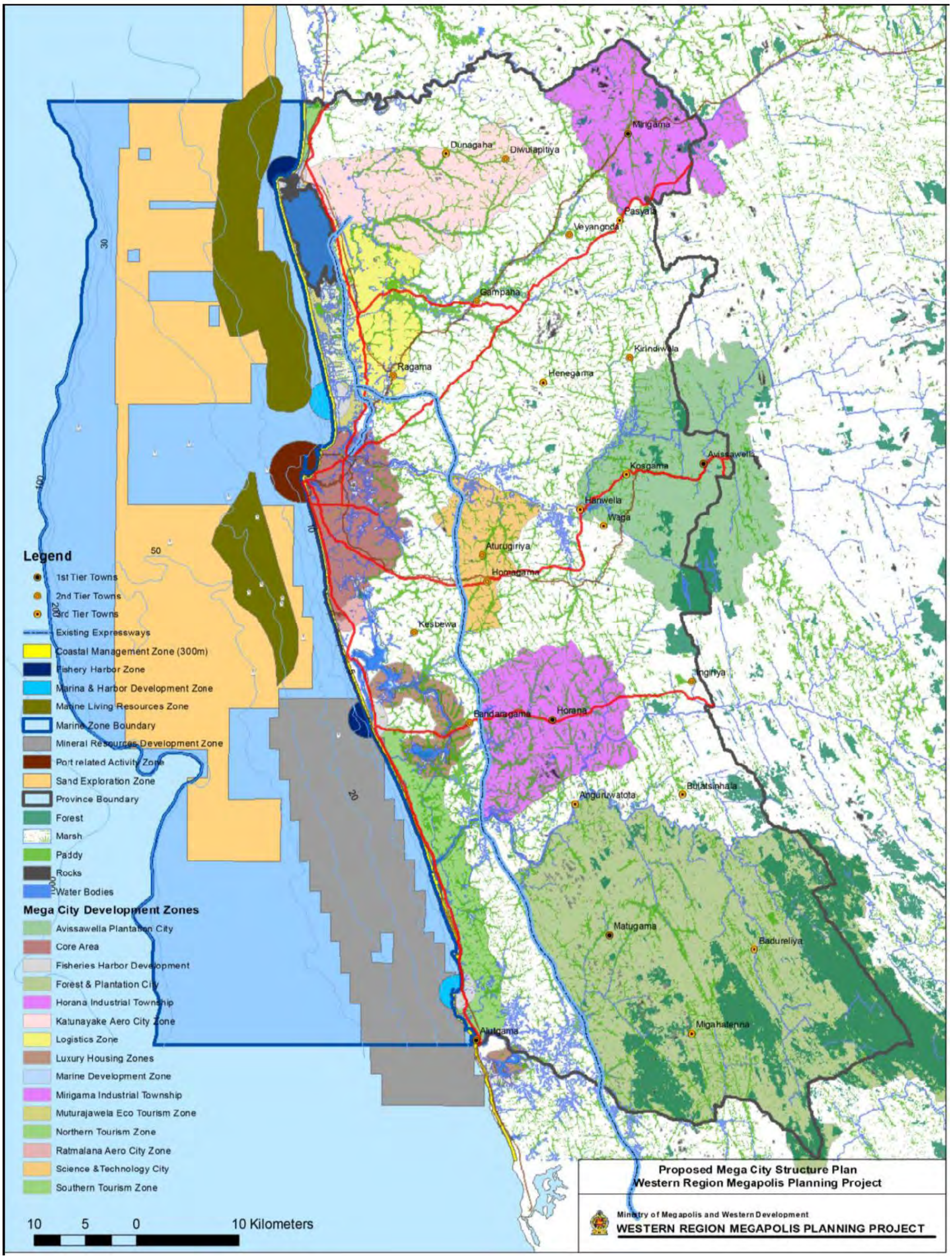
The conceptual framework that governs the formulation of the Megapolis structure plan for the Western province follows the steps below:

- Define an urban edge;
- Densify nodes on periphery of the core area;
- Link with mass transit and improve connectivity;
- Upgrade and densify key existing towns;
- Develop specialised economic clusters.

2.3.2 Proposed Key Development Zones

Following the selected concept of the structure plan, new major growth areas are proposed as shown in Figure 2.3.1. These areas are located away from the Colombo core area and have different functions.

- Aviation Hub – Aero City Zone in Katunayake,
- Industrial townships in Mirigama and Horana,
- Free Port and Logistics corridor between Katunayake and Colombo,
- Science & Technology city corridor between Kaduwela to Homogama,
- Plantation City in Avissawella,
- Plantation & Forest City in Matugama & Baduraliya area,
- Tourism resort areas
- Eco-tourism in Negombo &Muthurajwela and Airport city in Rathmala



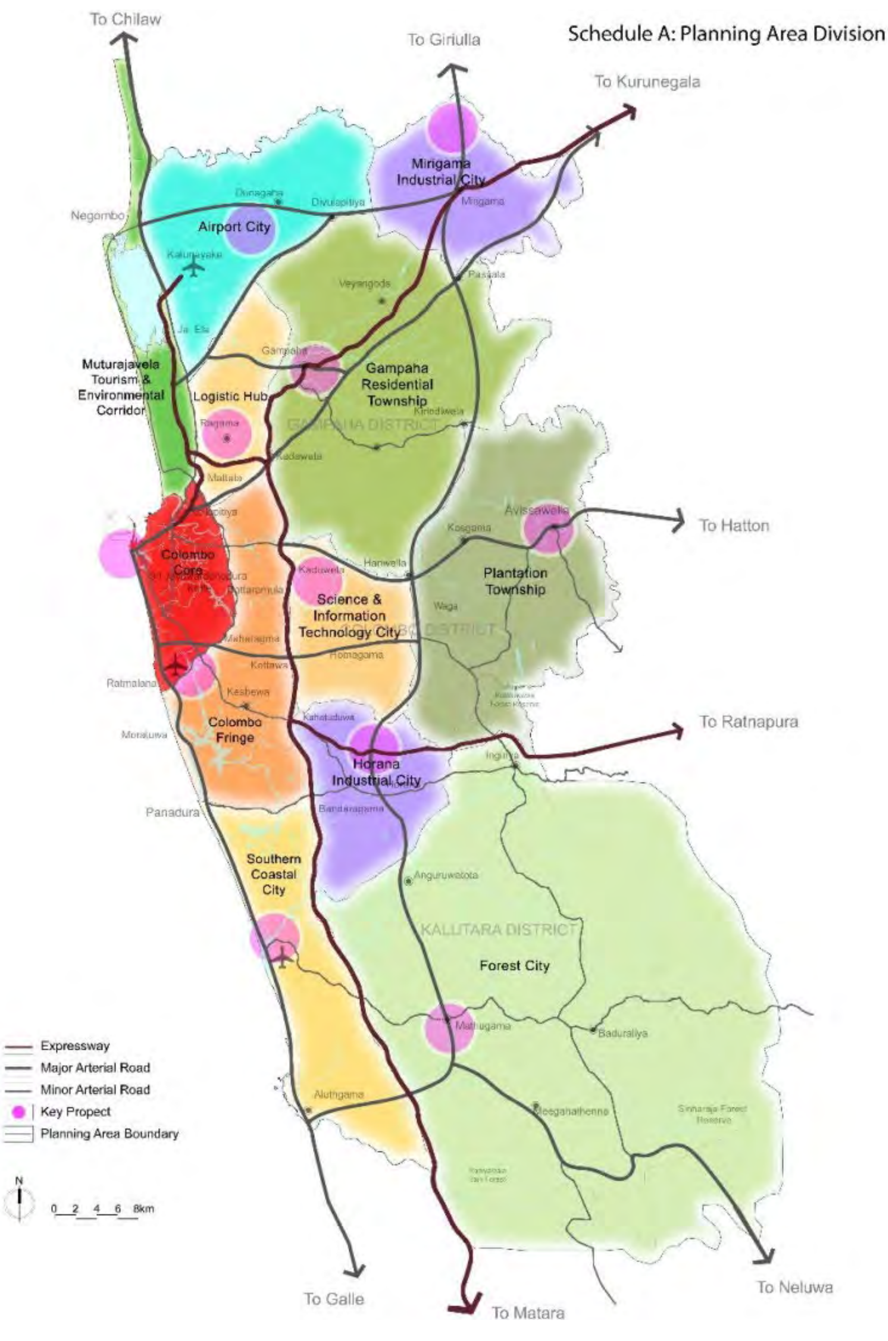
Source: Western Region Megapolis Planning Project, 2016

Figure 2.3.1 Proposed Mega City Structure Plan

2.3.3 Planning Area Division

12 Planning area divisions and 1 Marine zone are defined based on the current land use and the proposed new major growth area, as shown in Figure 2.3.2.

1. **Northern Coastal belt:** It consists with the Muthurajawela conservation area and the tourism zone along the Northern coastal belt.
2. **Aero City:** It consists with the airport zone which includes aviation related business clusters and complement the residential development with supporting facilities.
3. **Logistics Corridor:** It consists with the logistics corridor for warehousing and transshipment facilities with the support of residential areas in the surrounding.
4. **Mirigama Industrial City:** It consists with a new industrial estate for electronic and related clusters, SME clusters and the surrounding new residential development.
5. **Plantation City:** It consists with plantation areas around Avissawella with pockets of residential development. Plantation related businesses shall be the economic driver of this area.
6. **Central Business Distric (CBD):** CBD is the business centre, international gateway and the heart of the region with a very high density development and good quality environment and infrastructure.
7. **Inner Core Area:** Inner core is expected to be the high density commercial and mixed residential development area.
8. **Outer Core Area:** Outer core is expected to be the medium density residential and mixed commercial development area receiving spillover demand from the Colombo core.
9. **Science and Technology City:** It consists with IT Parks, Science Parks and Medical Technology Parks, Nano parks with the support of residential areas and related facilities. It needs to be planned to attract skills to work and live in these areas.
10. **Horana Industrial City:** It consists with 3 new industrial parks and new residential areas with its supporting facilities.
11. **Forest City:** Forest city aimed to create certain types of residential and tourism enclaves among the well protected agriculture and forested area.
12. **Southern Coastal Belt:** The Southern coastal belt will became a tourism area, and will also function as good residential areas, well connected by rail and highway to Colombo.
13. **Marine Zone:** The Marine zone is the sea area along the Western Region where sands, minerals and corals are located. This area needs a special plan to protect the environment while strategically utilizing the resources.



Source: Western Region Megapolis Planning Project, 2016

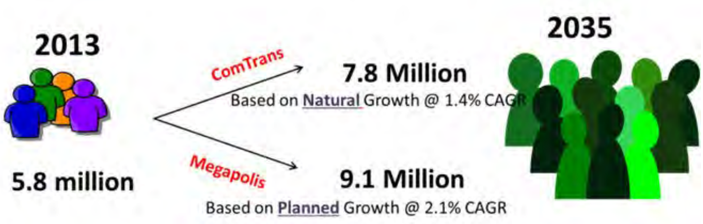
Figure 2.3.2 Proposed New Major Growth Area in Megapolis Master Plan

2.4 Socio-economic Indicators

2.4.1 Estimated Population of Western Province

As of 2013, the population of the Western Province was estimated at 5.8 million, and it is projected to increase to 7.8 million by 2025 with the development anticipated under the Megapolis Structure Plan, and further increase to 9.1 million in 2035 with the planned economic growth targets. This marks an average growth rate of 2.1%, which is higher than CoMTrans's projection in which 2035 population was 7.8 million or at average growth rate of 1.4%, as depicted in Figure 2.4.1.

This population projection was made based on a planned growth scenario that anticipates more in-migration from other regions and from overseas. Even though targeting 9.1 million inhabitants by 2035 requires monumental efforts and commitments by GoSL, this is a national policy that the Survey should follow. The details of the population projection and the distribution of population increase are analysed in the following sub-section.



Source: Megapolis Transport Master Plan

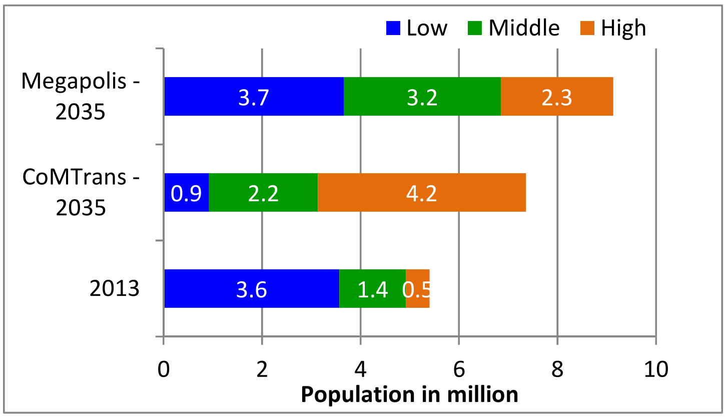
Figure 2.4.1 Estimated Population of Western Province in Megapolis and CoMTrans

2.4.2 Distribution of Estimated Population

(1) Population by Income

Figure 2.4.2 shows the population by income in 2013 and 2035 estimated respectively by Megapolis and CoMTrans. In 2035 under Megapolis, there will be larger share of the low income group (40% or 3.7 million population) and smaller share of the high income group (25% or 2.3 million population) as compared to CoMTrans, which is 13% (or 09 million population) and 57% (or 4.2 million population) for low and high income respectively. From this, it can be inferred that the Megapolis estimation is more practical and achievable.

Through the review, it was understood that, under the Megapolis in-migration concept, a mixture of people from different income backgrounds move into the Western Province, particularly the planning areas outside the CBD, to accept new employments in the airport, port, logistics and manufacturing sectors. For CoMTrans, however, the real household income for all income groups was assumed to increase proportionally with GRDP growth. Therefore, the share of the low income group in Megapolis is estimated to be higher than in CoMTrans.



Note: Low income refers to less than LKR 40,000/month; middle income refers to LKR 40,000-LKR 79,999/month; high income refers to LKR 80,000/month or more

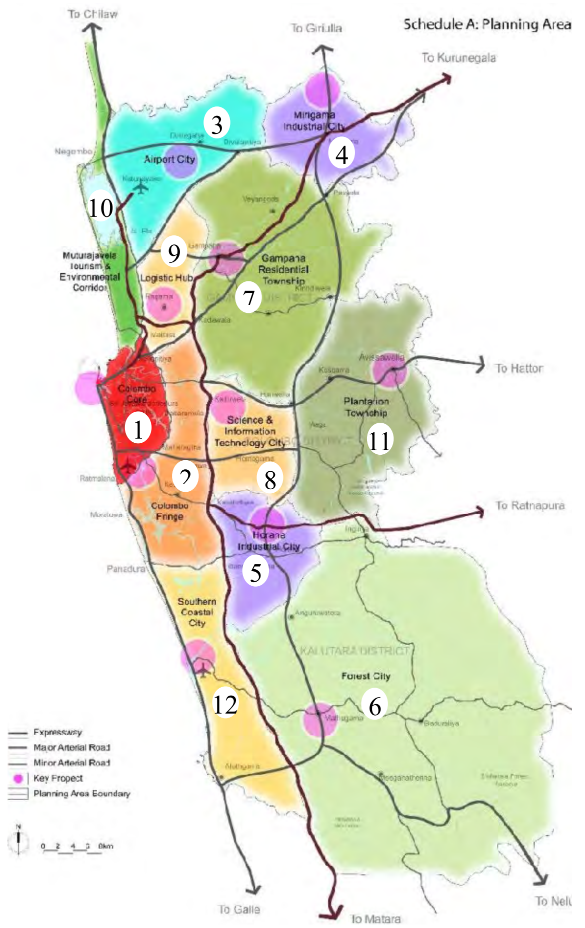
Source: Survey Team based on data from Megapolis and CoMTrans

Figure 2.4.2 Difference of the Population Distribution by Income between Megapolis and CoMTrans

(2) Population by Planning Area Division

Figure 2.4.3 shows the distribution of projected population by planning area in the years 2020, 2025, and 2030, together with the extent of each planning area.

Planning Area		Extent of Planning Area (ha)	Population ('000)		
			2020	2025	2030
1	Central Business district (CBD)	16,465	1,290	1,362	1,443
2	Colombo Fringe	43,713	1,158	1,263	1,383
3	Aero City	31,170	630	748	893
4	Meerigama Industrial City	17,403	185	221	264
5	Horana Industrial City	16,771	247	305	381
6	Forest City	73,215	383	418	459
7	Gampaha Residential Zone	64,139	954	1,060	1,185
8	Knowledge City	15,639	383	440	508
9	Logistics Corriodor	20,263	459	526	617
10	Muthurajawela Tourism Zone	11,048	359	425	508
11	Plantation City	16,690	282	338	407
12	Southern Tourism Corridor	46,390	588	655	737
Western Province		372,906	6,919	7,762	8,786



Source: Western Region Megapolis Planning Project, 2016

Figure 2.4.3 Distribution of Population and Extent of Planning Area

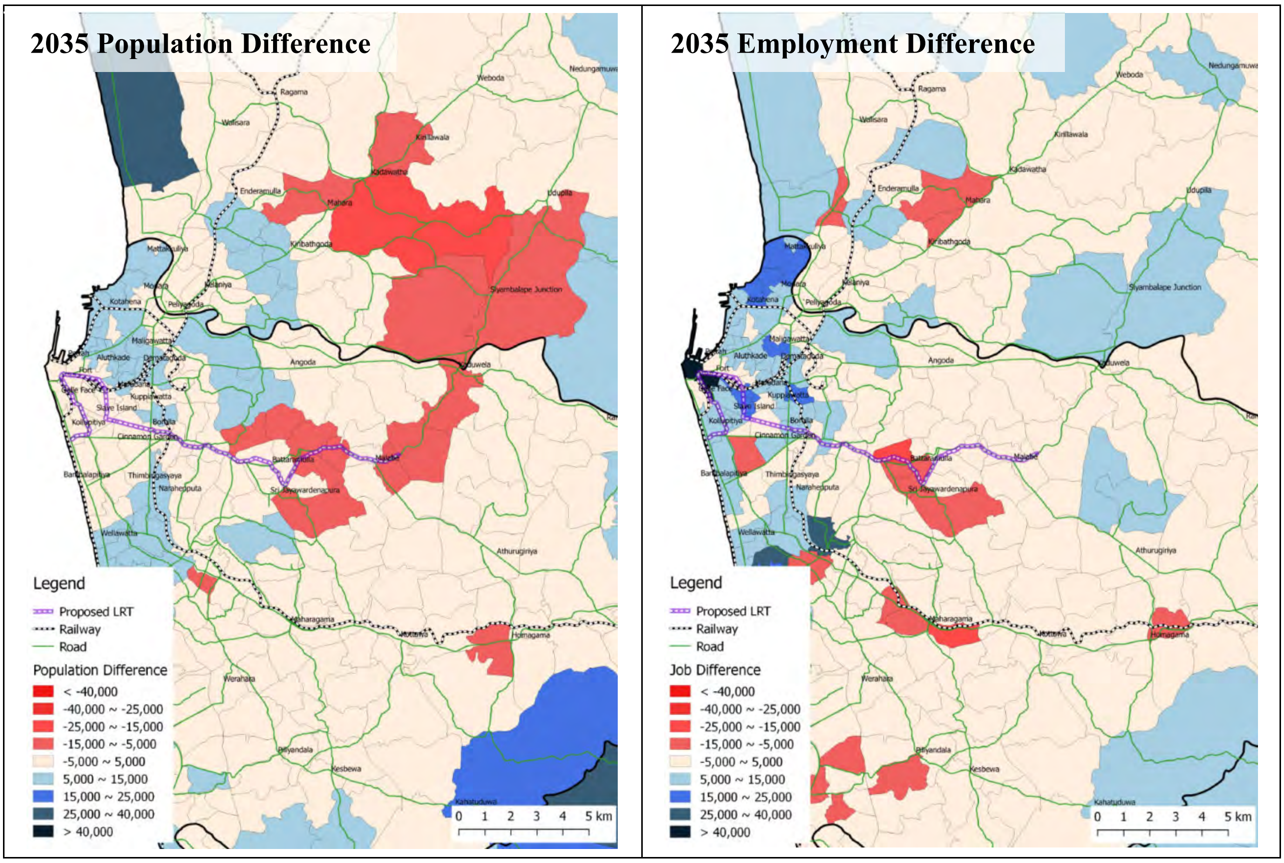
(3) Population by Traffic Analysis Zone (TAZ)

Under different structure plans in the Megapolis and CoMTrans plans, the projected total populations and the spatial population distributions differ. These imply that trip patterns under the Megapolis Master Plan will change, and require suitable transport solution to cope with future travel demand in the Western Province.

Figure 2.4.4 shows the difference of the 2035 population and employment between Megapolis and CoMTrans at the TAZ level, in the vicinity of the planned JICA-LRT corridor in particular: Blue colour indicates higher population and Red colour indicates lower population in Megapolis against CoMTrans. By observing the TAZs around the JICA-LRT alignment, it is understood as follows:

- Population, which is the main attribute of trip generation, does not show noticeable difference between the two master plans for the TAZs along the JICA-LRT corridor. Higher projected population by Megapolis is observed in the Northern and Southern parts of CMC due to the proximity to the employment in the CBD. Therefore, trips made by those CMC residents are mainly within the CMC. In this respect, it is hypothesized that the estimated JICA-LRT passenger volume between Megapolis and CoMTrans are not significantly different.

- Employment, being the main attribute of commuting trip attraction, was estimated to be higher in the CMC under the Megapolis Master Plan. Intuitively, employments in the CMC attract not only the trips from TAZs within CMC, but also some trips from suburban TAZs possibly those along JICA-LRT corridor. However, with the Megapolis structure plan, new employments will be created in each planning area beyond the CBD, such as in the airport, port, logistics and manufacturing sectors, with the population being distributed/allocated to meet the projected employments, as depicted in Figure 2.4.3 above. This restrains the commuting trips between suburban area and CBD. Consequently, the employment increase does not have significant impact on the JICA-LRT passenger estimation.



Note: The value of Megapolis minus CoMTrans, Blue indicates that Mogapolis has higher value and Red indicates that CoMTrans has higher value

Source: Survey Team

Figure 2.4.4 Difference of Population and Employment by TAZ between the Megapolis and CoMTrans in 2035

2.4.3 Gross Regional Domestic Product (GRDP)

Megapolis Master Plan forecasted the Western Province's GRDP at USD 215 billion in 2030 through monumental efforts and commitments to achieve the target of becoming a high income nation. This figure is significantly higher than the CoMTrans' forecast. Moreover, the annual GRDP growth rates in 2020, 2025, and 2030 of Megapolis are 17.5%, 14.0%, and 10.0%, whereas those of CoMTrans are assumed only at 6.5%, 6.0% and 5.0% in respective years based on the International Monetary Fund (IMF) estimate[3]. It is understood that the difference is mainly attributed to the newly proposed Megapolis structure plan and the proposed mega development projects.

Table 2.4.1 depicts the GRDP of the Western Province forecasted by CoMTrans.

Table 2.4.1 GRDP Forecast by CoMTrans 2012-2035

Indicators	2012	2020	2025	2030
GRDP at constant price 2002 (Bil. Rs.)	1,341	2,210	2,971	3,828
GRDP Annual Growth Rate	6.4%	6.5%	6.0%	5.0%

Source: CoMTrans

[3] Refer to CoMTrans Urban Master Plan Final Report, 2014, Page 168

2.5 Components of the Transport Master Plan by Megapolis

The Megapolis Transport Master Plan identified transport issues within the target region. To solve these issues, series of projects were proposed for each transport sub sector as follows.

2.5.1 Public Transport Improvement

(1) Railway Electrification

The following railway lines have been identified for modernization and electrification, including a park and ride facility in selected stations and the relocation of stations such as Wellawatta Station towards Wellawatta Canal. The first three lines are existing lines, while the last two lines are new lines to be added to the railway network.

- Panadura - Veyangoda - Polgahawela (RL-M1): 110 km (85 km within Western Region)
- Kelani Valley (KV) line (RL-M3): 60 km which connects major town centres such as Kottawa, Homagama, Nugegoda Dompe and Avissawella on High Level corridor and also it spans through Baseline road
- Ragama - Negombo line with new airport Access (RL-M2): 26 km
- Kottawa to Horana (RL-NR1) : 22 km
- Kelaniya to Kosgama via Biyagama, and Dompe (RL-NR2): 30 km which gives access to the proposed plantation city at Avissawella and the proposed logistics zone.

As of January 2018, Asian Development Bank (ADB) will commence the Consultancy Service for Feasibility Study and Detail Designed of Colombo Suburban Railway Project (CSRP) with the purpose to prepare feasibility study, detailed design, safeguard planning documents, and bidding documents for four priority railway projects (Maradana to Padukka (Kelani Valley Line)), Colombo to Rambukkana (Main Line), Colombo to Kaluthara South (Coastal Line), and Ragama to Negambo (Puttlam Line)).

(2) Rapid Transit System

The following three technologies, with the capacities in parenthesis, were considered as rapid transit system (RTS),

- LRT or Light Metro (30,000 PPHPD[4])
- Monorail (30,000 PPHPD)
- Bus Rapid Transit (BRT) (13,000 PPHPD)

LRT was decided as the mode by GoSL due to the following reasons.

- There are only a limited number of monorail manufacturers worldwide, which constrains the competitiveness of bidding process.
- With the monorail, it is difficult to expand the lines in the future because other MMWD's proposed RTS lines are LRT, and it is also difficult to increase number of cars for the monorail due to the difficulty of technical configuration.
- Certain sections of MMWD's other RTS lines in the suburban area will operate at-grade, which is impossible to introduce the monorail.
- Unfamiliarity of maintenance and inspection works of a monorail system in Sri Lanka.

[4] PPHPD: Passenger Per Hour Per Direction

The LRT lines that were proposed by the Megapolis Transport Master Plan are listed in Table 2.5.1. Among the 7 lines, RTS-1 and RTS-4 were identified as the priority lines in the master plan to connect the city centre, Sethsiripaya and Malabe area. This conclusion was the same as the concept of the monorail project in the CoMTrans and SKYTRAIN project, which was derived from the corridor analysis based on series of transport surveys.

Two proposed BRT lines are Fort – Moratuwa at Galle road and Fort – Kadawatha at Kandy Road. However, the Transport Sub-committee of the Megapolis Project identified that BRT was not sustainable to meet the demands for the design period of the next 20 years and rejected the proposal.

Table 2.5.1 Rapid Transit System Proposed in Megapolis Transport Master Plan

Line Name	Length	Major Sections	Elevated/at Ground
Green Line (RTS-1)	15km	Fort - Kollupitiya - Bambalapitiya - Borella - Union Place - Maradana	Elevated
Yellow Line (RTS-2)	11.5km	Fort - Maradana - Mattakkuliya - Peliyagoda	Elevated
Red Line (RTS-3)	10km	Dematagoda - Borella - Narahenpita - Kirulapone - Havelock City - Bambalapitiya	Elevated
Purple Line (RTS-4)	10km	Borella - Rajagiriya - Battramulla - Malabe	Elevated/at Ground
Pink Line (RTS-5)	9.6km	Malabe - Kottawa	Elevated/at Ground
Olive Line (RTS-6)	6km	Malabe - Kaduwela	Elevated/at Ground
Ash Line (RTS-7)	13km	Peliyagoda - Kadawatha	Elevated/at Ground

Source: Megapolis Transport Master Plan (Table made by Survey Team)

In addition to the LRT line, Feasibility Study for other RTS lines for PPP Scheme has been implemented since November 29th 2017 and will be completed within one year under MMWD's budget. The Inception Report has been delivered on December 28th 2017 and the first Interim Report is projected to submit at the end of January 2018. It is said that two RTS lines will be selected and investigated in future based on this Feasibility Study.

(3) Inland waterways

Three inland water transport (IWT) lines were identified as the following:

- Wellawatta – Battaramulla Line (IW1)
- Fort – Union Place (along Beire Lake) (IW2)
- Mattakkuliya – Hanwella (along Kelani River) (IW3)

The Wellawatta – Battaramulla Line intersects 6 main roads including Marine Drive, Galle Road, High-level Road, Baseline Road, Nawala Road and Parliament Road, out of which 3 of them are also main corridors as previously mentioned.

(4) Bus modernization

Proposals for bus modernization include developing a new specification for IT enabled smart bus services for the whole region with low floor kneeling and air-conditioning (A/C).

(5) Multimodal facilities

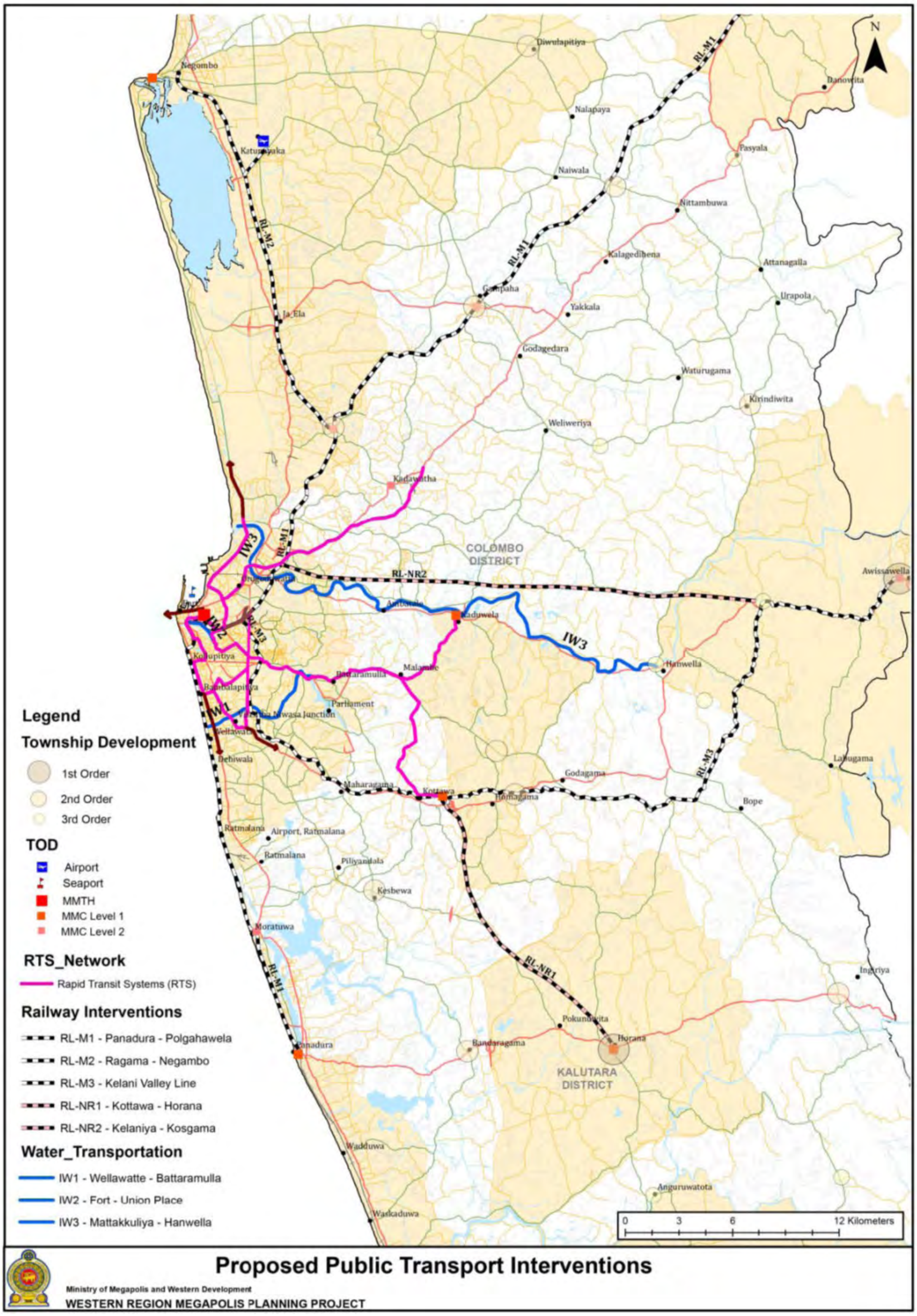
The construction of a main Transport Multimodal Hub is being proposed at Fort/Pettah, in Colombo. Several other transport terminal locations have been identified to be improved as Multi Modal Centres (MMC).

The proposed major MMCs are: Kottawa; Horana; Kadawatha; Kaduwela; Panadura; and Negombo/18th Mile Post. The minor MMCs will be located in Gampaha, Ragama, Moratuwa, Meerigama and Avissawella.

The Feasibility Study for Multi-modal Transport hub (MmTH) at Fort/Pettah: there was the study with technical support from JICA in 2014 and MMWD updated its plan after 2015, currently French Agency for Development (AFD) has started preparing Term of Reference (TOR) for a new Feasibility Study.

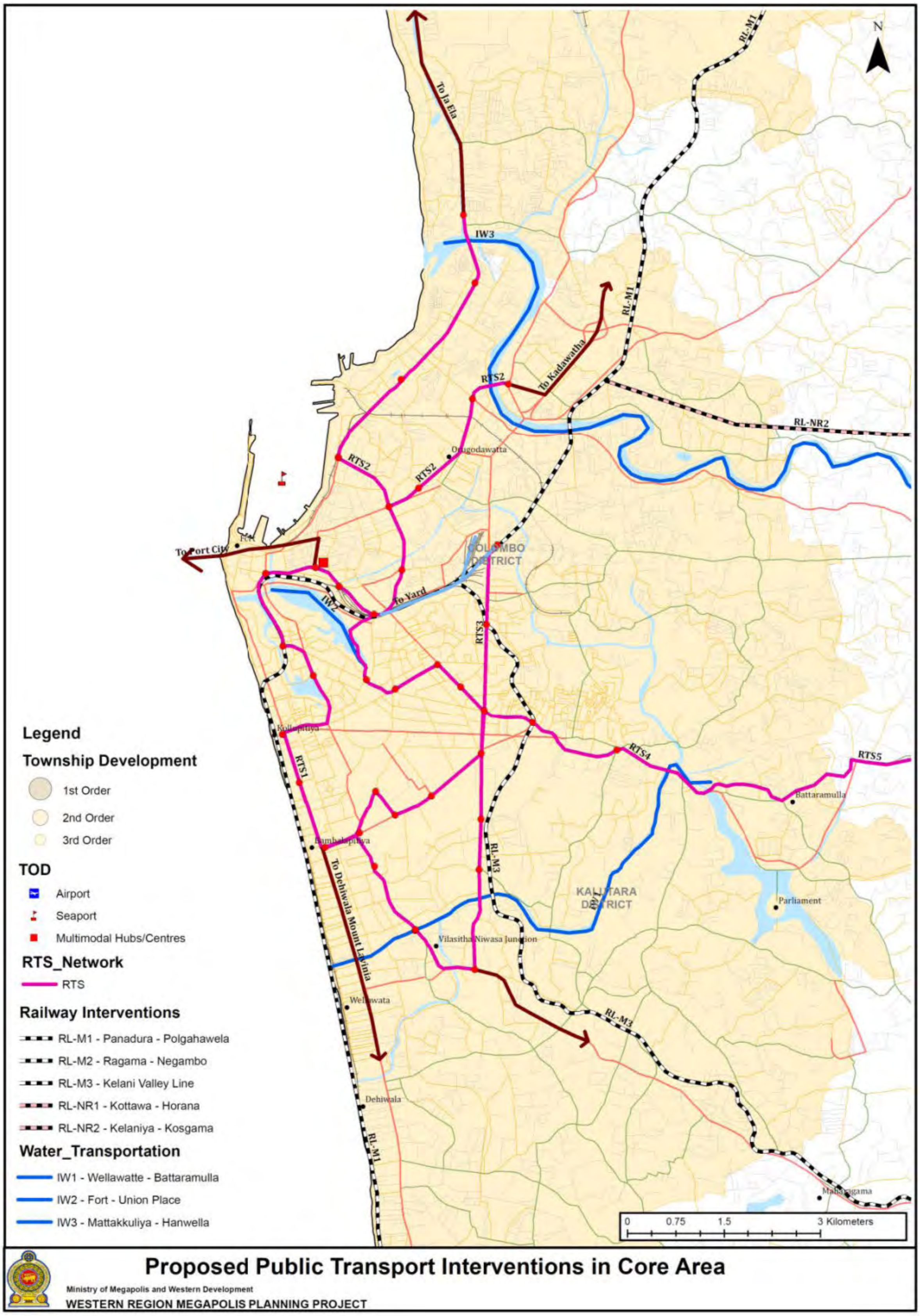
(6) School bus/Taxi regulations

A regulatory mechanism will be developed for School services/Taxi services including operational guidelines, driver/assistant registration, common identification system, etc.



Source: Megapolis Transport Master Plan

Figure 2.5.1 Proposed Public Transport Interventions in Western Region



Source: Megapolis Transport Master Plan

Figure 2.5.2 Proposed Public Transport Interventions in Core Area

2.5.2 Road Infrastructure Improvement

Road infrastructure improvements are proposed under the following categories:

(1) Capacity Improvement of Existing Roads

The following roads have been identified for improvement to meet a new growth plan on the Western region, and transport requirements within the new cities such as Horana, Meerigama and Divulapitiya that are to be developed under the Megapolis Transport Master Plan.

- Horana – Meerigama via Padukka, Kirindiwela
- Negombo – Divulapitiya Meerigama
- Ja-ela - Divulapitiyavia Ekala and Minuwangoda

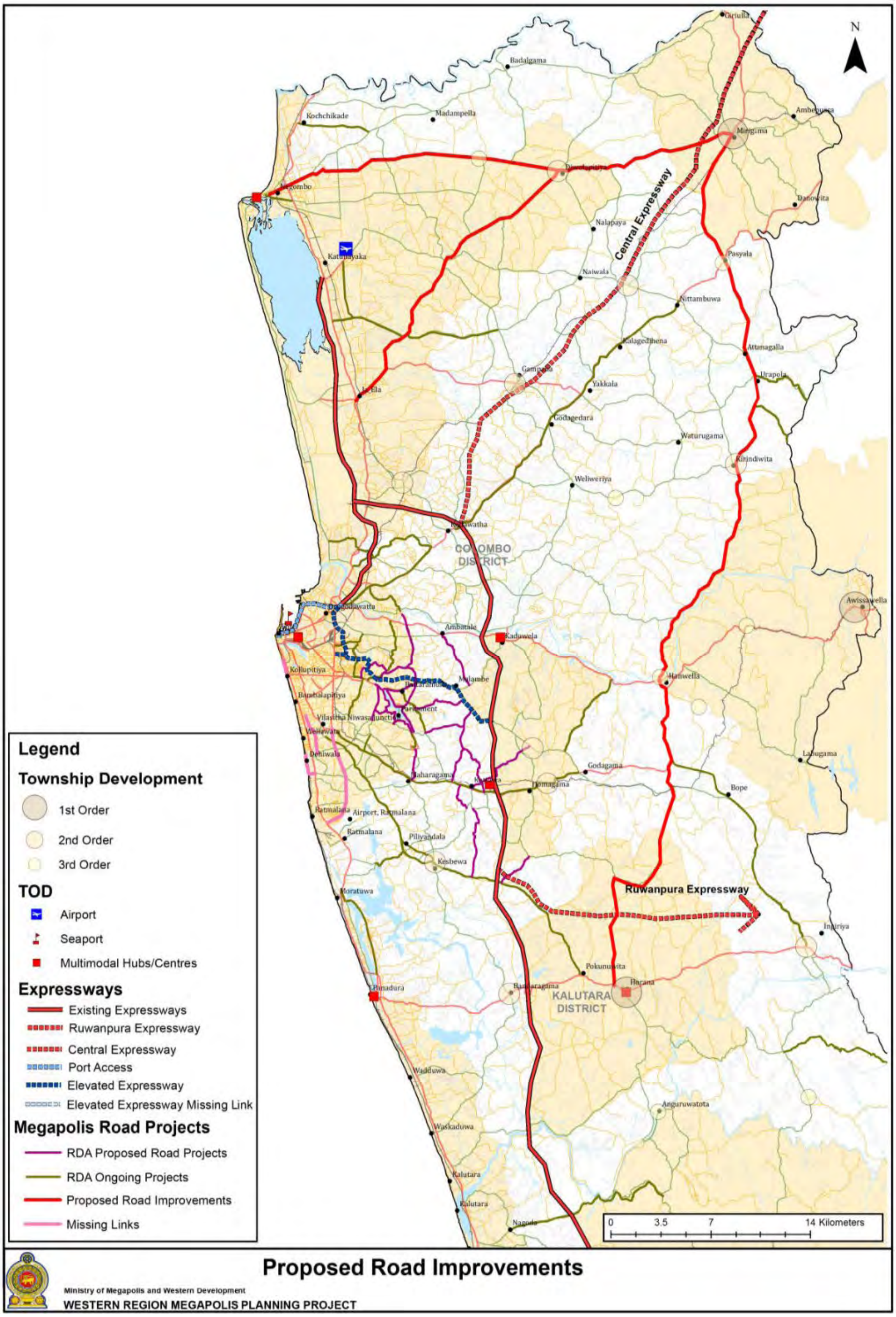
The transport plan also identifies following three missing links within Colombo:

- Marine Drive extension, to Galle Face Chathiya Road and Dehiwela Junction, with consideration of a feasibility of extension to Panadura in long term
- Baseline Road extension, from Kirulapone up to Maliban junction
- Duplication Road extension, up to Kalubowila Hospital Road

(2) Improve the Capacity of Existing Expressway Network / Improve the Expressway Network

The following national and urban expressway expansions are proposed:

- Ruwanpura Expressways
- Central Expressway
- Elevated expressway from New Kelani Bridge to Colombo Port (Port Access Expressway)
- Elevated expressway from New Kelani Bridge to Pore/Outer Circular Highway (OCH) (connects Southern Expressway/Outer Circular Expressway to the inner city providing a quick connection to vehicles arriving on both of the expressways)



Source: Megapolis Transport Master Plan

Figure 2.5.3 Proposed Road Improvements in Western Region

2.5.3 Transport Demand Management

The Megapolis Transport Master Plan proposes the TDM plan, which includes: flexible & staggering work hours; parking management; intersection control; traffic flow management and capacity increase by converting two-way streets to one-way; priority provision for high occupancy vehicles (HOV) on separate lanes; road pricing/road pricing of entry roads to CBD; traffic enforcement through Closed Circuit Television (CCTV) monitoring, etc.

2.5.4 Environmentally Sustainable Transport

The Master plan focuses on maintaining a sustainable environment through: improved facilities for pedestrians; encouragement of bicycle use and introduction of cycle/motorcycle paths; reduction of vehicle emissions; minimizing fuel usage; supply of Compressed Natural Gas (CNG); and establishment of electric charging facilities for buses and other vehicles.

2.6 Key Candidate Projects to be Considered in the Survey

The projects which were proposed in the existing plans need to be taken into considered in the future scenario in this Survey. For example, Megapolis Transport Master Plan proposed many projects as mentioned in above. Based on it, the projects which need to be considered in the Survey was confirmed by GoSL as shown in Table 2.6.1. The list of projects was provided by the NPD on May 17th 2017.

Table 2.6.1 List of Candidate Projects to be Considered in the JICA-LRT Survey

Project Name	Starting Year	Completion Year	Positional Relation with JICA-LRT
Elevated Expressway (New Kelani Bridge to Rajagiriya)	2018	2020	Nearby, Not crossing
Rajagiriya Flyover	2016	2018	On
Cotta Road Flyover	-	-	Crossing
Slave Island Flyover	-	-	On/others
Suburban Railway Electrification (WTC, Maradana)	2017	2022	Crossing
Upgrading KV-line (Cotta Road)	2017	2022	Crossing
Bus Priority Measures (Parliament JCT to Fort via Rajagiriya, Borella and Maradhana)	2017	2019	Along route
Multimodal Hub at Colombo Fort	-	-	On
Sethsiripaya Stage III	-	-	On
Multimodal Centre at Battaramulla	-	-	On
Office Complex at Denzil Kobbekaduwa Mawatha	-	-	On/others
Colombo Financial City Development	-	-	

Source: National Planning Department, May 2017

2.7 Proposed JICA-LRT System

Based on the official request, which MMWD made to the government of Japan under the STEP loan, the targeted JICA-LRT system to be considered has the following characteristics:

- Medium passenger capacity urban transport mode with rail-based system (which is not the so-called tram/street car).
- Totally elevated structure over the road because of limited space along JICA-LRT route within urban area.

Chapter 3 Outline of the JICA-LRT System

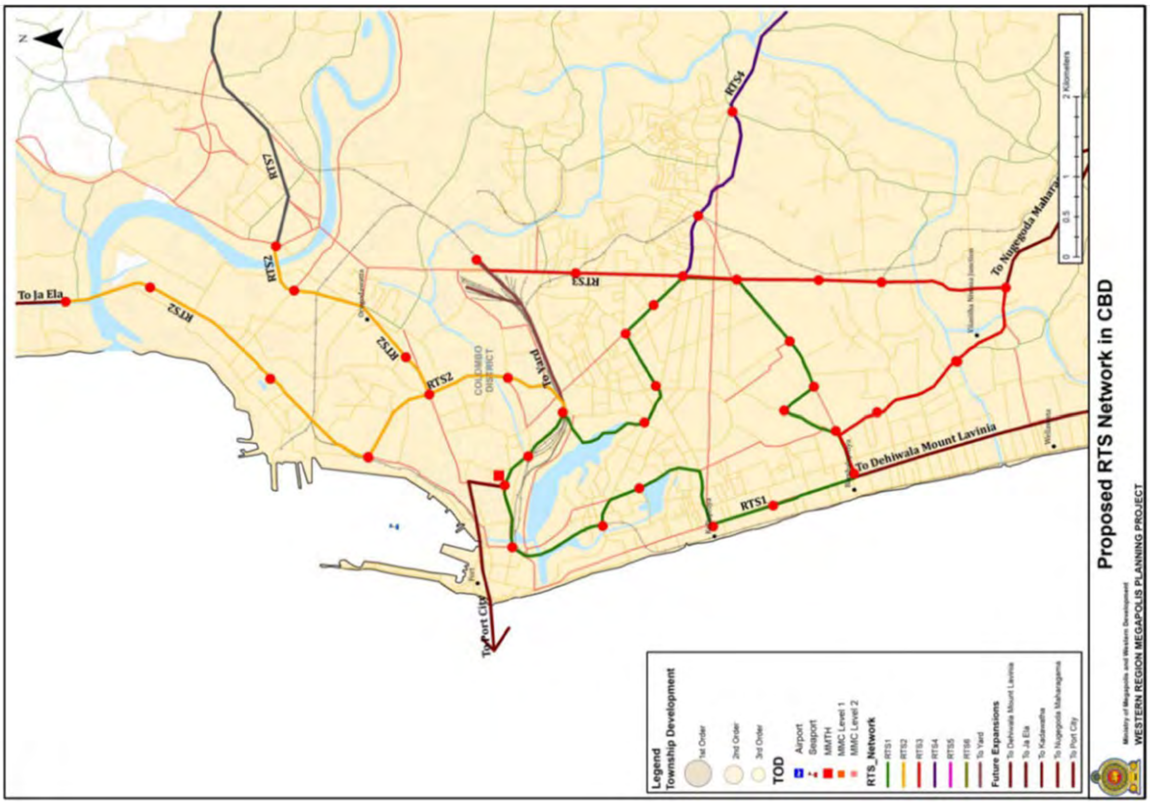
3.1 Connectivity and Proposed RTS System by MMWD

MMWD formulated the RTS System in Colombo Metropolitan area in the Transportation Master Plan (November 2016) as described in sub-section 2.1.2 (2). In the plan, total 7 transport lines were proposed with the entire length 75 km. Figure 3.1.1 and Figure 3.1.2 show details of the RTS routes prepared by MMWD.

The proposed RTS network was formulated based on the minimum spanning tree (MST), an algorithm developed in graph theory. At first, major trip generation and attraction points are identified as candidates of RTS stations as shown in red dots in Figure 3.1.1. These points are connected based on minimum spanning tree algorithm to make an efficient network in terms of the total construction cost. After that, special attention was made to create loops and to connect with other public transport hubs such as railway stations and bus stops which are shown in Figure 3.1.2. The detail of the methodology of RTS formulation can be found in the final report of Megapolis Transport Master Plan

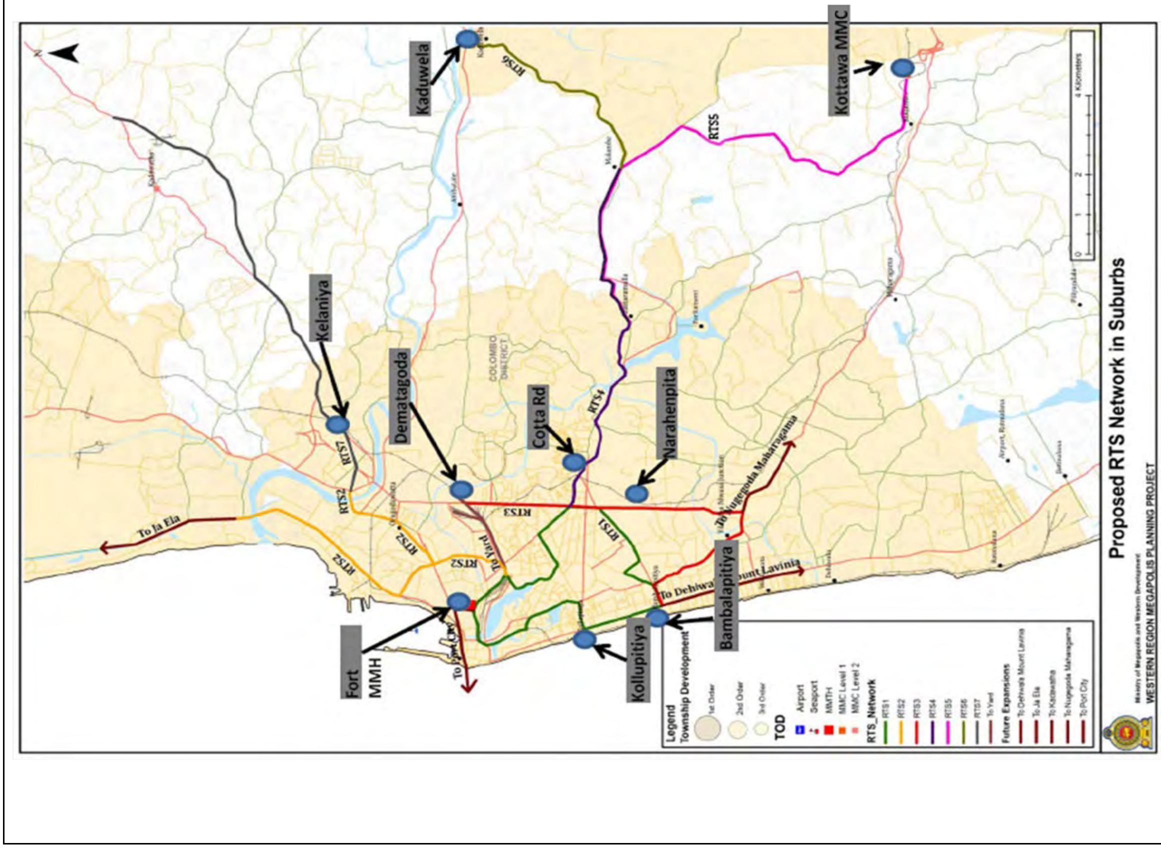
Among the networks of RTS, official request of Japanese ODA loan was made in February 2016 by GoSL for the section covering the Northern part of circular line of RTS-1 and RTS-4, which run along Malabe Corridor (Figure 1.2.1). The detailed alternative analysis of routes is described in Section 3.6. The major points/locations of the line requested are identified as follows.

- Kollupitiya
- Fort
- Maradana
- National Hospital
- Borella
- Rajagiriya
- Sethsiripaya
- Battaramulla
- Malabe



Source: Transport Master Plan (MMWD)

Figure 3.1.1 Major Connectivity Points of RTS in CBD

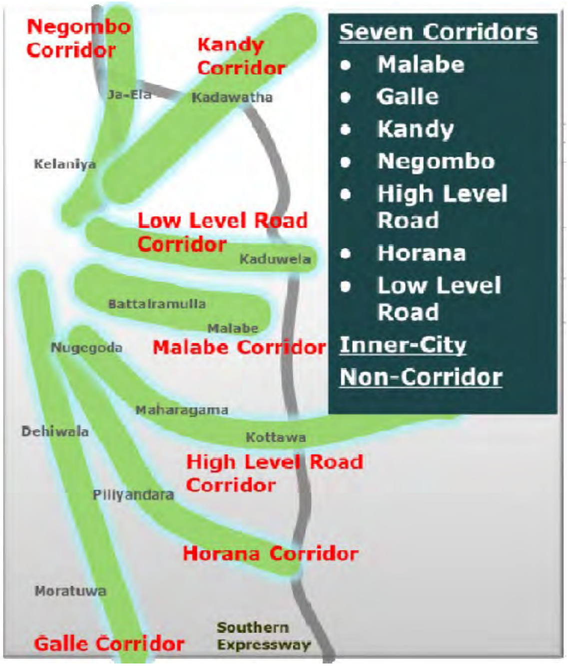


Source: Transportation Master Plan (MMWD)

Figure 3.1.2 Major Connectivity Points of RTS in Whole Network

3.2 Characteristics of Malabe Corridor

Malabe Corridor is one of the 7 major corridors which connect the city centre and the suburban areas (Figure 3.2.1). In CoMTrans study, corridor analysis was conducted for the 7 corridors. From the result of corridor analysis, Malabe corridor was identified as the highest priority corridor for the installation of middle sized elevated train system in CoMTrans study. In Megapolis Transport Master Plan, the route connecting Fort and Malabe (RTS-1 and RTS-4) was prioritised in the implementation plan for RTS.



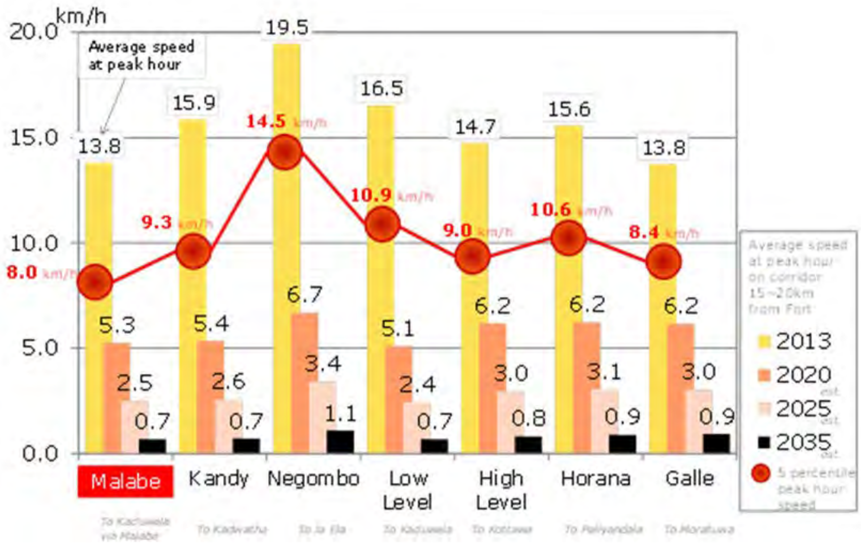
Source: CoMTrans Screen Line Survey, 2013

Figure 3.2.1 Major 7 Corridors Analysed in CoMTrans Study

In the corridor analysis, the characteristics of Malabe corridor are recognised as follows.

(1) Lowest Travel Speed

Malabe Corridor and Galle Corridor had the lowest peak hour average travel speed of 13.8 km/h. The five percentile lowest travel speed of the Malabe Corridor was 8.0 km/h which is the lowest among all transport corridors. If any solution was not implemented, the travel speed will be decreased to 5.3 km/h in 2020 as shown in Figure 3.2.2.

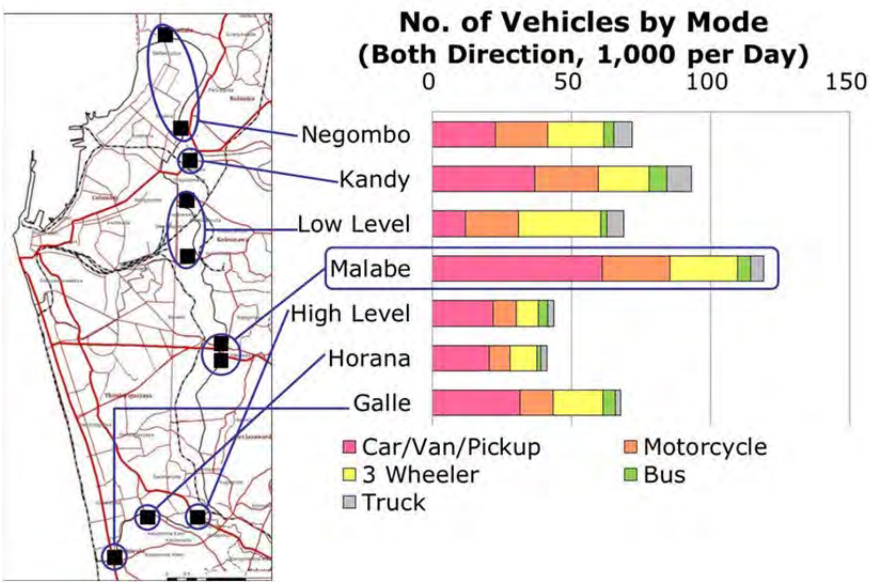


Source: CoMTrans Travel Speed Survey for 2013 and CoMTrans estimates for 2020, 2025 and 2035 (Do Nothing Scenario)

Figure 3.2.2 Peak Hour Travel Speed of Major Transport Corridors

(2) Highest Traffic Volume

Malabe Corridor has the traffic highest volume, 121,400 pcu/day/direction, followed by Kandy Corridor and Galle Corridor as shown in Figure 3.2.3. In peak hour, traffic amount for 5,100 pcu/hour is loaded to the capacity 4,400 at the CMC boundary on Malabe Corridor.



Source: CoMTrans Screen Line Survey, 2013

Figure 3.2.3 No. of Vehicles by Mode (Both Directions, 1,000 per Day)

(3) Highest Private Car Mode Share

Malabe corridor has the highest modal share of private cars, which reflects that the level of public transport service is lower than other corridors. To increase the public transport mode share, reliable public transport with enough capacity is required.

(4) Relocation of Government Offices

New administrative and commercial capitals are envisioned along Malabe corridor, including Sethsiripaya stage III and the Defence complex in Akuregoda. Therefore, both residential and employee population are expected to increase in the rate higher than natural growth.

(5) Narrow Road Section

Although, Malabe Corridor has total 10 lanes at CMC boundary (Parliament road and Kotte Road), narrow section has less than 20m. Therefore, solutions such as BRT cannot be selected because of the limited road space.

(6) Absence of Railway Service

Malabe, Horana and Low Level Road corridor have no railway based public transport system. If existing railway operates, the corridor capacity can be increased by improving the service level (speed and frequency) of railway. But, this kind of solution cannot be selected in the corridor without existing railway.

Table 3.2.1 and Table 3.2.2 show the summary of corridor analysis as reference.

7 corridors were analysed from the viewpoints of “Land Use and Environment”, “Urban Development Potential”, “Transport Infrastructure” and “Transport Issues” (Table 3.2.1). In general, most of the corridors have increasing population which is caused by ribbon development. Although the traffic volume is reached to capacity, resettlement for road widening is difficult because of the land price along the corridors.

Table 3.2.2 summarises the traffic condition of 7 corridors which was identified based on the series of traffic survey in CoMTrans Study. The average travel speed in peak hour is less than 20 km/h and peak hour loading percentage of bus exceeds 100%.

Table 3.2.1 Summary of Review for 7 Corridors

Corridor	Land Use and Environment	Urban Development Potential	Transport Infrastructure	Transport Patterns and Issues
Malabe	◦ New administrative and Commercial Capitals in Battaramulla ◦ Population increase from 2001 ◦ Sensitive areas (Town Hall and Diyawannawa Lake)	◦ High Population growth is expected ◦ Relocation of Ministry of Defence ◦ Sethsiripaya II government office ◦ New Universities at IT-Park/Malabe	**◦ No Railway line** ◦ 10 lanes at CMC boundary (Parliament road and Kotte Road) ◦ Narrow section less than 20m	◦ Highest modal share of private car ◦ Congestion at CMC boundary
Galle	◦ Ribbon development with high population density ◦ Several urban centres with universities ◦ Tourist spots along coast area	◦ Limited areas are remained for urban development around existing urban centres	◦ Railway Line (Coast Line) operates 92 trains/day/bothway ◦ 4 lanes at CMC boundary ◦ Narrow section less than 20m ◦ Marine drive to be extended	◦ Railway and Bus covers passenger in peak hour ◦ Highest modal share of railway ◦ Bottleneck at Dehiwala flyover ◦ Difficulty of resettlement for road widening
Kandy	◦ Ribbon development with high population density ◦ Several urban centres	◦ Potential of industrial/mixed development at Kelaniya and Kadawatha associated	◦ Railway Line (Main Line) operates 116 trains/day/bothway ◦ 6 lanes at Kalani bridge ◦ 2-4 lanes in other section	◦ Railway and Bus covers passenger in peak hour ◦ Largest passenger by Bus and Rail ◦ Inter-provincial

Corridor	Land Use and Environment	Urban Development Potential	Transport Infrastructure	Transport Patterns and Issues
		with highway construction (CKE, OCH)	◦ OCH to be connected with A01 ◦ Northern Expressway in FS phase ◦ CKE to be opened	passenger and freight traffic ◦ Difficulty of resettlement for road widening
Negombo	◦ International Airport ◦ Ribbon development ◦ Few urban centres	◦ Industrial development around the airport ◦ Potential of commercial development around CKE	◦ Railway (Puttalam Line) operates 30 trains/day/bothway ◦ 4 lanes in 20m width ◦ CKE connecting airport and Kelani	◦ Railway and Bus covers passenger in peak hour ◦ Highest number of heavy trucks ◦ Difficulty of resettlement for road widening
High Level Road	◦ Ribbon development ◦ About 4 urban centres	◦ Potential of mixed development at Kottawa associated with highway construction (OCH) ◦ 3K project around Kottawa by UDA ◦ Several commercial development	◦ Railway (KV Line) operates 18 trains/day/bothway ◦ 4 lanes in 12-18m width	◦ Difficulty of resettlement for road widening and double tracking of railway ◦ Urban traffic and long distance traffic are mixed
Horana	◦ Ribbon development ◦ Wetland ◦ About 1 urban centre	◦ No major urban development plan	**◦ No Railway line** ◦ Mainly 2 lanes with 12m width	◦ Limited space for public transport
Low level Road	◦ Ribbon development ◦ Low ground along Kelani river ◦ About 1 urban centre	◦ Potential of mixed development at Kaduwela associated with highway construction (OCH)	**◦ No Railway line** ◦ Mainly 2 lanes with 10~12 width	◦ Difficulty of resettlement for road widening ◦ Limited space for public transport

Source: Survey Team based on CoMTrans Technical Report 6

Table 3.2.2 Traffic Condition of 7 Corridors

Corridor	Peak hour road traffic (pcu/hour)	Hourly capacity (pcu/hour)	Peak hour travel speed	Peak hour bus load factor	Peak hour passenger volume (pax/hour)		Daily directional traffic volume (vehicles/day)	
Malabe	5,100	4,400	14 km/h	138%	23,500	Private: 9,600 Bus: 13,900	121,400	Bus: 4,800
Galle	2,900	2,300	13 km/h	101%	22,900	Private: 5,500 Bus: 9,500 Railway: 7,900	67,600	Bus: 3,790
Kandy	4,400	3,300	16 km/h	116%	37,200	Private: 8,700 Bus: 14,100 Railway: 14,400	95,200	Bus: 6,300
Negombo	4,000	4,400	19 km/h	142%	33,800	Private: 10,000 Bus: 9,400 Railway: 14,400	73,300	Bus: 3,400
High Level Road	2,000	2,300	16 km/h	106%	15,100	Private: 3,700 Bus: 9,900 Railway: 1,500	44,100	Bus: 3,100
Horana	2,200	2,300	19 km/h	106%	11,100	Private: 3,700 Bus: 7,400	41,300	Bus: 1,600
Low Level Road	2,900	2,200	18 km/h	171%	14,300	Rpivate: 6,500 Bus: 7,800	70,700	Bus: 2,400

Source: Survey Team based on CoMTrans Technical Report 6

3.3 Alternatives of Rail-based Mode

In Sri Lanka, under its stable economic growth, traffic on the road network from modes such as private car, buses, and moto-bicycles is projected to increase rapidly. Currently, about 1 million people are entering to the centre of Colombo daily, and this causes severe traffic congestion in the city centre and surrounding road networks. It is predicted that the existing road networks may not be able to handle future traffic demand.

Without having a rail-based public transport network, especially JICA-LRT on the Malabe Corridor, the following losses are predicted in future:

- Declining efficiency of economics activities due to large travel time loss from traffic congestion
- Increasing air pollution due to heavy vehicle transport
- Increasing noise pollution due to road transport
- Increasing road traffic accidents

Therefore, for both environmental and social aspects, it is desirable to implement JICA-LRT.

In the official request for JICA-LRT, elevated structure (viaduct) is considered to be applied along the entire route. The Survey Team determined that it is reasonable from the points of views described in the Table 3.3.1, in comparison with different structural options.

Table 3.3.1 Alternative Analysis on Different Structural Options for JICA-LRT

Items	Underground	On Street (Existing Roads)	Elevated (Viaduct)
Required length (km) for construction	Less than Elevated option (Required length (km) for construction between major connectivities such as Fort, Borella and Malabe can be shortened by straight line due to underground construction)	More than Elevated option (The route should pass on the exiting road)	As original
Construction cost	Highest of Civil Cost (approx. 3 times or more than elevated option)	Civil structure itself is not expensive. However, civil costs for intersections at SLR railway crossing and land acquisition costs will be higher than other options	As for civil cost: it is middle among the options As for total cost: it will be most economical option
Structural characteristics	With expensive "Tunnel Boring Machine", construction period can be reduced on ground, however, it is difficult for installation of machine into underground, and of construction of underground stations.	Structure can be simple; however, many flyover sections are required as complicated structures at SLR crossings and road intersections.	Numbers of piers on route is required.
Workability	Proper underground soil conditions and underground information for buildings is highly required. Highest difficulties exist in construction.	Easiest for construction on street but enough road space is required.	Construction of piers is installed at road median. It is necessary to grasp utility pipes at the installation point of piers. Traffic management during the construction is required.
Traffic problem	Occurs at the underground station area with large space.	Reduce existing road space and accelerate traffic congestion by car	Need traffic management (lane configuration, parking space) due to decrease width by piers
Natural condition	High risk of impact on groundwater and ground settlement	Noise and vibration impacts to residents living near roadside.	Noise and vibration are generated from the top of viaduct during operation
Land Acquisition, Resettlement	Need to confirm the rights of land in underground	Land acquisitions are required.	Land acquisition is most limited among the three options.
Landscape	Large structure happens at the entering of underground station, from/to underground near deport.	New scenery by tram on street	Consideration of appearance of elevated structure is required.
Safety	Consideration for evacuation at the time of flood or emergency stop	Consideration of residents and vehicles crossing at intersections	No crossings of residents and vehicles, relatively safe to operate
Noise and vibration	Although it is less than other options, vibration is transmitted to buildings depends on underground condition.	The largest noise and vibration affect residents living roadside compared to other options.	There are some noise and vibration to buildings with same height near the viaduct.
Total evaluation	**Not recommended** due to high construction cost and lack of technical familiarity	**Not recommended** since not enough space on ground and significant land acquisition required	**Recommended** Most desirable option in this project

Source: Survey Team

There was a discussion of a hybrid "viaduct" and "on-street" option for the route. However, land acquisition is an issue because the proposed route will be located in urban and/or sub-urban area, even on the east site of the project area (Malabe). In order to avoid and minimize land acquisition, it has been decided to adopt the elevated option for the entire route.

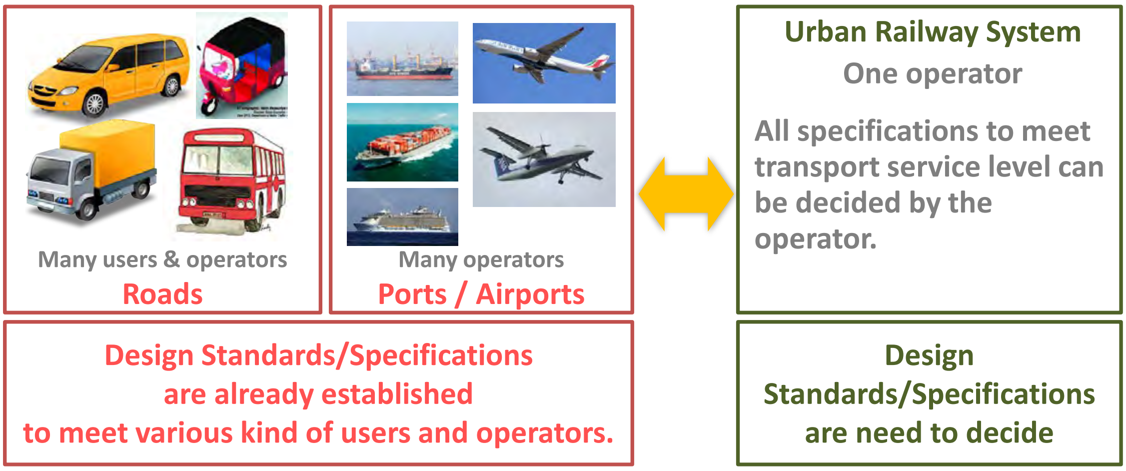
3.4 Basic Understanding of JICA-LRT System Development

At the beginning of this Project, the Survey Team emphasised the characteristics of urban railway development compared with other infrastructure development.

In general, roads, ports and airports are the infrastructure used by various types or sizes of vehicles/ships/airplanes. In other words, many operators and users can use these infrastructures. Therefore, in designing these structures, the design standards and specifications of roads/ports/airports should be regulated based on the cars/ships/airplane. The designers should just follow the regulated design standards and specifications for the infrastructure.

On the other hand, urban railway system is provided for one operator. It means that the operator can decide any specifications to meet their desired service level into the urban railway system.

Based on the understanding of the aforementioned characteristics, the Survey Team recommends that the project owner, MMWD, shall decide the service level and design principles for JICA-LRT in Colombo. After several discussions with MMWD, the service level and design principle are summarised in the next section of 3.5.



Source: Survey Team, presented at the Kick-off meeting on 28th February 2017

Figure 3.4.1 Characteristics of Urban Railway System Development

3.5 Design Concept

3.5.1 Design Principle

Based on a series of discussions with MMWD officials, the service level (design principle) of JICA-LRT in Colombo shall be selected as follows:

- Develop a User-Friendly JICA-LRT System

It implies that JICA-LRT should highly consider the principle of "think first for the JICA-LRT users". There are three important considerations for JICA-LRT users that should be incorporated in the planning and design stages.

- Comfort
- Safety
- Reliability

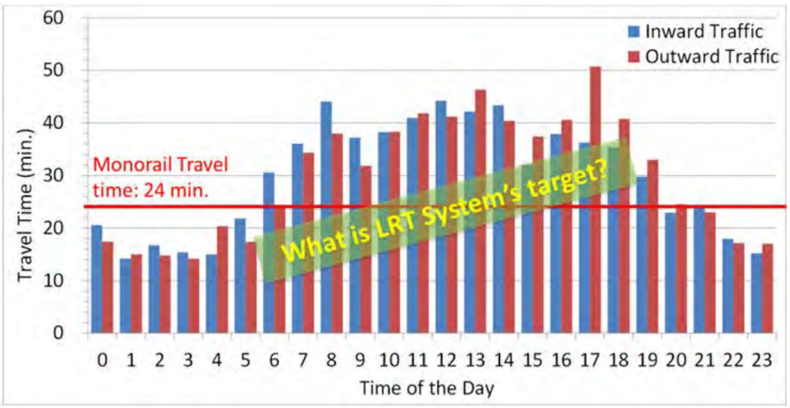
Comfort for users aims to provide enough "space in a car" for not only seating and but also standing during operation as well as boarding/alighting at the stations. The "comfortable seat" provision is another point of consideration. Materials and cleanliness is an important issue for users including disabled people. "Smooth ride" is ensured by engineering challenges to set the proper horizontal and vertical alignment without any occurrence of sudden vibrations and gallops. Enough space in a car helps the users to ride on/off with ease even during congested periods.

Safety is also an important issue, without any doubt. It is highly necessary to manage "train operation" not only for normal operation but also special events such as emergencies and evacuations. "Security" in the train and/or station is also an important point to be prepared. Note that access for medical treatment and firefighting are also considered during station development.

Reliability is the crucial point to be ensured for encouraging users. As JICA-LRT is running in an urban area, busy business people and time conscious people are potential users. Therefore, "shortening travel time" as well as "punctuality" are key points when designing the alignment, selecting rolling stock, and planning of signalling and telecommunication.

As the reference for shortening travel time and punctuality, evidence acquired from the SKYTRAIN study in 2013 was used. Figure 3.5.1 shows travel time by car between Fort Lake House Junction and Battaramulla Junction: Blue colour bar indicates the travel time from suburban areas to the centre of Colombo at different hours in a day, while the Red colour bar is out-flow away from the centre of Colombo. The results show that it requires 30 to 45 minutes to drive from Battaramulla JCT to Fort between 6 to 9 o'clock in the morning, and 50 minutes to return back to Battaramulla at around 5 o'clock in the evening.

Once JICA-LRT starts operation, the travel time can be constant during the day and can be shorter than travel by private car for most hours of a day, as shown in Figure 3.5.1 below (red horizontal line is SKYTRAIN's travel time). In a similar manner, JICA-LRT will discuss the target time between Fort to Sethsiripaya, which can be used for public awareness and facilitation.



Source: CoMTrans Travel Speed Survey, 2013

Figure 3.5.1 Travel Time and Target Time (Fort Lake House JCT – Battaramulla JCT)

In addition, the aforementioned principles cannot be applied without consideration of minimizing and avoiding negative impacts for both environmental and social aspects. The items that should be minimized and avoided as negative impacts for JICA-LRT in Colombo are described as follows:

- Environnemental Aspects: Construction impacts, vibration, noise
- Social Aspects: Land acquisition, livelihood impacts

3.5.2 Review of Rolling Stock

(1) Introduction

Since JICA-LRT is planned to be implemented as the Project by Japanese ODA Loan under STEP, Japanese products and system are to be applied to rolling stock to meet STEP conditions. In addition, GoSL needs to ensure the competitiveness at the bidding stage, it is recommended that specifications of rolling stock adopts standard model of commuter rolling stocks available in the market. As listed below, the following section shows the list of LRT urban railway systems throughout the world under major rolling stock manufacturers. In general, a lower price per car can be expected when the procurement volume is more than 100 cars.

- Japanese Manufacturers[5]
  - Hitachi
  - J-TREC
  - Kawasaki
  - Kinki Sharyo
  - Nippon Sharyo
  - Hitachi Rail Italy: HRV Trains, Driverless Metro
- Manufacturers in other countries
  - Alstom: Metropolis Metro
  - Bombardier: Movia, Innovia Metro
  - China Railway Rolling Stock Corporation (CRRC)
  - Siemens: Modular Metro, High Floor LRT

(2) Description of LRT Rolling Stock from different manufacturers

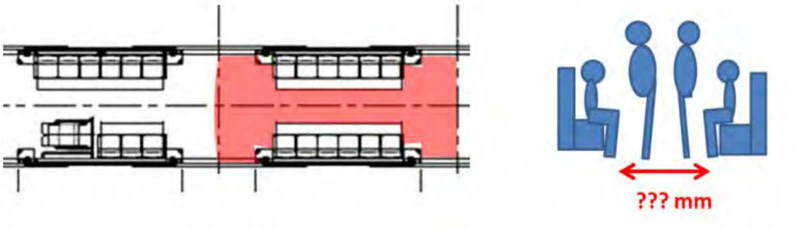
If a special size is requested, it will result in additional fees and time for development. It is recognized that LRT has two general categories. One category is “street car”, which has a narrow width of less than 2.65m due to running at grade on an existing road/street lane (sometimes operating in mixed traffic with other vehicle traffic). The other category is commuter trains, which has the width of 2.65~3.2m for running on dedicated track, especially elevated track.

International rolling stock manufacturers will be described as 1) Japanese Manufacturers and 2) Manufacturers in Other Countries, with the corresponding list of where the rolling stock is used in urban railway systems throughout the world. As shown in the next section, the world standard

[5] This “Japanese Manufactures” is synonymous with “A Japanese company(ies)” defined in “Operational Rules of Special Terms for Economic Partnership (STEP) of Japanese ODA Loans” below https://www.jica.go.jp/english/our_work/types_of_assistance/oda_loans/step/c8h0vm000053zae9-att/operational_rules.pdf

size of LRT rolling stock has a width of 2.65~3.2m and a length of 18~24m. The Survey Team recommends applying this world standard size rolling stock for JICA-LRT in Colombo.

One of the essential sizes is the “width of standing area”, which secures enough space for moving passengers for boarding/alighting between standing people. It affects the comfortability for inside the car, as well as the saving of time at the station by the smooth boarding/alighting.



Source: Survey Team

Figure 3.5.2 Image of Standing Area (Red Hatched Area) and Essential Size

1) Japanese Manufacturers

In Japan, there are many commuter trains running in urban areas, and most of the rolling stock is made by Japanese manufactures. General Japanese commuter rolling stock size is 2.75m ~ 2.95m in width and 18m ~ 20m in length.

Source: Survey Team

Figure 3.5.3 Tokyo Metro Marunouchi Line

Source: Survey Team

Figure 3.5.4 Osaka Subway Chuo Line

The detailed specifications for typical types operated by Japanese railways are shown in Appendix 2 (Tokyo Metro, Osaka Subway, Hanshin Electric Railway, JR East).

Many rolling stocks made by Japanese manufacturers are operated in the world such as in Egypt, England, Philippine, Singapore, USA and so on. An example of a rolling stock in operation outside of its category is the Manila LRT Line-1, Type 1200 series. This rolling stock has two bodies connected with articulated type bogie, with 2.59m in width and 13.21m in length for one body. Originally this articulated type is designed for street car, but in Manila, this rolling stock is used for LRT with dedicated track.

Source: Survey Team

Figure 3.5.5 Manila Line-1, Type 1200

<u>Hitachi Rail Italy (Italy)</u>

Hitachi Rail Italy delivers the "HRV Trains" to Milan (Figure 3.5.6), Naples, Madrid, Washington, and Los Angeles, etc. with 2.7m ~ 3.2m width and 17m ~ 22m length. They also deliver the "Driverless Metro" to Rome, Milan, Brescia, Copenhagen, Taipei and Honolulu etc. with 2.65m ~ 3.05 width and 12m ~ 20m length. Note that Hitachi Rail Italy is the company of the Hitachi group (Japan).

Source: Hitachi News Release 2017/2/13
(http://www.hitachi.co.jp/New/cnews/month/2017/02/0213a.html)

Figure 3.5.6 Milan Line 1&2

2) Manufacturers in Other Countries

Siemens AG (Germany)

Siemens has their rolling stock series named "Modular Metro", which they have delivered throughout the world including to Bangkok (Figure 3.5.7), Taipei, Kaohsiung, Nurnberg, Oslo, and Vienna. The width of this rolling stock series is 2.74m ~ 3.20m, and its length is 18.0m ~ 23.8m. In special cases, they also deliver a rolling stock with a 2.65m width.

Source: Survey Team

Figure 3.5.7 Siemens "Modular Metro" LRT in Bangkok BTS

For the North America market, they developed the S200 series LRT with high floor (Figure 3.5.8). They delivered the S200 series to the cities of Calgary and San Francisco, which has a width of 2.65m and a length of 35.7m ~ 41.5m when 2 cars are connected. The S200 series is an LRT rolling stock operating as a commuter train.

Source: Wikipedia (https://en.wikipedia.org/wiki/Siemens_S200)

Figure 3.5.8 Siemens S200 Series

Alstom (France)

Alstom has delivered their "Metropolis Metro" rolling stock to Barcelona, Amsterdam (Figure 3.5.9), Santo Domingo, Lima, and Panama City among others. The width of the "Metropolis Metro" is 2.7m ~ 3.2m, and its length is 18m ~ 24m as described in their catalogue, which also notes that other widths and lengths available on a case-by-case basis.

Source: UrbanRail.Net (http://www.urbanrail.net/eu/nl/ams/amsterdam.htm)

Figure 3.5.9 Alstom "Metropolis Metro" LRT in Amsterdam

In the special case for Shanghai Line 5, they delivered the rolling stock with a 2.6m width and 19.44m length (Figure 3.5.10).

Source: Wikipedia
(https://upload.wikimedia.org/wikipedia/commons/e/eb/Line_5_Train.JPG)

Figure 3.5.10 Shanghai Line 5

<u>Bombardier (Canada)</u>

Bombardier has delivered their "Movia" series to London, Bucharest, Delhi, Singapore (Figure 3.5.11), Shanghai and Toronto, among others, with 2.9m ~ 3.2m of width and 16.3m ~ 23.5m of length. In a special case, they also delivered a rolling stock with 2.629m width and 17.77m length to London. They have another series with a different driving system of Linear Motor Metro, named "Innovia Metro", delivered to Vancouver, Kuala Lumpur (Figure 3.5.12), Beijing, and New York, etc. with 2.4m ~ 3.2m width and 16.5m ~ 17.6m length.

Source: Survey Team

Figure 3.5.11 Singapore Downtown Line

Source: Wikipedia
(https://upload.wikimedia.org/wikipedia/commons/d/d9/Yosri042005PuteraLRT.JPG)

Figure 3.5.12 Kuala Lumpur Kelana Jaya Line

China Railway Rolling Stock Corporation (CRRC) Zhuzhou Electric Locomotive Co., Ltd.

Chinese Standard Commuter trains consists of 3 types. Type-A is 3.0m width and 22m length, Type-B is 2.8m width and 19m length, and Type-C is 2.8m width and 16.8m length.

Source: Wikipedia
(https://upload.wikimedia.org/wikipedia/commons/1/19/Wuhan_metro_line_2_train.png)

Figure 3.5.13 Wohan Metro Line 2 (Type-B)

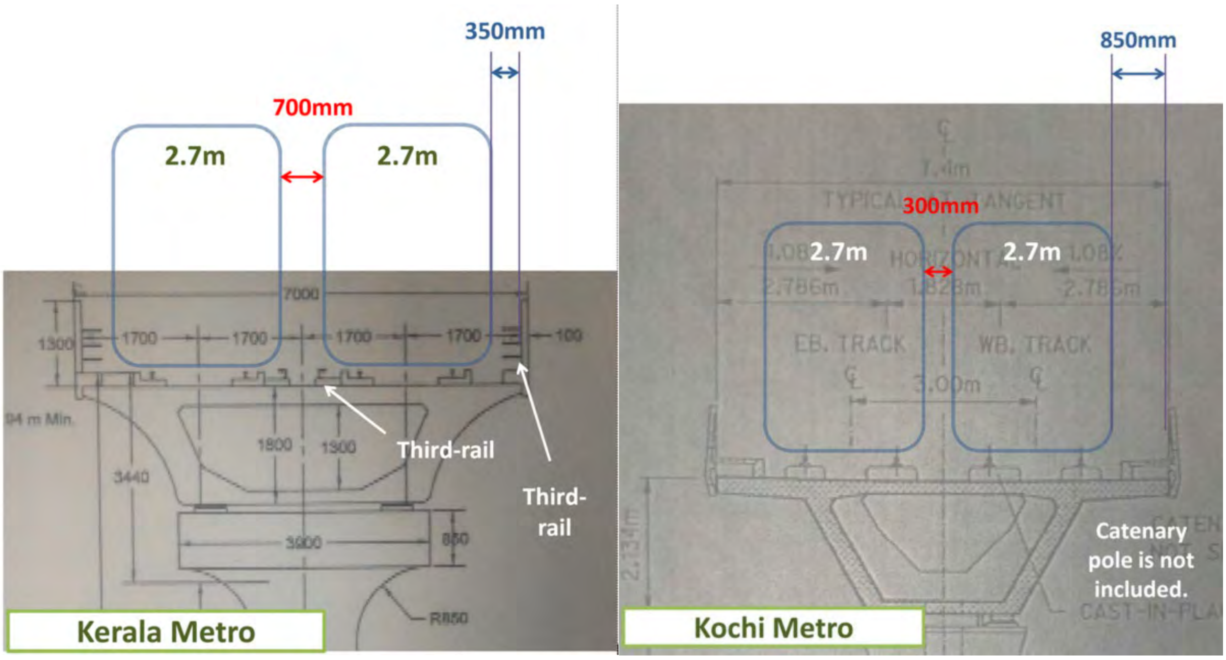
(3) Review on Viaduct Width in other Projects

The Survey Team reviewed the viaduct sizes which were designed recently for other projects (Kerala Metro, Kochi Metro in India). The figure below shows the difference between two design diagrams.

In the case of Kerala Metro, the double track viaduct width is only 7.0m, using the third rail system, and space between rolling stocks is 70cm. On the outside of the viaduct, there is only 35cm space between rolling stock and viaduct edge. This means that it is impossible for daytime inspection during train operating hours. If daytime inspection is required, there should be at least 70cm of space between rolling stock and viaduct edge.

In the case of Kochi Metro, the double track viaduct width is 7.4m, using catenary system. The space between rolling stocks is only 30cm. This space does not consider the window opened, so that conductor cannot confirm the behind over the window by his own eyes.

In the case of inspecting track or cable along the viaduct at operating time, there should be 70cm space for inspector way outside viaduct. At the same time, this space can be used for evacuation when electricity is shut down. Evacuation path for passengers is through the rolling stock side door and then walk to the nearest station.



Source: Survey Team

Figure 3.5.14 Kerala/Kochi Metro Viaduct Cross Section

3.5.3 Recommended Structures and Curvature

(1) Width of Viaduct and Right-of-Way

As described in Section 3.5.2, the recommended viaduct width (8.4m) for JICA-LRT was discussed. The major components of the viaduct are summarised as below:

- Construction Gauge (3.65m) and Rolling Stock Gauge (2.85m)
- Distance between centre of tracks (3.55m)
- Third Rail for Power Supply

- Installation space for Signalling Cable
- Passage for Inspection and Evacuation (w = 0.6 to 0.8m in both outside from construction gauges)
- Parapets (walls) at both sides of viaduct for Noise Protection (w = 0.15m)

MMWD decided to apply third rail system to JICA-LRT because it matches the urban landscape with slim appearance viaduct without any additional poles and catenary lines. Since the maximum train operation speed of JICA-LRT is considered as not more than 80km/h, third rail system can be applied. In addition, it can save the installation cost of the power line as well as maintenance cost because of simple structures and easy for maintenance. Since DC 750V is required (not DC 1,500V), some more substations need to be prepared. In case of future extension lines, it is recommended not to apply level crossing with roads since this urban railway system needs to safety and speedy operation as well as to avoid any disturbance with road traffic flow.

Note that this width (8.4 m) is for the straight section. In the case of curved sections, it is natural that the end of the car body deviates to the outside, and that the centre of the car body deviates to inside against the centre of track. Therefore, the construction gauge should be expanded at the curve section. In relation of this phenomenon, the width of the viaduct should also be expanded at the same size of the deviations. Expansion of the construction gauge width is approximated using the following formula:

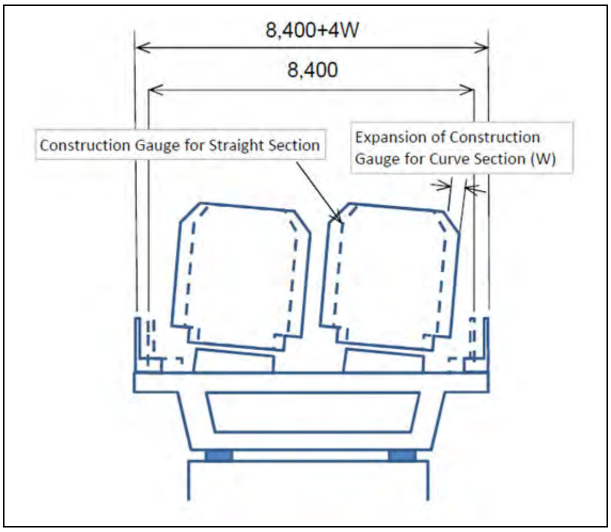
W = 22,500/R
where; W: Expansion of the Construction Gauge (mm)
R: Curve Radius (m)

The expansion of the construction gauge for each curve radius is shown in Table 3.5.1. Table 3.5.1 depicts the diagram of the explanation for the difference between curvature section and straight section.

Table 3.5.1 Expansion of the Construction Gauge for each Curve Radius

Curve Radius R (m)	Expansion of the Construction Gauge * W (mm)	Expansion of viaduct width for single track W1 (mm)	Expansion of viaduct width for double track W2 (mm) = 4xW
80 (reference)	281	560	1,124
100	225	450	900
125	180	360	720
130	173	346	692
150	150	300	600
175	129	258	516
200	113	226	452
250	90	180	360
300	75	150	300
400	57	114	228
500	45	90	180
600	38	76	152
700	33	66	132
800	29	58	116
900	25	50	100
1,000	23	46	92

* Expansion of construction gauge should be required in the radius of 1,000m or less. Source: Survey Team



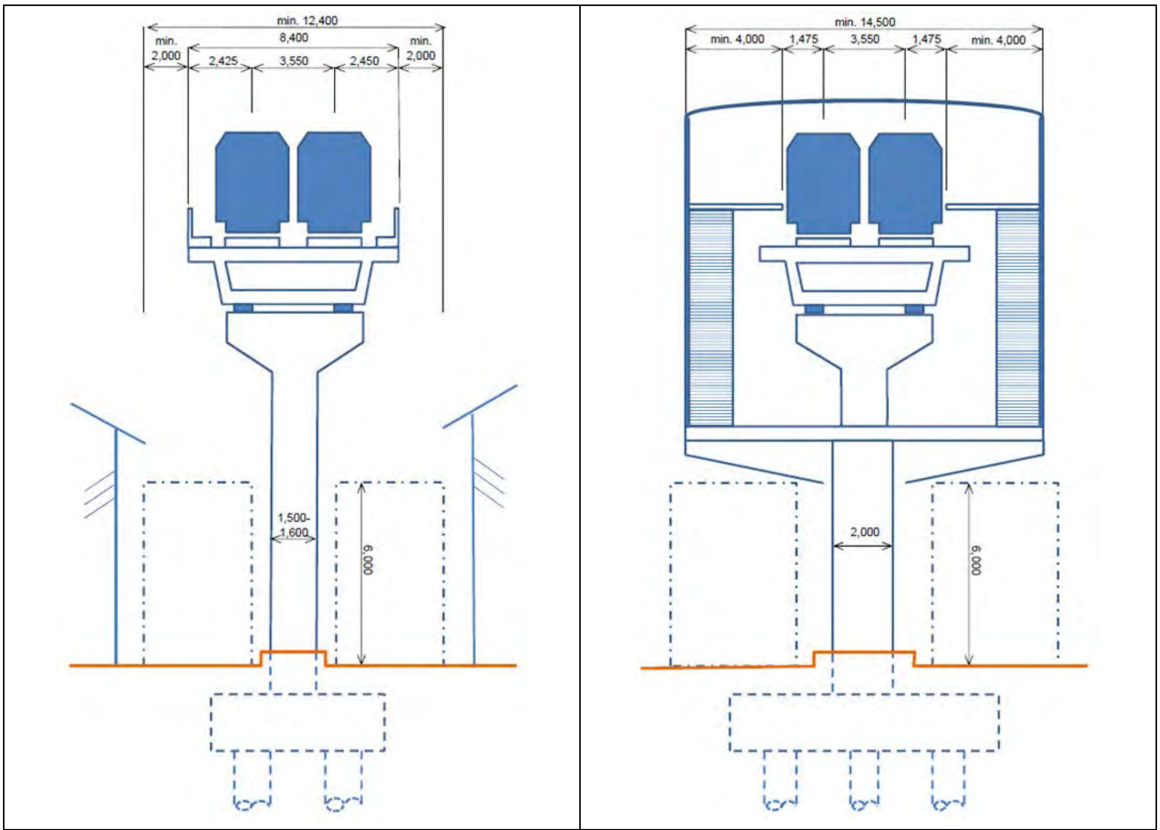
Source: Survey Team

Figure 3.5.15 Expansion of Construction Gauge and Viaduct Width

Right of Way (ROW) means the space to be acquired by the Project owner before starting the construction. It is preferred and proposed that the standard width of ROW be set at 2.0m for each side from the outside of the viaduct to building lines. This 2.0m space is used as: construction space for substructure and viaduct; and evacuation space using a ladder car to building close to the viaduct in case of fire. This width can be negotiable if the local conditions allows during detailed design stage.

Combining the viaduct width (8.4m at straight section) and 2.0m width for both sides, the standard width of ROW is set as 12.4m at cross section.

Figure 3.5.16 shows the typical cross section at straight sections of the viaduct as well as general station; dimensions are in mm. Note that stations are designed in accordance with the local condition, so that it will be discussed and determined in the preliminary design stage. The platform width of 4.0m is the general size that consists of the stairs to the concourse.



(a) Typical Cross Section between Stations | **(b) Typical Cross Section in Station**

Figure 3.5.16 Typical Cross Section

(2) Minimum Horizontal Curve Radius

Sharper curves at the corner may require smaller land acquisition and resettlement. However, sharper curves should have to be considered carefully due to the following issues:

- Speed restriction for safety train operation
- Squeak noise from rail and wheel
- Higher construction cost by applying head-hardening rail (high wear-resistance)
- Higher maintenance cost by wearing of rail and wheel
- Additional equipment for reduction of noise, rail and wheel wearing

Based on the above issues, extremely sharp curves are not recommended for a steel-wheel-based railway system. From various international experiences of railway operators and general understanding by rolling stock manufacturers' standard catalogue described in Section 3.4.2, the Survey Team recommends that the minimum horizontal curve radius be set at 100m. It is observed that additional development costs and countermeasures are required if minimum curve radius is lower than 100m, and may result in limited number of bidders.

(3) Speed Restriction for Train Operation at Curves

Based on the Japanese railway operator's practices, the speed restriction for safety operation at various curves is summarized as follows (Table 3.5.2):

Table 3.5.2 Speed Restriction at Curves

Curve Radius (m)	Speed Restriction
> 400	-
350-400	80-85 km/h
300-350	75-80 km/h
250-300	65-75 km/h
200-250	60-65 km/h
150-200	50-60 km/h
100-150	30-50 km/h
80-100	20-30 km/h
60-80	15-20 km/h

Source: Survey Team, based on Regulations of Japanese Railway Operators

In practice, the actual speed restriction at curves is decided by not only the curve radius, but also by other factors such as transition curve length, applied cant and allowable cant deficiency. It is recommended that safe design parameters for cant and transition curve be considered to realize the design principle as discussed in Section 3.5.1.

3.6 Route Plan

3.6.1 Route Alternatives: Proposed JICA-LRT Route, Previous SKYTRAIN (Line 1 & 2)

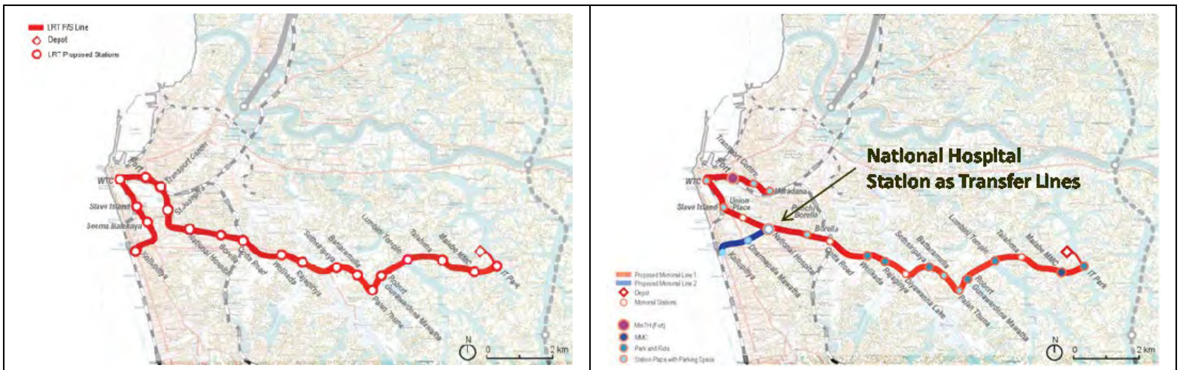
As prescribed in Sections 1.2 and 3.1, the agreed-upon JICA-LRT route covered under the Survey consists of the Northern part of RTS-1 and RTS-4 as proposed in the Megapolis Transport Master Plan; It is called the proposed JICA-LRT route for the Project (Alternative-1) in the letter issued by MMWD titled the Survey Route (LRT/JICA/PLN/05) on 23rd May 2017.

On the other hand, both GoSL and JICA confirmed in September 2016 that the portions of the northern part of RTS-1 which are different to the SKYTRAIN trace will be examined in the Preparatory Survey to determine the optimum alignment for the Project.

Basically, both routes have the same section that stretches from Depot (IT Park and Malabe) to the centre of CMC where the national hospital and town hall are located. It is worth noting that during the meeting on 1st March 2017, MMWD members explained to the Survey Team about their previous internal research on the route for the RTS-4 and the Northern part of RTS-1 (for which communications were made by letters; ref. 685R7411-004 and PMU/TDP/TP/05). For the RTS-4, the route between Denzil Kobbekaduwa Mw. via Pannipitiya Road proposed by SKYTRAIN was selected instead of New Kandy Road, in consideration of the road width. For the Northern part of RTS-1, the proposed JICA-LRT route was changed at Ward Place because the potential users are expected to decrease due to shifting of Department of Immigration & Emigration, as well as the engineering difficulties along the narrow road between the National Hospital buildings. It has been confirmed that the pedestrian deck will be constructed to connect directly from the National Hospital Station to the National Hospital building. The only difference is the connection of route between the National Hospital Station and the Kollupitiya Station.

The Proposed JICA-LRT route runs on Union Place and T.B. Jayah Mw., and crosses SLR lines near Maradana to Fort, and then reaches to Kollupitiya.

As for the Previous SKYTRAIN Route, one is running on Union Place to Slave Island then to Fort/ Maradana (Line-1), while the other is connecting for only a short section between National Hospital and Kollupitiya (Line-2). Each JICA-LRT route is mapped and shown in Figure 3.6.1.



(a) Proposed JICA-LRT Route (Alternative 1) | **(b) Previous SKYTRAIN (Alternative 2)**

Source: Survey Team

Figure 3.6.1 Route Image for JICA-LRT System

Table 3.6.1 shows the result of the integrated evaluation of the alternatives, including network concept, train operation, and environmental and social considerations.

Based on the results, it is recommended the Proposed JICA-LRT Route (Alternative 1) as the most preferred option for JICA-LRT in Colombo. Further details of the route, such as alignment will be examined with several options at the concerned areas.

Table 3.6.1 Comparison of Alternative Routes

Route Plan Item	Alternative 1 Proposed JICA-LRT Route	Alternative 2 Previous SKYTRAIN Route (Line-1 and Line-2)
Network Concept	• Contributing to alleviating traffic congestion along the Malabe Corridor in Colombo Metropolitan Area (CMA).	
	• Forming a part of entire RTS network by MMWD transport master plan, having expandable line.	• Different network concept of the RTS network (i.e. difficult to form RTS-1 as circular line and to connect with other RTS lines).
Train Operation	• One direction operation; simple	• Two lines with different operations; complicated
General conditions for Demand	• 2020: 1.00 • 2035: 1.00	• 2020: 0.98[6] • 2035: 0.95
	• Alternative 1 has slightly larger passenger volume than Alternative 2. • Not high demand is estimated in Line -2	
General conditions for Demand	• Higher potential to attract users along the line (demand can be expected) • Although some sections have longer distance, alignment improvements shorten travel time to acquire more customers.	• Necessary transfer to Line-2 at National Hospital reduces the number of passengers who need transfer. • It is detour route for the costumer of SLR mainline to Battaramulla.
Social/Environmental	• New two new sharp curves* require land acquisition of commercial buildings. • Integration with new development of SLR is expected.	• Around the National Hospital Station as transfer lines, there are possibility of additional land acquisitions and intersection improvement. • No relation with new development area around Transport Centre (SLR).
Pros	• Easy for operation. • Higher demand can be anticipated.	• Less impact on the commercial buildings at those two locations.
Cons	• Impacts on the commercial buildings at those two locations*.	• Complexity in operation of two lines
Total Evaluation	**Recommend**	-

*: One point is the junction with S. A Dharmapala Mw. and Sri James Pieris Mw. Another is Junction with T. B. Jayah Mw. and Union Place.
Source: Survey Team

3.6.2 Proposed Route/Alignment[7]

(1) Technical Parameters applied to Alignment Planning

Detailed alignments and station locations along the route are examined in accordance with the technical parameters, and then other technical solutions at the concerned section/area are considered. Table 3.6.2 shows the technical parameters applied to the alignment planning for the preliminary design.

[6] The numerical number is based on the results of the preliminary demand forecast to compare the relative difference of daily passenger volume between the route alternatives, which was conducted in phase-1 of the survey. The passenger volume of Alternative 1 in each year is set as the baseline (=1.00).
[7] "Route" is defined as a way that JICA-LRT follow to get between stations. "Alignment" is defined in both horizontal and vertical layouts to describe the line uniformity (straightness) of the rails.

Table 3.6.2 Technical Parameters for Alignment Planning

Technical Parameters	Specifications
Gauge	1,435mm (Standard gauge)
Traction Power	3rd rail, DC750V
Max. Train Operation Speed	80km/h
Max. Train Operation Speed on the section of tight curve radius 100 m	30km/h ~ 40km/h
Min. Distance between Tracks	3.55 m
Min. Width of Viaduct and ROW	8.4m, 12.4m (2.0m margin from each side of Viaduct)
Min. horizontal curve radius	Main line: 100m Main line along platform: 300m Depot 100m
Min. Circular Curve Length	20m
Min. Tangent Length	20m
Type of Transition Curve	Cubic Parabola
Max. Gradient	Main line: 35/1,000 Station: 5/1,000 Depot or train stabling area: Level
Min. Vertical Curve Radius	Gradient change of more than 10/1,000 : 3,000 m Unavoidable cases : 2,000 m
Turnout/Switch (decree of branching)	Main line: 1:10 Depot: 1:8
Clearance from the surface of the road	6.0m
Platform Length	120m for 6 cars
Min. Width of Platform	Island Type: 6.0m Siding Type: 4.0m

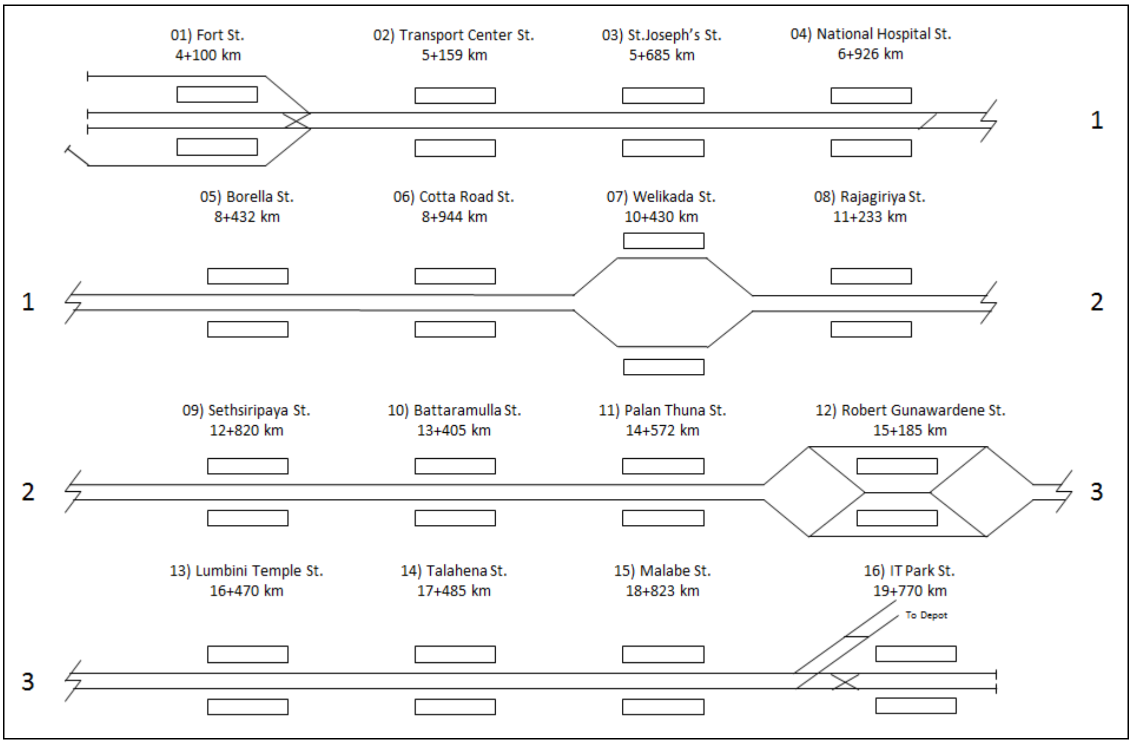
Source: Survey Team

(2) Outline of the Routes

Taking into consideration the above technical parameters for alignment planning, careful examination has been carried out, especially for the station locations and sharp curve sections.

However, GoSL officials decided in the Cabinet that the route to pass through Gangaramaya Temple up to Kollupitiya should be considered carefully due to social considerations necessary and cannot be confirmed at this moment, thus that the initial stage for the project has only the section of Fort-Malabe-Depot and the section from Fort to Kollupitiya will be treated as a future extension.

The track layout of the Survey route is illustrated in Figure 3.6.2.



Source: Survey Team

Figure 3.6.2 Station Name and Numbering

Narrative description for the outline of the route, with the station name and number, is summarized as follows:

1) (01) Fort St. – (05) Borella St.

(01) Fort St. which is the beginning station of the JICA-LRT, is located in the north-east of Fort Station of SLR. This station has 4 tracks with 2 island type platforms that can accommodate train stabling at night and the future extension. There are some buildings owned by SLR in the station area, and these will be redeveloped according to JICA-LRT construction.

After leaving (01) Fort St., the route passes on Bastian Mw., which is in the south side of Bus Terminal, and enters the redevelopment area of SLR. (02) Transport Centre Station is located at the redevelopment area of SLR. The route crosses the railway yard with the long bridge and heads south to T. B. Jayah Mw. (03) St.Joseph's Station, located close to Excel World Entertainment Park. The width of T. B. Jayah Mw. is approximately 20m.

The route turns to the left with a 102m radius curve and enters to Union Place. The width of Union Place is approximately 14m excluding the pavements on both sides. After crossing Lipton Circle, the route reaches (04) National Hospital Station on Ward Place.

The route head east on Ward Place, approximately 24m wide, and crosses Baseline Rd. In order to avoid impact on Borella shopping center and the Bo Tree in the east of the Borella Junction, the route passes between them. There is an underground walkway in this junction. The route then reaches (05) Borella Station.

2) (05) Borella St. – (08) Rajagiriya St.

After leaving (05) Borella Station, the route heads east on Cotta Road. This road is 2 lanes on each direction with the centre median and is approximately 22m wide. (06) Cotta Road Station is located to the west of Cotta Road Station of SLR. Electrification and elevation of SLR is planned. Crossing SLR, the route passes on Cotta Rd. and Sri Jayawardenepura Mawatha Road. This road is 3 lanes on each direction with the centre median and the width of this road is approximately 18m; however, the pavements and green zone on each side is wide.

The route is divided into two single tracks as to sandwich the Rajagiriya Flyover. The east-bound track passes in the north side and the west-bound one passes in the south side. (07) Welikada Station is located the west area of this section.

The route merges into one again and reaches (08) Rajagiriya Station passing on Sri Jayawardenepura Mawatha Road, approximately 32m in width including sidewalks of both sides.

3) (08) Rajagiriya St. – (10) Battaramulla

After leaving (08) Rajagiriya Station, the route crosses Diyawanna Lake with shortcut. The route passes the north area of the park. The 132kV transmission line crosses the route around 12km300. The route goes behind Sethsiripaya Stage-3 with 102m radius of S-shape curve. (09) Sethsiripaya Station is located in front of Sethsiripaya Stage-1. The route turns to the right with 102m radius curve and reaches (10) Battaramulla Station in the Battaramulla junction. The north area of this station will be developed as BattaramulaMMC.

4) (10) Battaramulla – (16) IT Park St.

The route heads south on Pannitipiya Road, approximately 20m wide, and turns to the left with a 122m radius curve and reaches (11) Palan Thuna Station. The route passes on Denzil Kobbekaduwa Road and reaches (12) Robert Gunawardene Station, which has 3 tracks with 2 island type platforms.

The route turns to the right at Koswatta Junction with another 102m-radius curve in order not to pass the Thalangama Environmental Protection Area (EPA).

The route then enters to New Kandy Road and reaches (13) Lumbini Temple Station. The width of New Kandy Rd. is approximately 17m including the hard shoulders of both sides.

The route reaches (16) IT park Station through (14) Talahena Station and (15) Malabe Station. (15) Malabe St. is located close to the bus terminal, which will allow for connections/transfers to bus service. There are sharp curves with 102m radii, before and after (14) Thalahena Station, and ups and downs between (14) Thalahena Station and (16) IT Park Station. The 132kV transmission line also crosses the route around 19km300. (16) IT park Station is located close to the canal, and the paddy field around the station can be developed into car parking for Park & Ride and other facilities.

5) (16) IT Park St. – Depot

The depot access line branches off the main line at 19km520, before (16) IT Park St., goes to the north on the paddy fields and then reaches the depot. Length of the depot access line is 1000m.

The depot structure should be an elevated deck, above the high water level of floods.

(3) Alternative Analysis on Route and Station Locations

1) Introduction of Alternative Analysis

The route and the station locations are proposed in compliance with the technical parameters shown in Table 3.6.2. However, several locations with particular features, such as accessibility to facilities required for customers, reduction of construction cost, restriction on alignment for avoiding social and environmental negative impacts, are examined individually with alternative options.

In this section, the following items are discussed on alternative options and comparative study for the route, vertical and horizontal alignment, and the locations at the station and the depot:

Table 3.6.3 Sections Considered for Alternative Analysis

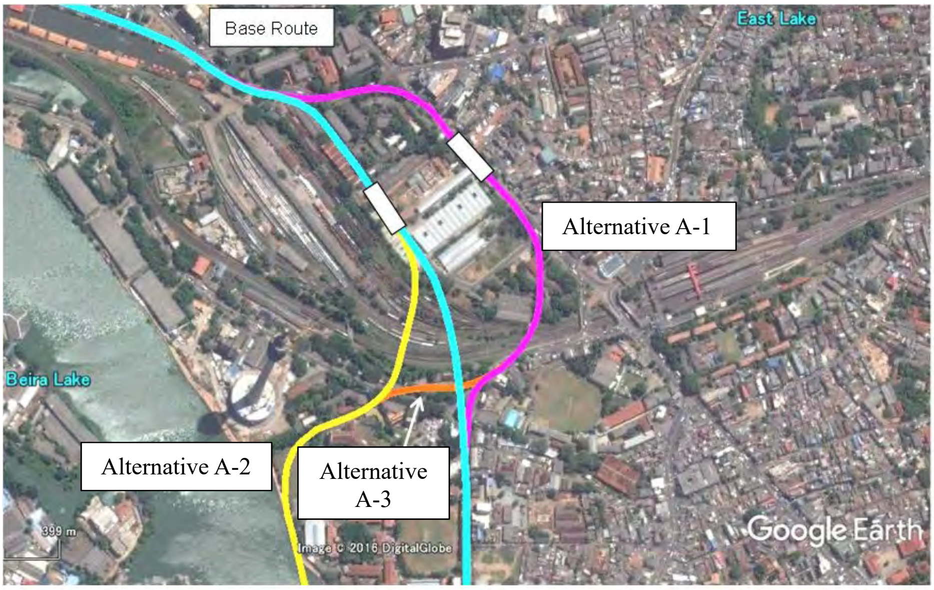
No	Alternative section	Reason for alternative consideration
A)	Crossing of existing rail tracks	Crossing over existing rail tracks near Maradana presents technical challenge due to the crossing distance that need to be considered.
B)	Transport Centre (Maradana) – Borella section	There were two alternative routes with different land use patterns between Maradana – Borella.
C)	Borella Junction area	The impact on Bo tree and Borella super market need to be considered.
D)	Cotta Road - Sethsiripaya section	The sensitivity of road between Cotta road – Sethsiripaya section was raised and alternative route was considered.
E)	Welikada Station (Rajagiriya Flyover)	Rajagiriya flyover is already being constructed on the centreline of the road on the proposed route. Two alternatives were considered.
F)	Sethsiripaya Sation and its surroundings	Demand for passengers who access government offices need to be considered.
G)	Thalangama EPA Area	Building a railway across the EPA is not a permitted activity according to the EPA Gazette. Thus, avoiding the EPA is necessary.
H)	Depot Location	Depot area requires a significant area to give way for parking of rolling stocks and other facilities. Ideally, the depot should be located at the end of the route. Available land with suitable area that can accommodate the JICA-LRT depot is limited in Colombo.

Source: Survey Team

2) Alternative Analysis

A) Crossing of Existing Rail Tracks

Several alternative routes were examined for the section crossing on existing railway tracks near Maradana. Since several tracks are lined together, the distance needed to cross the railway tracks is lengthy. This requires technical challenge because a pillar for support cannot be built on railway tracks.



Source: Survey Team Note: Alternative A-3 was deleted from alternative analysis.

Figure 3.6.3 Alternative routes for crossing existing railway

Table 3.6.4 Comparison of Alternative Route

Items	Base Route (Light Blue)	Alternative A-1 (Pink)	Alternative A-2 (Yellow)
Description	Goes through the properties of SLR and exits at Darley Rd	Use existing roads (Olcott Mawatha, Technical Junction, Maradana Rd, TB Jayah Mawatha to Darley Rd)	Goes through the properties of SLR and exits at Beira Lake
Length	Shortest route	Longer route than base route	Longer route than base route
Length of Railway crossing	Medium distance at approximately 120m	Shortest distance of railway crossing at approximately 80m	Longest distance of railway crossing at approximately 180m
Technical Feasibility	Longest span (160m) of crossing existing railway track. No sharp curves	Shortest span (80m) of crossing existing railway track. Three sharp curves Increase in travel time	Two sharp curves before exiting Beira Lake Increase in travel time
Noise and vibration	Less noise and vibration impacts	Noise and vibration may affect residents living near/along roadside.	Noise and vibration may affect people residing/working in buildings close to the route.
Land Acquisition, Resettlement	Least land acquisition required. Properties that will be affected are owned by SLR.	Land acquisition may be required before and after crossing the railway tracks. Approximately 5 structures will be affected.	Land acquisition may be required, after railway crossing and before exiting Beira Lake. Approximately 2 structures will be affected. Other properties that will be affected are owned by SLR.
Total evaluation	Most desirable option for this project since it is confirmed that the crossing of existing railway track (160m) is considered to be feasible, [Recommended]	Not recommended due to high construction cost, land acquisition, environmental and social impacts	Not recommended due to relatively high construction cost, land acquisition, environmental and social impacts

Source: Survey Team

B) Transport Centre (Maradana) – Borella Section

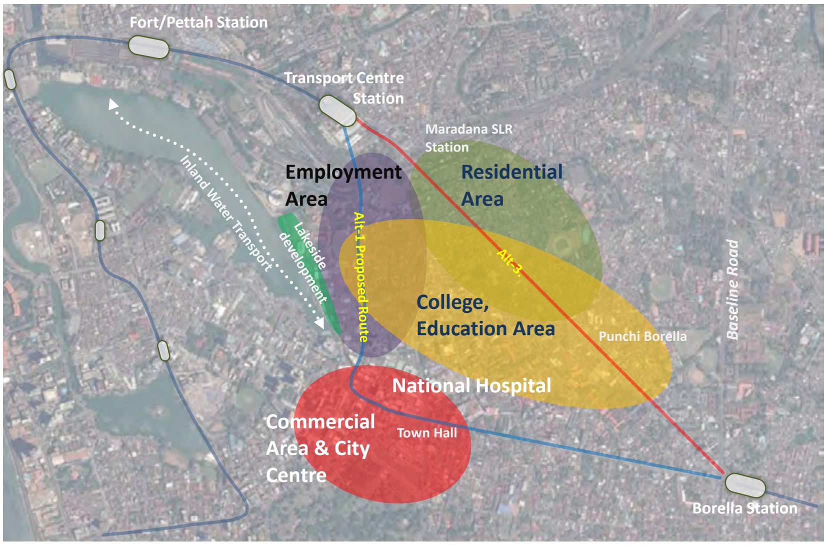
The letter issued by MMWD dated on 23rd May 2017 (LRT/JICA/PLN/05), entitled as "Acceptance of the study route for JICA-LRT feasibility study", requested an investigation of another deviation: the route from Borella to Maradana via Punchi Borella on the P De S Kularatne Mw. It is considered as another alternative route (Alternative B-3 as shown in red colour line in Figure 3.6.4).

In the following sub-sections, the investigations on Alternative B-3 from several viewpoints are described, and the major concerns over the suggested Alternative B-3 are discussed in detail. Based on the investigation, the Survey Team concludes that Alternative B-1 is to be selected as the route for JICA-LRT in Colombo, especially from the viewpoint of responding to the current passenger demand in the central area of Colombo to solve traffic congestion in the city, which is the most important objective of the Project.

<u>Overall Observation: Difference in Land Use Characteristics</u>

Figure 3.6.4 demonstrates that the land use characteristics along Alternative B-1 and Alternative B-3 vary greatly. Observations from the two alternatives are summarized as follows:

- Proposed route (Alternative B-1, blue line): Serves the high employment area of the CBD, provides connection to commercial and city centre, and enables direct access to the National Hospital.
- Route suggested by MMWD (Alternative B-3, red line): Loses the opportunity to serve the above users as it is more focused on the residents along the route.



Source: Survey Team

Figure 3.6.4 Land Use Image around the Alternative B-1 and Alternative B-3

<u>Evidence and Estimation Results</u>

It is recommended that the proposed route (Alternative B-1) has more advantages than the suggested route (Alternative B-3) with following evidence and estimation results.

a) **Passenger Demand Aspects/RTS Network Concept**

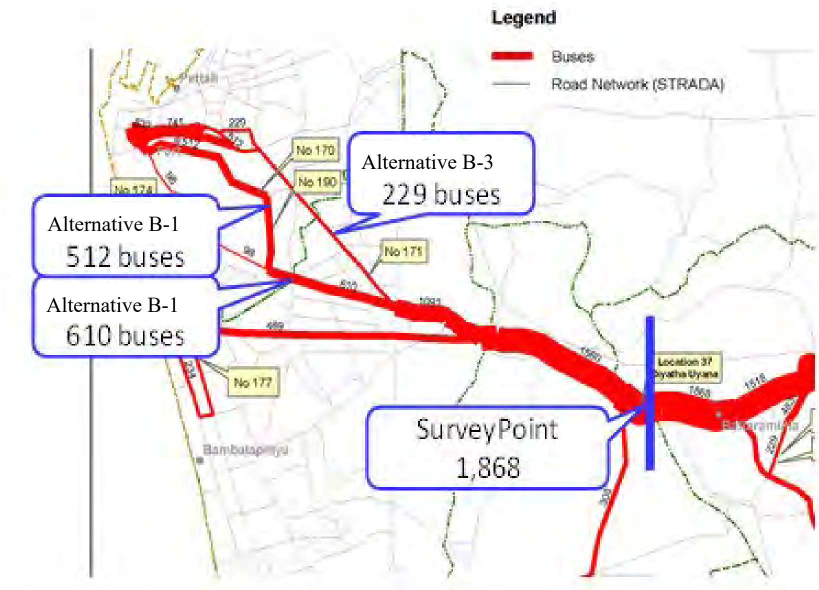
- Demand forecast (daily passengers for JICA-LRT):

  - The difference of estimated passengers is not significant (Table 3.6.5) although the number of passengers of Alternative B-3 is slightly less than that of Alternative B-1 in 2020 and 2035[8].

Table 3.6.5 Daily Passenger Volume Ratio

	Daily Passenger 2020	Daily Passenger 2035
Alternative B-1	1.00	1.00
Alternative B-3	0.97	0.97

Source: Survey Team



Source: Survey Team

Figure 3.6.5 Bus Route Survey at Diyatha Uyana (Bi-direction 24 hours)

- Current public transport usage based on bus route (frequency) analysis

  - Alternative B-3 will lose public transport users along the Malabe Corridor. Figure 3.6.5 indicates that, along the Alternative B-1 route, there are more buses running back and forth on Malabe Corridor.

- RTS network concept

  - During formulating the Megapolis Transport Master Plan, major destination nodes were identified around centre of the city, e.g., the Town Hall area, which should be connected by the RTS network. In addition, with the RTS network in the future, no direct connection between Borella and Maradana was proposed in this master plan.

[8] The numerical number is based on the results of the preliminary demand forecast to compare the relative difference of daily passenger volume between the route alternatives, which was conducted in phase-1 of the survey. The passenger volume of Alternative B-1 in each year is set as the baseline (=1.00).

b) Social Aspects

Table 3.6.6 Comparison of Catchment Volume in 2035 (800m from Station)

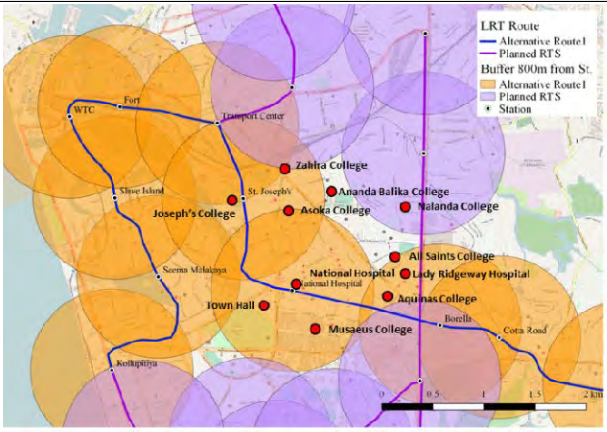
Year 2035		Alternative B-1	Alternative B-3
Trip Generation	Population	44,634	39,409
	Student at Home	6,475	5,975
	Employee at Home	19,080	16,717
Trip Attraction	Student at School	41,168	41,879
	Employee at Workplace	183,756	82,859

Source: Survey Team

- Difference of land use characteristics between Alternative B-1 and Alternative B-3 described earlier is further elaborated on and summarized as follows:

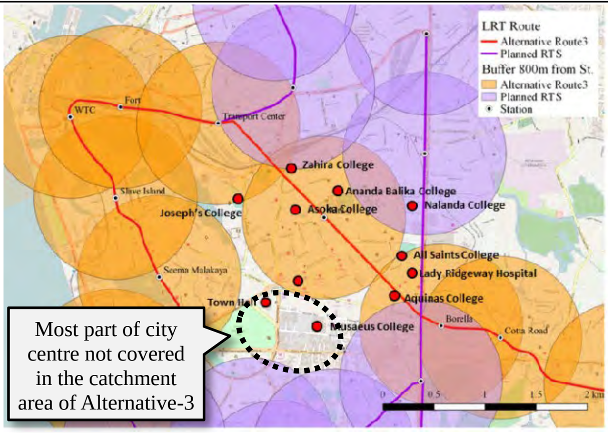
- Alternative B-1 goes across offices and the city centre, whereas Alternative B-3 goes mainly across residential areas. Table 3.6.6 reveals that, in terms of trip generation, Alternative B-1 and Alternative B-3 are comparatively similar; however, in terms of trip attraction, Alternative B-1 is superior because it covers more than twice the number of employees as Alternative B-3 does.
- In particular, Alternative B-3 will eliminate the connectivity to the city centre in the future, and it will also lose connecting to the envisioned residential development area at the Beira Lake side (Figure 3.6.4).
- Regarding colleges and employment locations around the routes, Figure 3.6.6 depicts the different catchment area from the station of each route. Alternative B-3 loses the city centre along with some colleges and major office/employment locations along the Alternative B-1.

Alternative B-1 and Other RTS Routes

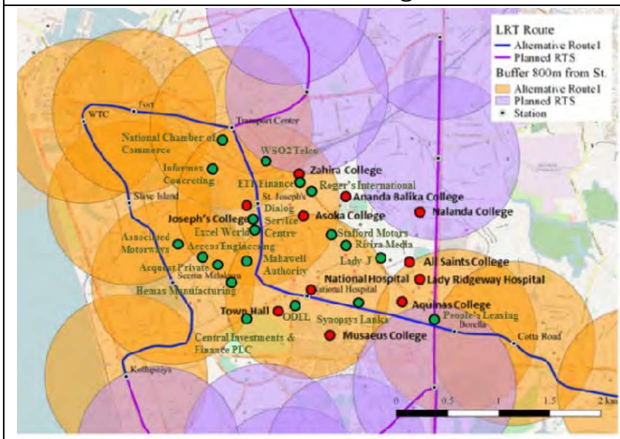


Location of Colleges

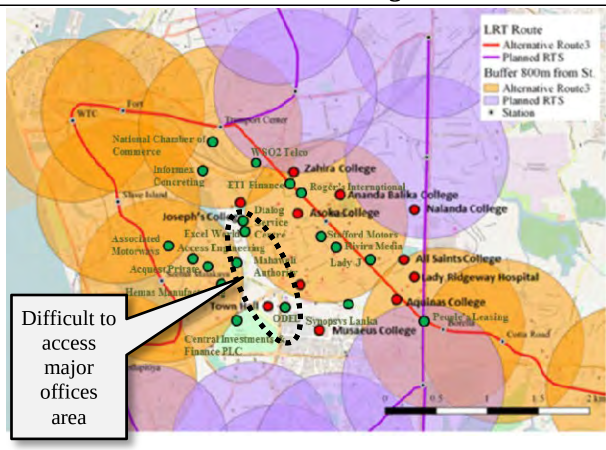
Alternative B-3 and Other RTS Routes



Location of Colleges



Location of Colleges and Employment Area



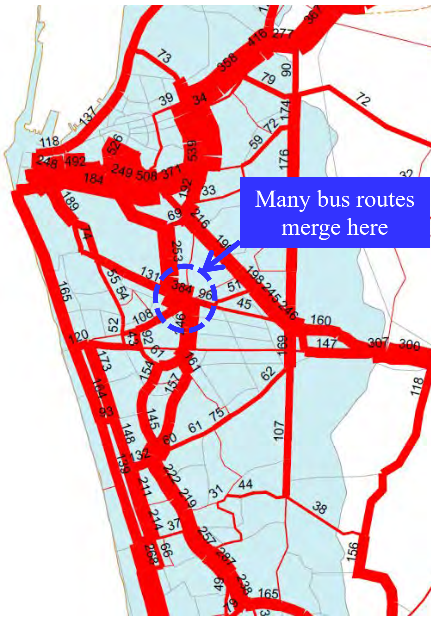
Location of Colleges and Employment Area

Source: Survey Team, the base map from OpenStreetMap

Figure 3.6.6 Catchment area of JICA-LRT Stations of Alternative Route and Other RTS Lines

c) Inter-modal Connectivity Aspects

- Current public transport users based on number of bus (peak hour 2013) in Figure 3.6.7 highlights the points below:
  - The Town Hall area is one of the highest bus linkage points from/to everywhere in CMC.
  - Alternative B-3 will lose the inter-connectivity with these bus routes.
- Connectivity with IWT in Beira Lake
  - Alternative B-3 cannot connect to IWT, which is planned to link Fort/Pettah to the city centre (see Figure 3.6.6).



Source: CoMTrans, 2013

Figure 3.6.7 Total Bus Volume during Peak Hour

d) Technical Difficulties Aspects

- Alternative B-3 requires large technical considerations for how to cross the SLR by flyover to not disturb any shops and old buildings.
- More integrations are required with the future rehabilitation of the Maradana Road bridge due to the electrification of SLR (Alternative B-3 should be separated from this project).
- Alternative B-3 needs more careful countermeasures for traffic management during JICA-LRT construction in the Maradana area due to high traffic volume and one-way traffic flows.
- At the Borella junction, Alternative B-3 will be carefully examined to avoid touching the Bo Tree.
- Alternative B-3 faces difficulties for the placement of the receiving and traction sub-stations (long distance from national grid for receiving sub-station and required space for traction sub-station). This issue is further discussed in Chapter 4.

e) Social and Environmental Consideration

- Land Acquisition/Resettlement: Alternative B-1 requires land acquisition of car dealer shop(s) due to tight curvature section on Union Place. On the other hand, Alternative B-3 requires no land acquisition. Regarding the resettlement, both alternative routes do not require the resettlement except there are small shops on Alternative B-3 as shown below.
- Integration of Current Station with Small Shops: Alternative B-3 requires the integrated development with small shops at Maradana Station.
- Landscape: Along Ward Place on Alternative B-1, branches of street trees will need to be cut during the construction period. Once constructed, JICA-LRT will run above the street trees.

f) Construction Cost

- Both alternatives have different factors to save or increase the total cost for construction, and some of the factors are shown below. The difference in the construction cost for two alternatives is considered to be relatively small in principle (e.g. 2.5% of total construction costs).

- Length of viaduct:	Alternative B-3 is approx. 430m shorter than Alternative B-1
- Length of bridge across the SLR:	Alternative B-1 (150m), Alternative B-3 (80m)
- Number of station:	Alternative B-1 (2), Alternative B-3 (1)

Considering a) to f), Alternative B-1 is recommended due to the overriding advantage of transport network.

C) Borella Junction Area

There is a religiously significant Bo tree at Borella Junction. Several devotees visit the place to pray and give donations. Bo trees are regarded as sacred and cutting down of Bo trees are not accepted religiously and culturally. Thus the Bo tree needs to be avoided. Beside the Bo tree is the Borella Supermarket, which houses more than 200 small shops and businesses. Costs for compensation and relocation of these businesses will be significant if the Borella supermarket will be removed to give way to a multi-modal transport center.

Source: Survey Team

Figure 3.6.8 Alternative routes for Borella Junction Area

Table 3.6.7 Comparison of Alternative Route

Items	Alternative C-1 (Red Line)	Alternative C-2 (Blue Line)
Description	Route that will impact the Borella Supermarket to give way for development of a multi-modal transport center, linked with Borella Station (red shaded area)	Route that avoids cutting of the Bo tree and the Borella Supermarket The Borella Station is located at the blue shaded area
Land acquisition and resettlement	Demolition of the Borella Supermarket will affect more than 200 small businesses operating inside. These businesses (including the employees) will have to be compensated.	No land acquisition required as the route goes right through the center median of the road. There is enough space for the train station, including ROW.
Cost	Expensive costs for land acquisition and compensation for affected small businesses.	No additional cost due to land acquisition and resettlement
Cultural aspect	The Bo tree will be fully avoided	Some branches of the Bo tree may have to be trimmed. Need to obtain consent from the chief monk and relevant stakeholders and perform the proper rituals
Total evaluation	Not recommended due to land acquisition and costs.	Most desirable option for this project, [Recommended]

Source: Survey Team

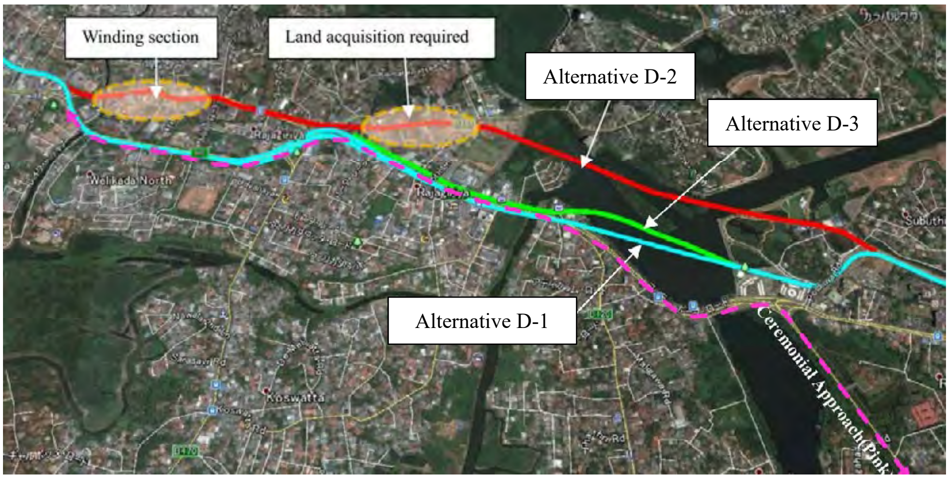
D) Cotta Road - Sethsiripaya Section

The proposed route from Cotta Road to Diyawanna Lake is on Sri Jayawardenepura Mawatha. This road is a ceremonial approach into the Capital City of Sri Lanka under special planning regulations prepared by UDA in early 1980. Even though these regulations could not be fully implemented with undue influences and the envisaged Ceremonial Character has yet to be achieved, the UDA is now in the process of regaining such character by various means.

JICA-LRT structures on the centre of the road will impact on the landscape and utilization of this road. To avoid this impact, there are two options.

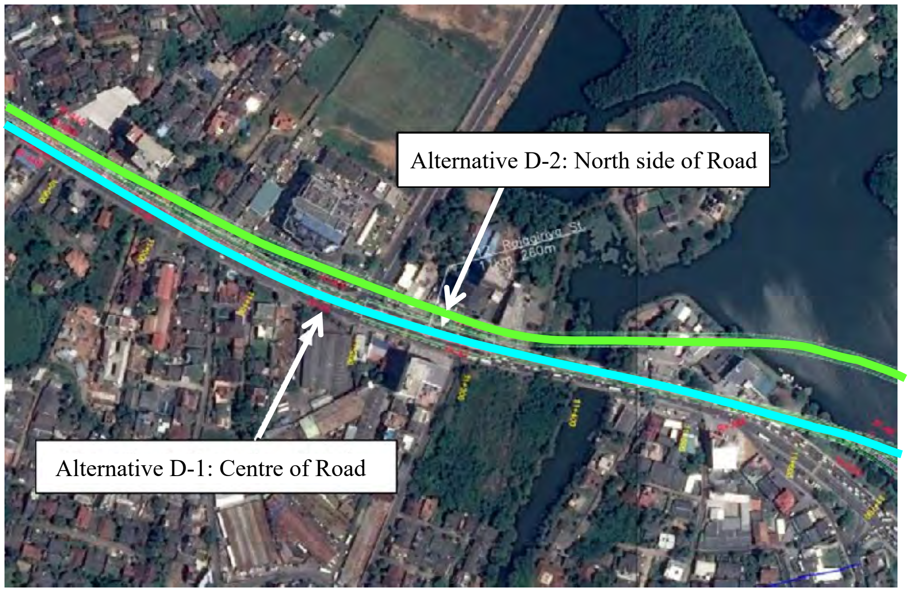
- Alternative D-1: Base Route (Centre of Sri Jayawardenepura Mawatha through Diyawanna Lake)
- Alternative D-2: Via Old Cotta Road and go behind Diyawanna Lake.
- Alternative D-3: North side of Sri Jayawardenepura Mawatha

Each alternative route is shown below:



Source: Survey Team

Figure 3.6.9 Sections for Alternative Analysis (Cotta and Sethsiripaya)



Source: Survey Team

Figure 3.6.10 Sections for Alternative Analysis (Cotta and Sethsiripaya)

The comparison of alternative route is shown below:

Table 3.6.8 Comparison of Alternative Route

Item	Alternative D-1 (Blue Route)	Alternative D-2 (Red Route)	Alternative D-3 (Green Route)
Description	Via Sri Jayawardenepura Mawatha through Diyawanna lake (Base Route)	Via Old Cotta Road and go behind Diyawanna Lake	North side of Sri Jayawardenepura Mawatha to avoid JICA-LRT at centre of road
Length	Base	100m shorter than Alternative D-1	Almost same as Alternative D-1
Technical aspect	Although technical feasible to go along the sides of Rajagiriya Flyover section, the cost is high. Less sharp curve	Going along Rajagriya Flyover is not required. Old Cotta Road has more sharp curves, requiring more land acquisition.	Although it is technically feasible to go along the sides of Rajagiriya Flyover section, the cost is high. Less sharp curve
Transport catchment	Information not available	Information not available	Information not available
Social aspect	Can be mostly managed with no land acquisition.	Approximately 20 houses to be relocated	2~3 buildings and commercial property need to be acquired.
Aesthetic	Disturb the concept of Ceremonial approach. However, area is already impacted with high raised buildings	No significant impact	Possible to mitigate the landscape impact on the concept of Ceremonial approach by having JICA-LRT route on the side of road
Hydrology	Shortest Diyawanna Lake section	Longest Diyawanna Lake section	Second shortest Diyawanna Lake section
Ecological Environment	No significant issue	Island with mangrove in Diyawanna lake which is habitat of birds will be affected	No significant issue
Overall	Alternative D-1 is selected due to less land acquisition involved, [Recommended]	Alternative D-2 is not preferred option due to the land acquisition issue, which can be studied further.	Alternative D-3 can still be examined further during the detail design stage considering land availability along the road.

Source: Survey Team

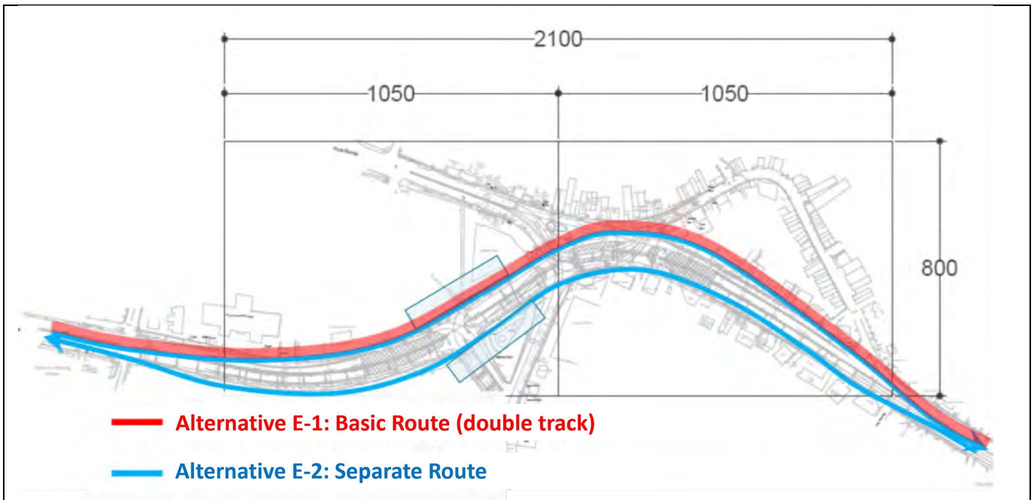
E) Welikada Station (Rajagiriya Flyover)

Rajagiriya flyover is already being constructed on the centreline of the road on the proposed route. Since the JICA-LRT cannot use the centreline, there are two options for the Welikada Station layout.

In SKYTRAIN study, this station was planned to locate at the middle of the road. However, the flyover has been constructed there and the change of the station location is required. Since the space for the station and the viaduct is not sufficient around the station area, the route around Welilkada Station is examined as follows:

Alternative E-1 passes the north side of the flyover with double track, and land acquisition is required in both side of the road, especially in the east area. The station platform and facilities can be installed in one place.

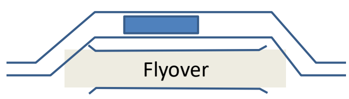
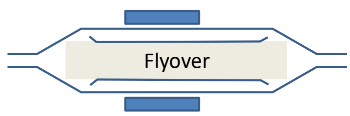
Alternative E-2 divides two single tracks and each track passed across the flyover. This can minimize land acquisition because of the narrower single track viaduct structure and installation of the piers on the side road. The platform and station facilities of Welikada Station should be divided on both sides of the flyover. Both platforms will be connected by a foot bridge across the tracks and the flyover. Although some land acquisition is required on both sides of the road, the east area of the Flyover can minimize additional land acquisitions if RDA allows installing the pier(s) on the frontage roads. For traffic flow management, 2 lanes for frontage roads are not necessary because upper-stream lane configurations are 3 and 2 lanes run into flyover. In between of the 30m or 40m interval of piers, a bus stop area will be provided on the one lane of the frontage road.



Source: Survey Team
Note indicated size (mm) is 1/300 model development

Figure 3.6.11 Alternatives for Rajagiriya Flyover Section

Table 3.6.9 Comparison Table of Alternative Route around Welikada Station

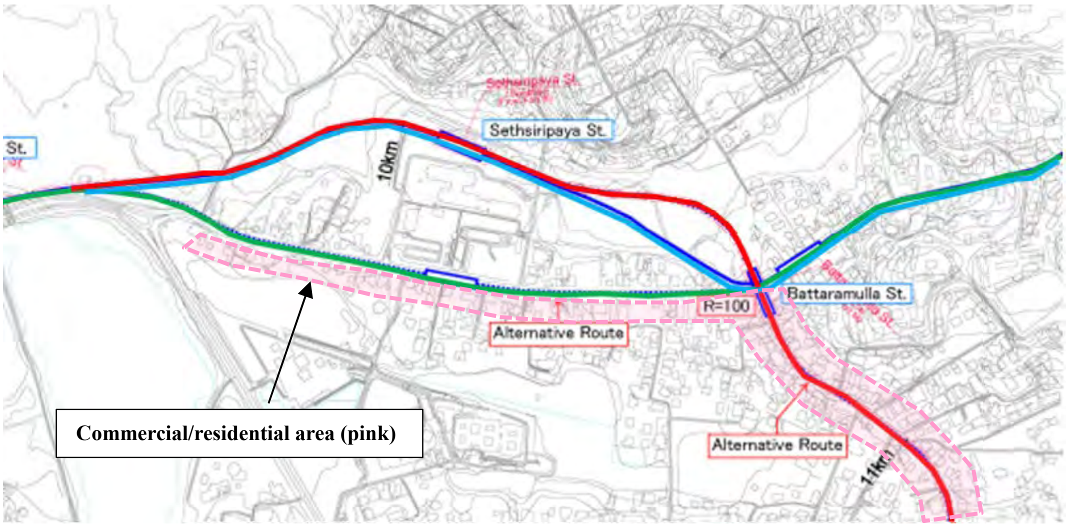
	Alternative E-1	**Alternative E-2**
Image		
Route	North side with double track	Two single tracks along the Flyover
Land Acquisition and Resettlement	5 or more buildings along the alignment	One or two buildings at corner of alignment
Location of Welikada Station Platform	One station with platform(s) will be installed so that large space for station is required.	Separated platforms will be separately installed at both side of the Flyover
Recommendation	-	**Recommend**

Source: Survey Team

Alternative E- 2 is recommended since there are fewer legal restriction and land acquisition issues.

F) Sethsiripaya Station and its Surroundings

Existing roads are comparatively narrower. Demand for passengers who access government offices (Sethsiripaya and Battaramulla South) need to be considered. Three options have been considered.



Source: Survey Team

Figure 3.6.12 Alternative Routes for Sethsiripaya Station and its Surroundings

Table 3.6.10 Comparison of Alternative Route

Items	Alternative F-1 (Blue)	Base Route (Green)	Alternative F-2 (Red)
Description	Goes to the back of Sethsiripaya, exit Battaramulla Junction then use existing road (Kotte-Bope Rd) Sethsiripyaya Stn will be built on existing road.	Use existing road (Kotte-Bope Rd) and go straight to Malabe (East side) Sethsiripaya Station will be built on an open area allocated for government offices.	Goes to the back of Sethsiripaya, exit Battaramulla Junction, then go South to Palan Thuna Junction Sethsiripaya Stn will be built on an open area allocated for government offices.
Length	Shortest route	Longer than Alternative F-1	Longest route
Passenger Demand	Less passenger demand	Can cater to government offices located in Sethsiripaya and Suhurupaya.	Can cater to government offices located in Sethsiripaya, Suhurupaya, and along Denzil Kobbekaduwa Mawatha
Technical Feasibility	No sharp curves	One sharp curve Increase in travel time	Two sharp curves before exiting Battaramulla Junction Increase in travel time
Noise and vibration	Noise and vibration impacts on structures at a close distance along the JICA-LRT route	Less sensitive receptors because the area (Sethsiripaya, Suhurupaya) is newly developed with open spaces	Noise and vibration may affect people residing/working in buildings close to the route.
Land Acquisition, Resettlement	Most land acquisition required due to narrow roads and planned train station	Less land acquisition required because it goes through government land. However, acquisition is not feasible because a new government building (Suhurupaya) has just been completed along the route (straight portion before exiting Battaramulla junction)	Less land acquisition required because it goes through government land (e.g. Sethsiripaya, Suhurupaya). Avoids the newly built Suhurupaya.

Items	Alternative F-1 (Blue)	Base Route (Green)	Alternative F-2 (Red)
Total evaluation	Not recommended due to land acquisition and other environmental and social impacts	Not feasible due to a newly built government building in Battaramulla	Most desirable option for this project, [Recommended]

Source: Survey Team

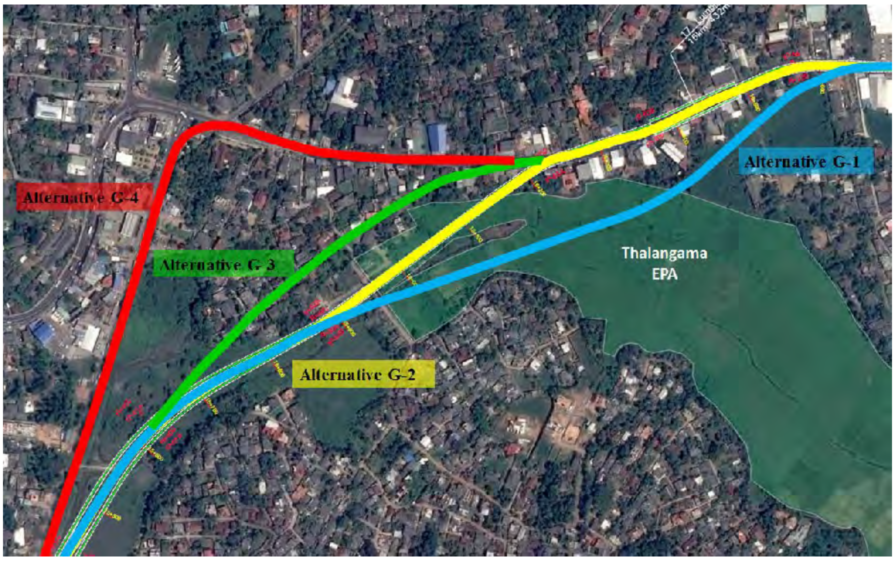
G) Thanlangama Environmental Protection Area

For the section between Denzil Kobbekaduwa Mawatha and B240 (Malabe Road), 4 alternative routes were studied. The best route in terms of technical and practical perspective (less curves, no obstruction (houses), short distance) was considered to be the route which passes through Thalangama EPA, shown as the Blue Route in Figure 3.6.13.

Thalangama EPA was designated as EPA by CEA, and only limited activities are allowed in EPA. Therefore, following alternative routes were studied further and the comparison of potential impact is summarized in Table 3.6.11.

- Alternative G-1: Passing through Thalangama EPA (400m) and shortest route
- Alternative G-2: Passing through Thalangama EPA with minimum distance (200m)
- Alternative G-3: Passing outside of EPA boundary (buildings will be impacted)
- Alternative G-4: Passing on existing road

Considering the importance of Thalangama EPA as well as the social impact (land acquisition), the Red Route (passing on existing road) was considered to be preferred route.



Source: Survey Team

Figure 3.6.13 Alternative Routes in Thalangama EPA

Table 3.6.11 Alternatives Analysis in Thalangama Area

Item	Alternative G-1 (Blue Route)	Alternative G-2 (Yellow Route)	Alternative G-3 (Green Route)	Alternative G-4 (Red Route)
Description	The shortest route passing through EPA	The shortest and less curve route crossing a portion of EPA	The route that goes outside of EPA boundary.	The route goes on existing road.
Length	Shortest	Second shortest	Second longest	Longest
Technical aspect	No significant issue	No significant issue	No significant issue	Sharp curve at the corner. Increase in travel
Transport catchment	Approximately same for all routes			
Social aspect	Approximately 2-3 houses to be relocated	Approximately 2-3 houses to be relocated	Approximately 20 houses to be relocated	One commercial building and 3-4 houses might be relocated.
Aesthetic	Most significant due to the disturbance of EPA	Less significant compared with Alternative G-1	Less significant compared with Alternative G-1 and G-2.	Not significant issue
Hydrology	Minor impact due to disturbance of flooding plain	Minor impact due to disturbance of flooding plain	Minor impact due to disturbance of flooding plain	No significant issue
Ecological Environment	The route runs through the northern edge of EPA.	The route runs through the northern edge of EPA.	No significant issue	No significant issue
Overall	Not recommended due to legal restriction of EPA	Not recommended due to legal restriction of EPA	Not recommended due to land acquisition issue	Selected as recommended route since there is no legal restriction and significant land acquisition issue [Recommended]

Source: Survey Team

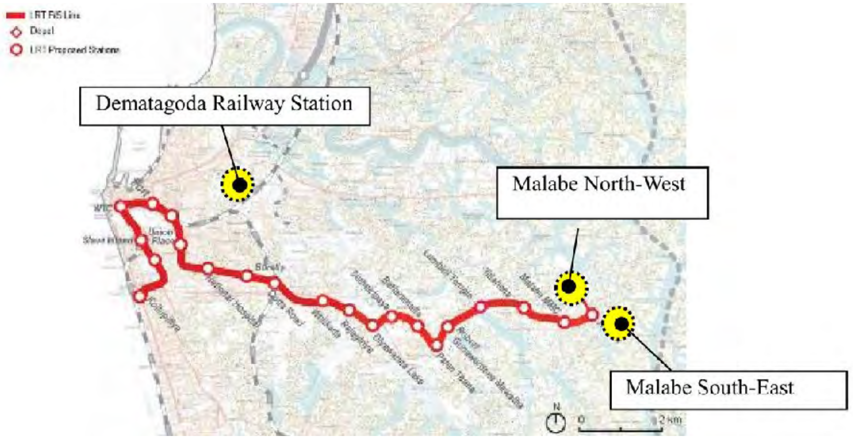
Alternative G-4 is recommended since there is no legal/policy (JICA guideline) restriction and significant land acquisition issue.

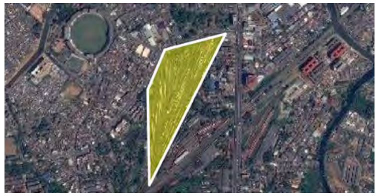
H) Depot Location

The location of the depot should be not in the city centre, but at the other end of the line that is a residential area. In the morning, trains will enter the line from the depot to start operation. The direction of the trains will be towards the city centre, which is the same direction as the movement of the people commuting to work. Similarly, trains will go back to the depot when people are going back to their residences in the evening.

There are three potential sites; a) Dematagoda Railway Station site, b) Malabe South-East area and c) Malabe North-West area. The alternative analysis is shown in Figure 3.6.14.

Alternative H-1 can be secured the sufficient land, but construction cost is high because 1,500m of the elevated viaduct is required. In addition, the discussion with SLR to use this land is required. On the other hand, Alternative H-2 is required the resettlement to secure the sufficient land for the depot. From the view point of site condition and social impact, Alternative H-3 Malabe North-West area is recommended.



	Alternative H-1 Dematagoda Railway Station site	Alternative H-2 Malabe South-East area	Alternative H-3 Malabe North-West area
			
Site Condition	A existing railway depot	An agricultural land	An agricultural which is considered as a flood retention area.
Ares	approximately 7ha.	approximately 3.5ha.	10~15ha.
Distance from Main line	approximately 1,500m along SLR	approximately 500m including a bridge crossing the canal	approximately 700m.
Land Acquisition	The land including the access line to the depot should be leased from the Railway Department.	Resettlement is required in order to secure sufficient area.	Agricultural land needs to be acquired.
			Recommend

Source: Survey Team

Figure 3.6.14 Alternative Analysis for Depot

Chapter 4 Preliminary Design

4.1 Introduction

This chapter aims to explain the preliminary design results that were established through intensive discussion with the experts of the Survey Team, in order to create a more practical and reasonable JICA-LRT system in Colombo, in line with the Design Principle presented in 3.5.1. The following items are summarized in the section below:

- Preliminary Design
  - Site Conditions
  - Alignment Plan and Profile
  - Demand Forecast
  - Structure Design
  - Rolling Stock
  - Operation Plan
  - Depot
  - Signal and Communication
  - Electrical and Mechanical (E&M)/Power Supply
  - Station Development
  - Construction Plan

The Preliminary Cost Estimation and Project Evaluation (Economic Analysis) are to be discussed at separate chapters.

4.2 Site Conditions

4.2.1 Topography

The JICA-LRT route is lying within a highly populated and built up region between Malabe and Colombo Fort; especially close to the coast, the area is readily accessible by a dense network of roads. The main railway line from Colombo to Galle runs by the side of the coast for most of the way.

The area along the JICA-LRT route is generally relative to sea level in altitude particularly in the western side. The altitude increases rapidly to the east of the escarpment of the central highlands beyond the project area.

Drainage is predominately from east to west through a principal river, the Kelani River, and a few tributaries cross the JICA-LRT route. The river flows at low level during the dry season, but at high level during the rainy season due to a wide catchment area. Flooding is common and a persistent problem.

4.2.2 Climate

(1) Temperature and Rainfall

Colombo experiences a tropical monsoon climate that is fairly temperate throughout the year. From March to April, the average high temperature is around 33°C. The monsoon season is from May to August and from October to January, when heavy rain with thunder and strong wind occur. The city sees little relative diurnal range of temperature, although this is more marked in the drier winter seasons when minimum temperatures average 22°C. Rainfall in the city averages around 2,500mm a year.

Table 4.2.1 shows monthly mean temperature total rainfall in Colombo, and the highest and the lowest records of temperature, heaviest records of rainfall and strongest record of wind are shown in Table 4.2.2.

Table 4.2.1 Monthly Mean Temperature Total Rainfall in Colombo

Month	Mean Temperature (°C)		Mean Rainfall (mm)
	Max.	Mini.	
Jan	32.4	24.2	65.3
Feb	32.5	24.9	106.7
Mar	32.9	26.0	91.3
April	33.3	26.5	185.9
May	31.6	25.8	752.4
June	31.1	26.8	132.3
July	30.7	26.3	49.2
Aug	31.0	27.1	1.1
Sep	30.6	26.5	29.0
Oct	31.1	25.7	374.0
Nov	30.7	24.3	404.8
Dec	31.4	24.2	165.1

Source: Department of Meteorology

Table 4.2.2 Records of Temperature, Rainfall and Wind

		Record	Date
Temperature (℃)	Highest	37.0 ℃	23rd-Sep-1987
	Lowest	18.2 ℃	13th-Jan-2011
Rainfall (mm)	10 min.	23mm	16th-Dec-2015
	1 hour	126mm	08th-Dec-2015
	1 day	493.7 mm	04th-June-1992
Wind (m/s)		34.5 m/s	30th-July-2012

Source: Department of Meteorology, 2016

(2) Cyclones

Cyclones are one of the most critical meteorological disasters, and considered the most significant natural disaster that takes place in Sri Lanka.

Averagely, two cyclones per year approaching or landing in Sri Lanka often cause major damages. Especially, the cyclone named "Roanu" had caused severe damage by flooding rivers in Colombo. And, the flooding occurred around the proposed depot area is close to the canal.

4.2.3 Flooding

There are three (3) locations where the JICA-LRT route crosses the flood areas, namely:

- Diyawanna Lake
- Depot area (Paddy areas adjacent to Madiwala East Diversion Canal)
- Parliament (Talangama EPA)

Based on the flood model by SLLRDC, water levels and extra backwater (flood lift) is shown below.

Table 4.2.3 Flood for 100 return years

No	Location	Scenario	Flood Level (m)			Remarks
			Without JICA-LRT Mean Sea Level (MSL)	With JICA-LRT MSL (m)	Backwater (Flood Lift) (m)	
1	Diyawanna Lake	Baseline-10 Year	2.1	2.1	Nil	No significant backwater
2		Construction-10 Year				
3	Depot Area	Baseline-10 Year	4.62	**	**	**
4		Construction-10 Year	**	4.91	0.29	Backwater is considerable
5		Construction-10 Year with 3m wide peripheral canal	**	4.8	0.18	Backwater reduces with the proposed canal
6		Baseline-50 Year/100 Year	7.16/8.38	**	0.09/0.06	No backwater during the Operation Stage
7		Operational-50 Year/100 Year	**	7.25/8.42		
10	Parliament	Baseline-100Year	3.16	3.16	**	There is no difference in WL due to introduction of JICA-LRT pillars
11		Construction-100 Year	**	3.16	0.00	

Source: SLLRDC, Survey Team

Some places of the JICA-LRT route outside the aforementioned flood prone areas could be subject to pocket flooding during/after heavy rain. Such flooding could hamper construction, and cause damage to exposed utilities and to open pile trenches.

The wetlands and streams along the JICA-LRT are shown in Figure 9.3.5 (Chapter 9).

4.2.4 Geological Conditions

In this Survey, 20 boring surveys were carried out along the JICA-LRT route. Together with the previous boring data conducted by the SKYTRAIN Project, there are total of 33 boring data points. The location of boreholes and the soil profile are shown in Appendix-3.

Mostly the sub-surface of the JICA-LRT route was found with the residual soil and completely weathered rocks covers the fresh rock. The recommended design parameters of the sub-surface are shown below:

Table 4.2.4 Recommended Design Parameters of the Sub-Surface

Layer No.	Layer description	Average Standard Penetration Test (SPT)	Shear strength parameters	Ultimate Bearing capacity (kN/m^2)	Elastic Modulus E (kN/m^2)
1	Residual soil	14-24	c' = 8kPa, φ'= 29	400	15,000
2	Completely weathered rock I	30-40	c' = 10kPa, φ'= 32	700	20,000
3	Completely weathered rock II	> 50	c' = 10 kPa, φ'= 38	1,500	25,000

Source: Survey Team

Based on the result of rock coring, the depth to fresh rock for each borehole is shown below:

Table 4.2.5 Depth to Fresh Rock

Location	BH 51	BH 52	BH 53	BH 54	BH 55	BH 56	BH 57
Chainage	20+100	19+500	17+630	17+760	15+930	13+860	12+200
Depth to Hard bed rock (m)	10.50	10.50	27.50	28.80	8.90	9.80	15.50

Location	BH 58	BH 59	BH 60	BH 61	BH 62	BH 63	BH 64
Chainage	18+980	11+312	10+047	9+690	7+768	7+004	6+652
Depth to Hard bed rock (m)	7.50	19.90	18.10	17.00	14.20	23.90	23.50

Location	BH 65	BH 66	BH 67	BH 68	BH 69	BH 70
Chainage	5+886	5+444	5+172	3+143	1+520	0+993
Depth to Hard bed rock (m)	21.80	11.60	6.30	21.00	24.70	22.80

Source: Survey Team

Because the depth to fresh rock is observed at different levels at each point, further boring surveying will be required in the detailed design stage.

4.2.5 Earthquake

Earthquake rarely occurs in Sri Lanka. Therefore, seismic loading does not need to consider in the design of the structure.

4.3 Alignment Plan and Profile

As discussed at the design principle in Chapter 3, with the purpose of running rapidly as well as stability and safety for JICA-LRT, it is important to plan a suitable alignment for the train operation speed. If there is steep gradient and/or sharp curve with a speed limit, required travel time will increase due to the decrease in train speed. Therefore, the alignments with requiring speed limit shall be minimized as much as possible.

As mentioned above, the realistic alignment is designed considering the avoidance of speed limits as well as the feasibility after checking the restriction of land space at the site.

The general information of JICA-LRT route is shown below:

Table 4.3.1 General Information of Route

Route Length	15.7km
Number of Station	16
Average Distance between Stations	1.0km
Track	Double Track incl. Depot Access Line
Structure	Elevated in all section
Actual Maximum Gradient	Main Line: 2.0%, Depot Access Line: 2.5%
Number of Sharp Curves R=102m	Main Line: 9, Depot Access Line: 2
R=110m	1
R=120m	3
Number of Depot	1 (Malabe area)
Maximum Number of Car per Train	6 cars

Source: Survey Team

The Plan and Profile drawings are shown in Appendix 4.

In addition, mobile mapping system and drone survey had been implemented and the results are described in Appendix 15. This data will be utilised for the detail design stage.

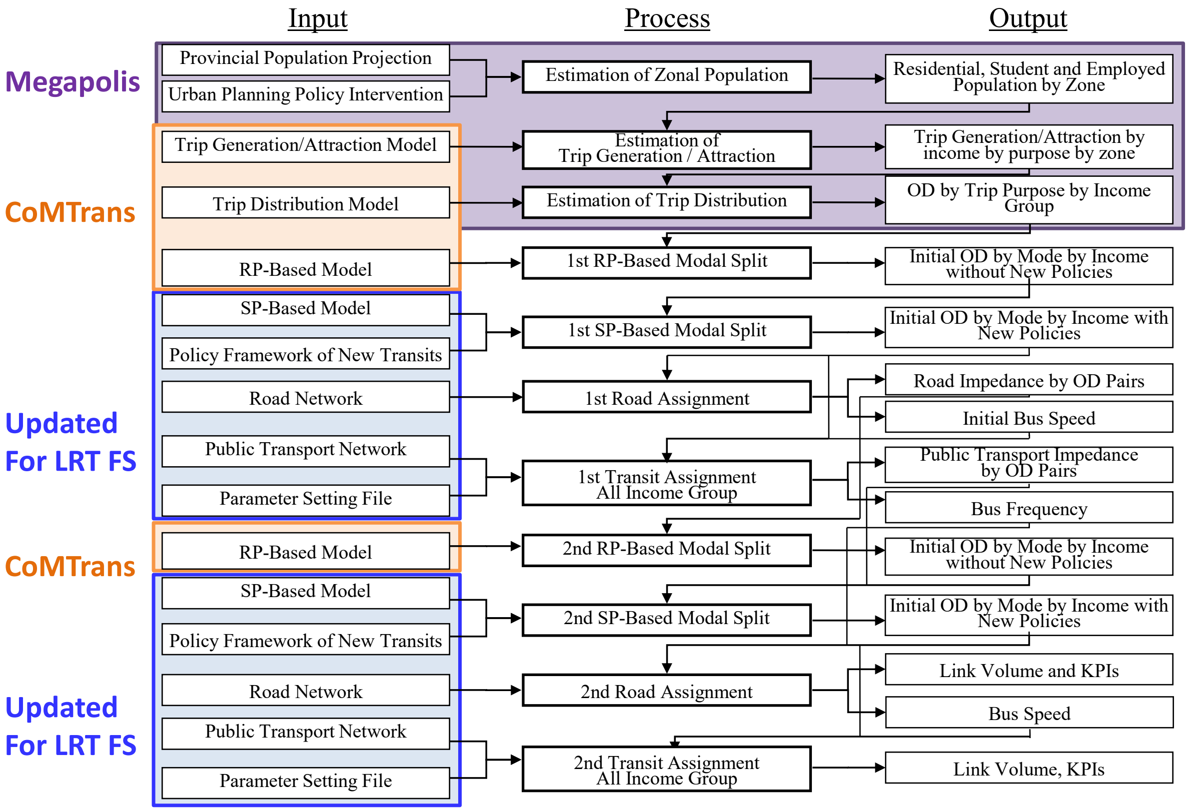
4.4 Demand Forecast

4.4.1 Methodology

Both CoMTrans and Megapolis Transport Master Plan followed the same four-step methodology of the demand forecasting, as shown in Figure 4.4.1. In both master plans, modal split, road assignment, and transit assignment (public transport) were iteratively conducted twice or more. The same methodology was used for the demand forecast in this Survey. The detailed methodology can be found in the Technical Report No. 5 Transport Demand Forecast in the CoMTrans Final Report.

In the Megapolis Transport Master Plan, some inputs are revised based on their policy, structure plan and socio-economics assumptions (framed by purple box in Figure 4.4.1). The detail of the change in structure plan and assumptions are introduced in Chapter 2 in this report.

In this Survey, some inputs were updated based on the assumption that was made for the JICA-LRT Survey (framed by blue box in Figure 4.4.1).



Source: Survey Team based on CoMTrans Technical Report

Figure 4.4.1 Flow of Transport Demand Forecast

4.4.2 Project Scenarios

Transport demand forecast results highly depend on the future project scenario. If the project scenario is changed, the road and public transport network for traffic/transit assignment has to be changed. In addition, the OD table by mode has to be updated, because modal share depends on the road/public transport network.

In the Megapolis Transport Master Plan, several project scenarios were considered for each year, as shown in Table 4.4.1. In this Survey, the traffic/transit assignment was conducted based on scenario Megapolis Case A for both 2020 and 2035. The difference from the Megapolis Case A is the following points:

- New Kelani Bridge - Rajagiriya is added to the network in 2035
- Only JICA-LRT section is included, instead of RTS 1 and 4 (Figure 4.4.3)

There is discussion of whether other RTS lines (RTS 2, 3, 5, 6 and 7) should be included in the scenario. Implementation of other RTS line is in progress, and the feasibility study has been proceeding. However, they are not included in the scenario of the Survey, because the implementation plan has a positive impact to the number of the proposed JICA-LRT passengers. Since the study of other RTS line is in progress, the Survey should follow the scenario without the positive impact to avoid optimistic results in the economic and financial analysis.

Table 4.4.1 Project Scenarios for Transport Demand Analysis

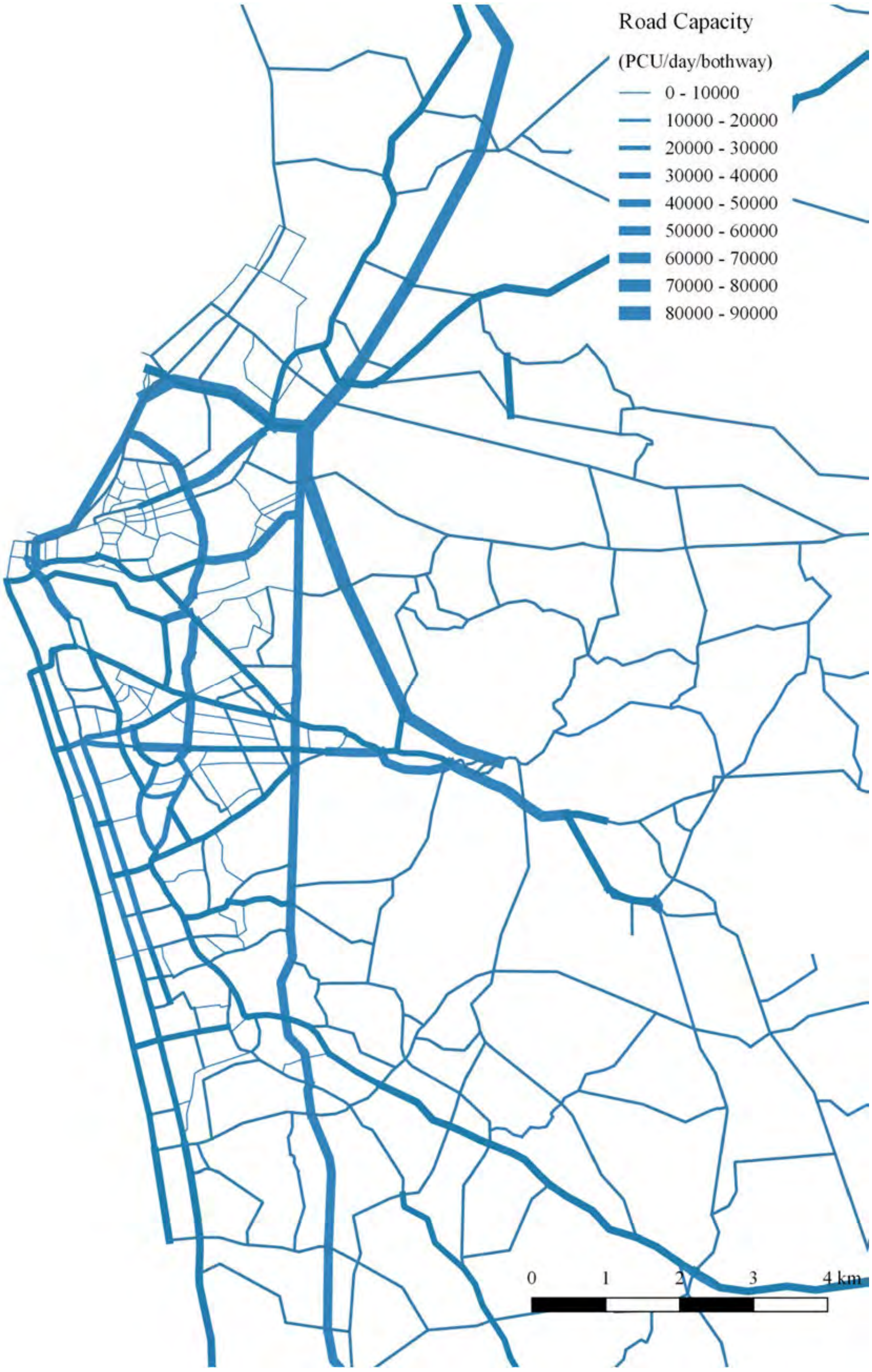
Projects	2020	2035
RTS or LRT		
Proposed LRT Line	✓	✓
Railway Electrification and Modernization		
Panadura - Veyangoda - Polgahawela Line	✓	✓
Kelani Valley Line up to Kottawa	✓	✓
Kelani Valley Line up to Kottawa to Avissawella	✗	✓
Negambo Line with Airport Access	✗	✓
New Rail Lines (Normal / Electrified)		
Kottawa - Horana Line	✓	✓
Kelaniya - Kosgama Line	✗	✓
Roads		
Marine Drive Extension to Dehiwala	✓	✓
Marine Drive Extension to Galleface	✓	✓
Duplication Road Extension	✗	✓
Baseline Extension	✗	✓
RDA on going Projects	✓	✓
RDA Proposed	✗	✓
OCH III	✓	✓
Inland Water Transport		
Wellawatta - Battaramulla (W1)	✓	✓
Fort - Union Place (W2)	✓	✓
Mattakkuliya - Hanwella (W3)	✗	✗
Expressway		
Central Expressway	✗	✓
Ruwanpura Expressway	✗	✓
Kelaniya - Port Access	✓	✓
New Kelani Bridge - Rajagiriya	✗	✓
Modernization of Public Bus Transport System in Western Region	✓	✓

Source: Megapolis Transport Master Plan, 2016

4.4.3 Network Assumptions

(1) Road Network

The road network file of the Megapolis Transport Master Plan was used in this Survey, which was developed based on the road development/improvement plan and the assumptions of MMWD. In the road network, some of the proposed new roads in the CoMTrans Master Plan are not included. On the other hand, the capacity improvement plan of existing roads is included. The road network with road capacity in 2035 is shown in Figure 4.4.2.



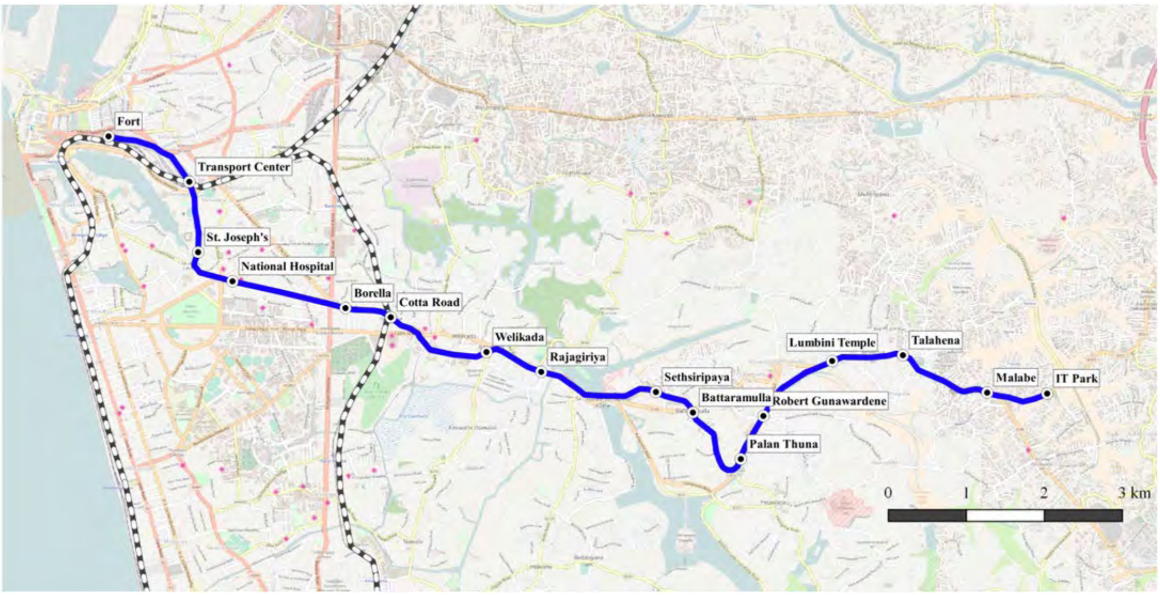
Source: Survey Team

Figure 4.4.2 Road Network in 2035

(2) Railway Network

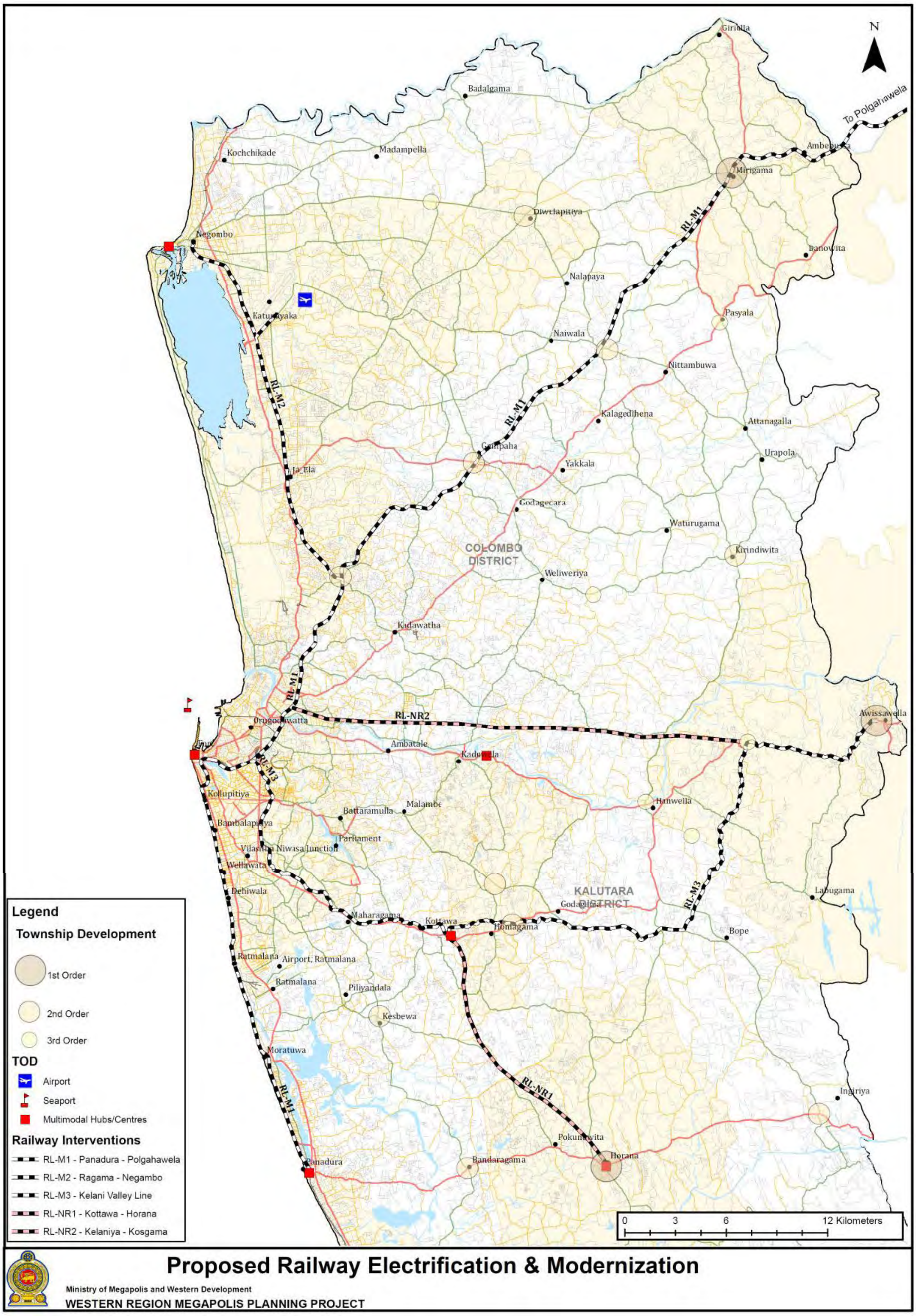
Figure 4.4.3 shows the JICA-LRT route and station location in the demand forecast model. The total length is 17 km, and 16 stations are located roughly every 1 km from Fort to IT Park. The JICA-LRT line has strong connections with other transport mode at the east-end, west-end and middle of the network (Fort, Transport Centre, Borella, Cotta Road and Malabe). The line also covers the area that has current transport demand in the city centre and the area that has potential transport demand around Sethsiripaya and Battaramulla.

Figure 4.4.4 shows the proposed railway line for railway electrification and modernization in the Megapolis Transport Master Plan. The routes and level of service of railway proposed in the Megapolis Transport Master Plan was followed in this Survey. High speeds and frequent operation of the railway are planned in the master plan to achieve its vision of maximizing the use of sustainable public transport modes.



Basemap: OpenStreetMap
Source: Survey Team

Figure 4.4.3 Proposed JICA-LRT Route



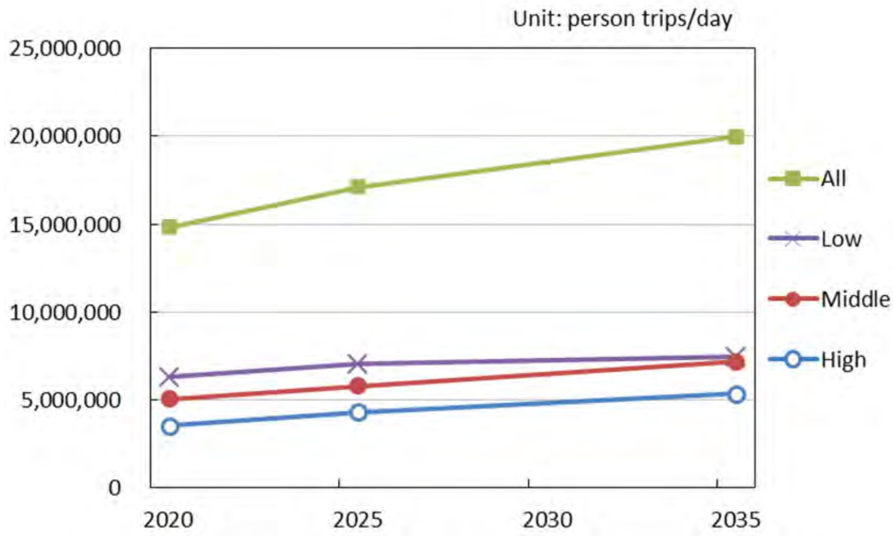
Source: Megapolis Transport Master Plan

Figure 4.4.4 Proposed Railway Line for Railway Electrification and Modernization

4.4.4 Trip Distribution

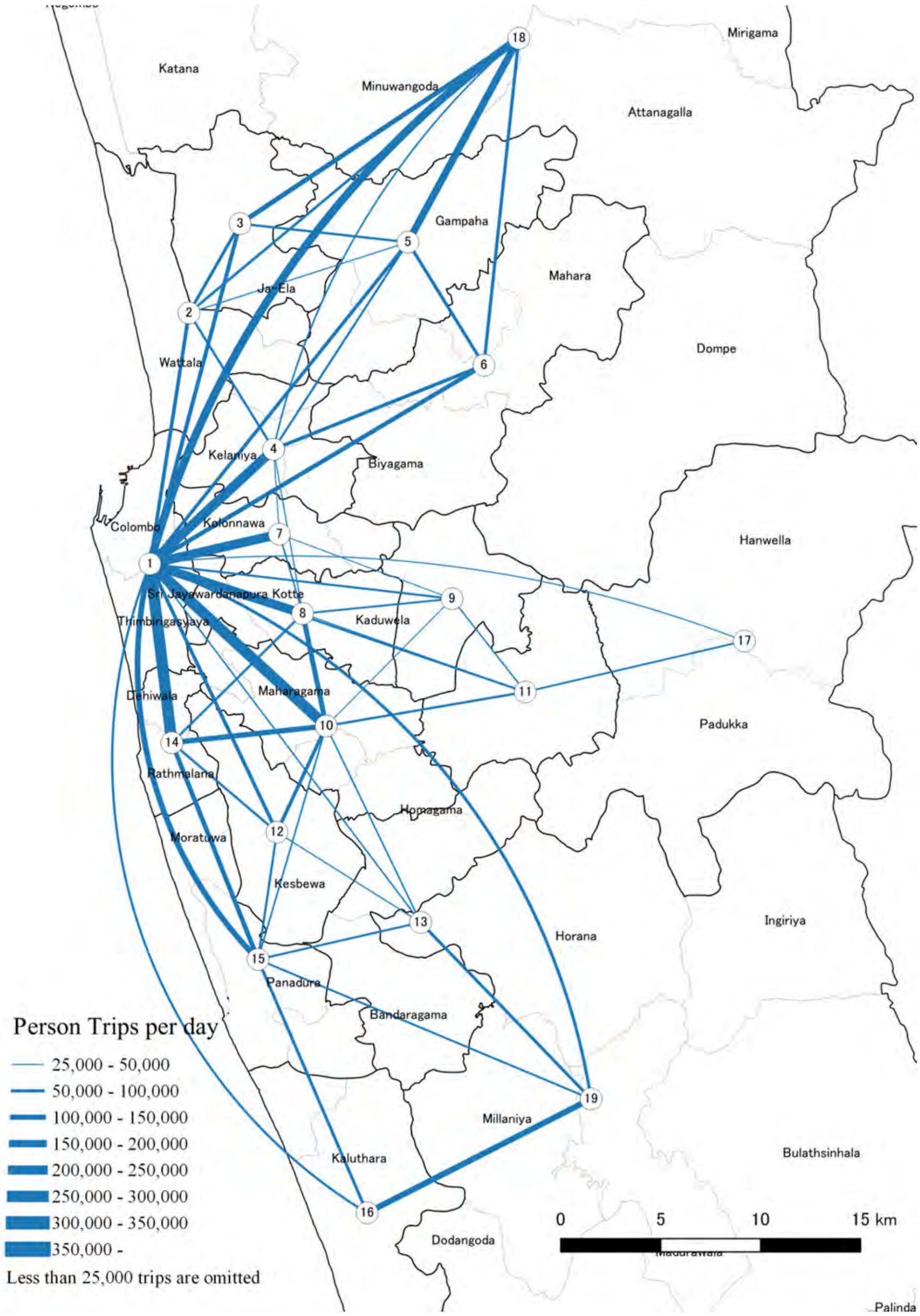
Distribution OD matrices were developed for the Megapolis Transport Master Plan and shared with the Survey Team. The distribution OD was developed by the same generation/attraction model and distribution model, but a different population and economic framework was used to reflect the policy introduced in Chapter 2 of this report. Figure 4.4.5 shows the number of person trips by income level in Western Province. An almost linear growth is expected between 2020 and 2035.

Figure 4.4.6 and Figure 4.4.7 show the person-trip demand line in 2020 and 2035. A large volume of travel demand is observed between the city centre and suburban area along 7 major corridors, and the travel demand significantly increases from 2020 to 2035. In addition, a considerable number of trips is confirmed between the neighbouring suburban areas. Generally, a dramatic change was not observed in the characteristics of desire line, when compared with that in the CoMTrans study.



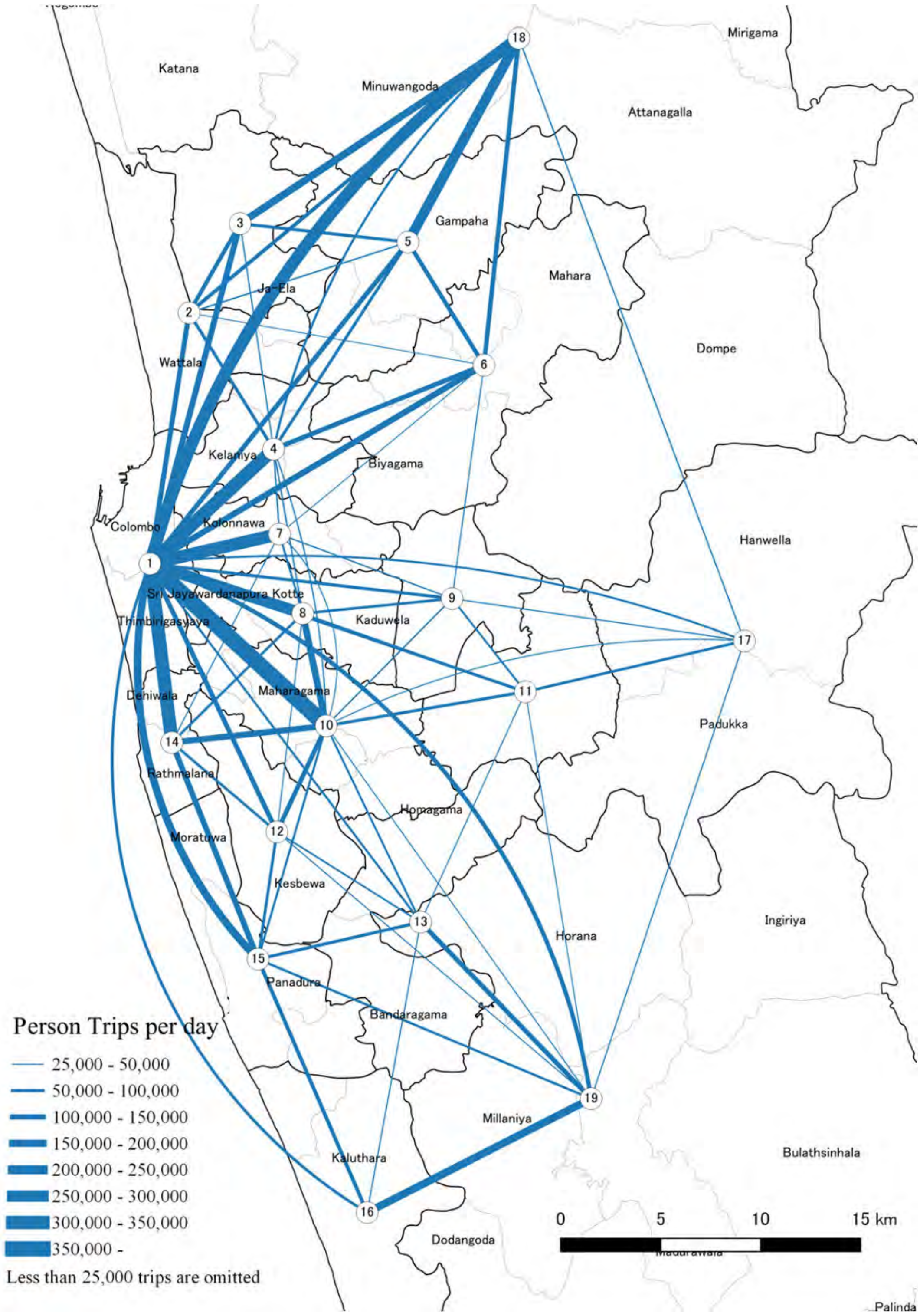
Note: Number of trips includes intra-zonal trips
Source: Ministry of Megapolis and Western Development, graph by Survey Team

Figure 4.4.5 Number of Person Trips in Western Province



Source: Ministry of Megapolis and Western Development, graph by Survey Team

Figure 4.4.6 Person-Trip Desire Line (All Purposes) in 2020



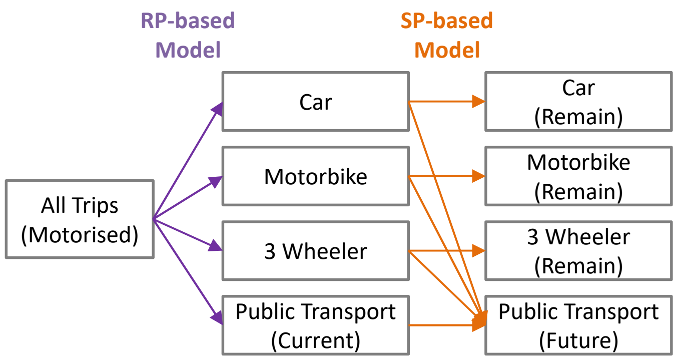
Source: Ministry of Megapolis and Western Development, graph by Survey Team

Figure 4.4.7 Person-Trip Desire Line (All Purposes) in 2035

4.4.5 Modal Choice

Since the JICA-LRT and modernised railway are new transport modes in Sri Lanka, special attention should be paid to transport mode choice. Following the CoMTrans and Megapolis plans, a two-step discrete choice modal split was conducted, as shown in Figure 4.4.8. In the first step, a Revealed Preference (RP) based model was applied to split all motorised trips to existing modes. In the second step, a Stated Preference based model was applied to describe the mode shift to new modes.

A modal choice model using the discrete choice theory is a relatively stable modelling method in terms of space and time differences. Even though spatial location or time is not equal, individual choice of a certain group of people in a specific condition, such as travel time and fare, is empirically stable. With regard to the mathematical structure, a prevalent "multinomial logit model", which can represent unique characteristics of each choice such as transportation mode, was employed.



Source: Survey Team

Figure 4.4.8 2 Steps Modal Split

(1) Revealed Preference (RP) based Model

In this Survey, the same RP-based model was applied as the CoMTrans and Megapolis plans without changes. The RP-based model had been developed based on the Home Visit Survey (HVS), which was conducted in the CoMTrans study. The model structure and parameters can be found in the Technical Report No. 5 Transport Demand Forecast in the CoMTrans Final Report.

(2) Stated Preference (SP) based Model

In this Survey, the SP-based model was updated based on the request from the MMWD. The previous model required many variables as inputs, such as population/employment or railway availability of origin/destination zones. These variables helped to improve the model fitness in some models. However, to prepare all variables is time consuming, and it was confirmed that these models have enough fitness without these variables. The same SP survey data was used for the SP-based model development.

The parameters of the updated SP-based models are presented in the following part. Only the modal shift model from motorcycle was developed by income class; this is because it is observed that people use motorcycle as a mode regardless of their income level.

Table 4.4.2 Parameter Estimation Results of Car to New Public Transport Shift Model

Summary

Model:	**Binary Probit**
Number of estimated parameters:	5
Number of observations:	6077
Number of individuals:	6077
Null log-likelihood:	-4212.3
Cte log-likelihood:	-4091.2
Init log-likelihood:	-4212.3
Final log-likelihood:	-3287.8
Likelihood ratio test:	1848.8
Rho-square:	0.219
Adjusted rho-square:	0.218

Model Structure

$$V_{new} = ASC_{New} + \beta_{timeNew} TTT_{new} + \beta_{cost} Cost_{new} + \beta_{HTO} Dummy_{HTO}$$
$$V_{Car} = ASC_{Car} + \beta_{timeCar} TTT_{Car} + \beta_{ERP} ERP$$

Estimated Parameters

Name	Value	Std err	t-test	p-value	Desctiption
ASC_NEW	0	fixed			Alternative specific constants for the New Public Transport
ASC_CAR	0	fixed			Alternative specific constants for the current mode (Car)
B_COST	-0.00559	0.000286	-19.54	0	Parameter for travel cost
B_ERP	-0.00739	0.000222	-33.26	0	Parameter for Electric Road Pricing
B_HTO	-0.216	0.0474	-4.57	0	Parameter for dummy variable of trip purpose (1 if purpose is Home to Other)
B_TIME_NEW	-0.021	0.00117	-17.9	0	Parameter for total travel time by the New Public Transport
B_TIME_RP	-0.0141	0.000962	-14.65	0	Parameter for total travel time by the current mode (Car)

Vi : fixed utility function of alternative i

Source: Survey Team

Table 4.4.3 Parameter Estimation Results of 3 Wheeler to New Public Transport Shift Model

Summary

Model:	**Binary Probit**
Number of estimated parameters:	6
Number of observations:	1280
Number of individuals:	1280
Null log-likelihood:	-887.2
Cte log-likelihood:	-854.5
Init log-likelihood:	-887.2
Final log-likelihood:	-764.7
Likelihood ratio test:	245.1
Rho-square:	0.138
Adjusted rho-square:	0.131

Model Structure

$$V_{new} = ASC_{New} + \beta_{timeNew} TTT_{new} + \beta_{cost} Cost_{new} + \beta_{HTW} Dummy_{HTW} + \beta_{HTS} Dummy_{HTS}$$
$$V_{3W} = ASC_{3W} + \beta_{time3W} TTT_{3W} + \beta_{ERP} ERP$$

Estimated Parameters

Name	Value	Std err	t-test	p-value	Desctiption
ASC_NEW	0	fixed			Alternative specific constants for the New Public Transport
ASC_3W	0	fixed			Alternative specific constants for the current mode (3-Wheeler)
B_COST	-0.00753	0.00108	-6.96	0	Parameter for travel cost
B_ERP	-0.00739	0.000637	-11.62	0	Parameter for Electric Road Pricing
B_HTW	0.553	0.109	5.08	0	Parameter for dummy variable of trip purpose (1 if purpose is Home to Work)
B_HTS	0.304	0.0949	3.2	0	Parameter for dummy variable of trip purpose (1 if purpose is Home to School)
B_TIME_NEW	-0.0125	0.00246	-5.09	0	Parameter for total travel time by the New Public Transport
B_TIME_3W	-0.00374	0.00186	-2.01	0.04	Parameter for total travel time by the current mode (3-Wheeler)

Vi : fixed utility function of alternative i

Source: Survey Team

Table 4.4.4 Parameter Estimation Results of MC to New Public Transport Shift Model (Low Income)

Summary

Model:	**Binary Probit**
Number of estimated parameters:	5
Number of observations:	1677
Number of individuals:	1677
Null log-likelihood:	-1162.4
Cte log-likelihood:	-1144.7
Init log-likelihood:	-1162.4
Final log-likelihood:	-1026.5
Likelihood ratio test:	271.7
Rho-square:	0.117
Adjusted rho-square:	0.113

Model Structure

$$V_{new} = ASC_{New} + \beta_{timeNew}TTT_{new} + \beta_{cost}Cost_{new} + \beta_{HTS}Dummy_{HTS}$$
$$V_{MC} = ASC_{MC} + \beta_{timeMC}TTT_{MC} + \beta_{ERP}ERP$$

Estimated Parameters

Name	Value	Std err	t-test	p-value	Desctiption
ASC_NEW	0	fixed			Alternative specific constants for the New Public Transport
ASC_MC	0	fixed			Alternative specific constants for the current mode (Motorcycle)
B_COST	-0.00985	0.00104	-9.46	0	Parameter for travel cost
B_ERP	-0.015	0.00116	-12.93	0	Parameter for Electric Road Pricing
B_HTS	-0.385	0.0932	-4.13	0	Parameter for dummy variable of trip purpose (1 if purpose is Home to School)
B_TIME_NEW	-0.0106	0.00211	-5.05	0	Parameter for total travel time by the New Public Transport
B_TIME_MC	-0.012	0.00177	-6.79	0	Parameter for total travel time by the current mode (Motorcycle)

Vi : fixed utility function of alternative i

Source: Survey Team

Table 4.4.5 Parameter Estimation Results of MC to New Public Transport Shift Model (Middle/High Income)

Summary

Model:	**Binary Probit**
Number of estimated parameters:	5
Number of observations:	1051
Number of individuals:	1051
Null log-likelihood:	-728.5
Cte log-likelihood:	-725.2
Init log-likelihood:	-728.5
Final log-likelihood:	-607.1
Likelihood ratio test:	242.8
Rho-square:	0.167
Adjusted rho-square:	0.16

Model Structure

$$V_{new} = ASC_{New} + \beta_{timeNew}TTT_{new} + \beta_{cost}Cost_{new} + \beta_{NHB}Dummy_{NHB}$$
$$V_{MC} = ASC_{MC} + \beta_{timeMC}TTT_{MC} + \beta_{ERP}ERP$$

Estimated Parameters

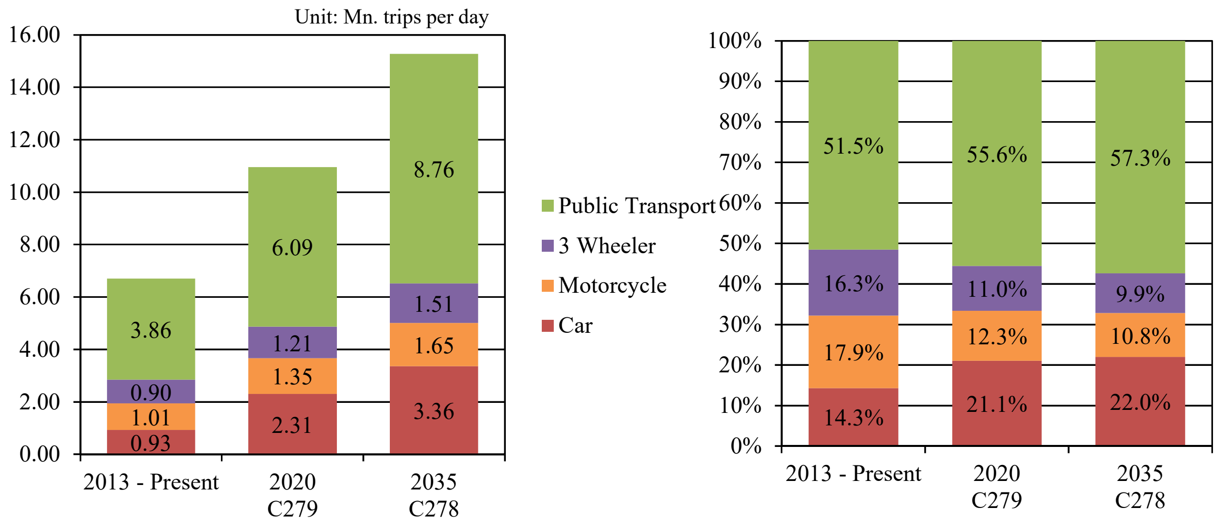
Name	Value	Std err	t-test	p-value	Desctiption
ASC_NEW	0	fixed			Alternative specific constants for the New Public Transport
ASC_MC	0	fixed			Alternative specific constants for the current mode (Motorcycle)
B_COST	-0.00673	0.00162	-4.16	0	Parameter for travel cost
B_ERP	-0.0195	0.00154	-12.71	0	Parameter for Electric Road Pricing
B_NHB	0.275	0.115	2.39	0.02	Parameter for dummy variable of trip purpose (1 if purpose is Non-home based Business)
B_TIME_NEW	-0.0198	0.00307	-6.45	0	Parameter for total travel time by the New Public Transport
B_TIME_MC	-0.00757	0.00288	-2.63	0.01	Parameter for total travel time by the current mode (Motorcycle)

Vi : fixed utility function of alternative i

Source: Survey Team

4.4.6 Modal Share

Based on the updated SP model, the modal split was conducted. Figure 4.4.9 shows the number of trips by mode and modal share at each year. The total number of trips is the same as the Megapolis Transport Master Plan, because the same socio-economic framework was used in this Survey. The public transport mode share will be slightly increased, supported by the improvement of public transport that is proposed in the Megapolis Transport Master Plan.



Source: Survey Team

Figure 4.4.9 Number of Person Trips by Mode and Modal Share

4.4.7 Settings for Traffic/Transit Assignment

Other than the above mentioned input data, many parameters have to be set to conduct the traffic/transit assignment. In this sub-section, some of these parameters are presented.

(1) Fare of Public Transport

In the model, the base fare cost is applied when passengers use JICA-LRT. If the travel distance by JICA-LRT is longer than 1.5 km, distance based fare is applied.

For the fare of the JICA-LRT, four types of fare levels were examined in the demand forecast following the examination in CoMTrans Study. These fare levels were set considering the fare of existing bus[9] service. Generally, low fare can attract more passengers compared to higher fare during the initial stages, while revenues from public transport will be limited.

After the demand forecast and the economic/financial analysis, Normal×2.3 was identified as the most feasible fare for the following reasons.

- From a financial viewpoint, it is estimated as the most feasible fare level, maximising the fare revenue of JICA-LRT.

[9] In CoMTrans and Megapolis study, future bus fare was estimated (base fare = 11.7 LKR, distance based fare = 2.21 LKR/km). This value was set based on the modelled current bus fare (base fare = 9 LKR, distance based fare = 1.7 LKR/km) with fare raise in the future.

- From a political viewpoint, it does not exceed the maximum paying capacity of passengers (100 LKR for Fort-Malabe) which was discussed in the PMU members as affordable fare level.
- From social and economical viewpoint, the estimated number of passengers is enough to contribute mitigation of traffic congestion along Malabe corridor.

The results of the demand forecast and economic/financial analysis by fare level are summarised in Chapter 7.

Table 4.4.6 Fare of New Railway Transport

Fare Level	Base Fare Cost	Base Fare Distance	Distance based Fare	Fort-Sethsiripaya	Fort-Malabe
	LKR	km	LKR/km	LKR	LKR
Normal	11.7	1.5	2.21	28	40
Normal ×1.2	15	1.5	2.55	34	48
Normal ×1.5	18	1.5	3.4	43	62
Normal ×2.3	27	1.5	5.1	64	93

Source: Survey Team

(2) Service Level of Public Transport by Mode

Table 4.4.7 Service Level of Public Transport by Mode

Item	Bus	Modernised Railway	JICA-LRT
Frequency	Dependent on demand	Dependent on demand Initial setting is 1 - 12 trains per hour	Dependent on demand Initial setting is 20 trains per hour
Capacity*	60 passengers per vehicle (average of medium and large buses)	2,000 passengers per one train set	1,000 passengers per one train set
Speed	80% of road speed, maximum speed is 20km/h	23~50 km/h (depend on Line)	28.5 km/h

Note: *100% capacity is seating capacity plus comfortable standing passenger capacity. Standing passengers can hold a hand strap or a hand rail.

Source: Survey Team

(3) Toll of Expressway in Model

In the road traffic assignment, each trip is loaded to the minimum generalised cost path, considering the delay caused by the traffic congestion. The generalised cost normally consists of time and cost. The travel time are converted to cost unit by using the value of time. As the travel cost for route choice, toll of expressway was taken into considered.

In the STRADA[10] model, the toll of the expressway has to be inputted by fixed value or distance based value by each link. However, in actuality, the expressway toll cannot be described in these ways if the toll rate is defined for each entrance/exit pair. Therefore, regression models were

[10] STRADA is software for transport demand forecast, developed by JICA under the leadership of Prof. Hideo Nakamura at Tokyo University in 1993. STARDA is comprehensive, simple and cost effective software, which is also used in RDA in Sri Lanka. The software consists of 17 individual modules. 8 modules were used to build private and public transport networks, trip assignment, view assignment outputs and manipulate data through Geographic Information System (GIS) and STARADA.

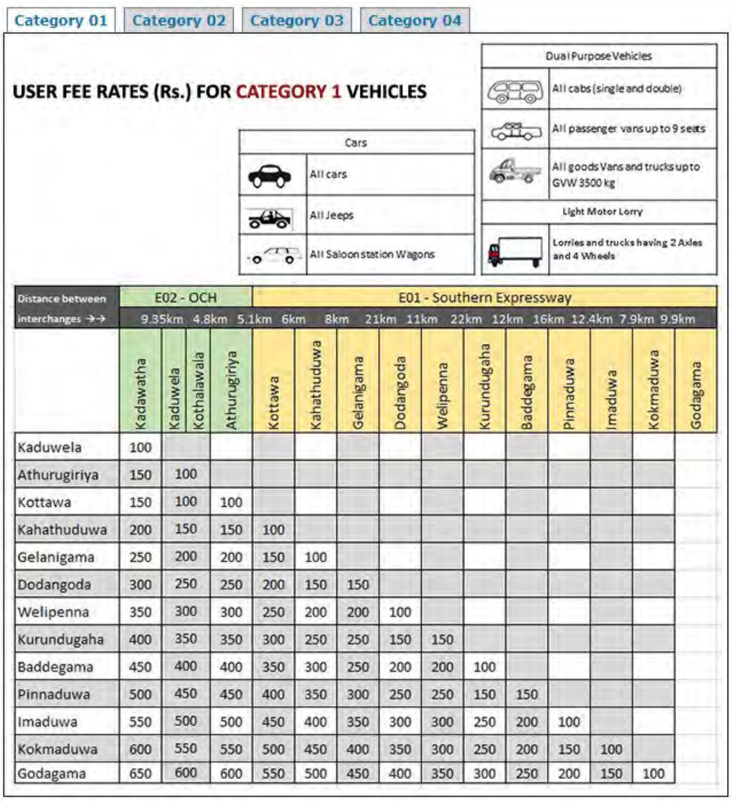
developed by University of Moratuwa to minimize the difference between the toll in the model and the complicated toll actually implemented.

The variables estimated in the regression model are shown in Table 4.4.8 by type of expressway. The regression model for inter-city expressway was developed based on the current toll system of Southern Expressway (E01), which is shown in Figure 4.4.10 and Figure 4.4.11. The model for urban expressway was developed based on the toll of Colombo-Katunayake Expressway (E03). The toll system and category of vehicle types are published in the RDA's website.

Table 4.4.8 Setting for Toll of Expressway

Car Categoty of RDA	Inter City Expressway		Urban Expressway	
	Fix	per Km	Fix	per Km
Category 1	76.47	3.64	108	7.4
Category 3	76.32	11.85	92	20.1
Category 4	93.77	15.53	46	30.6

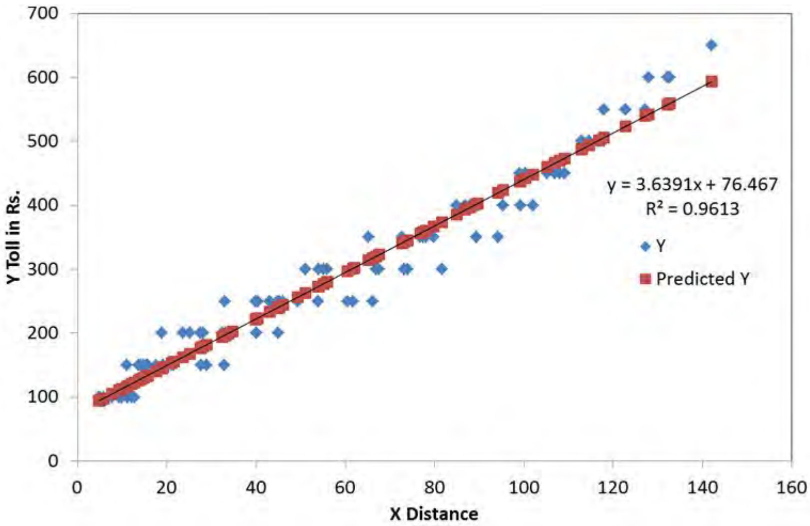
Unit: LKR
Source: Ministry of Megapolis and Western Development



Distance between interchanges →→	E02 - OCH			E01 - Southern Expressway										
	9.35km	4.8km	5.1km	6km	8km	21km	11km	22km	12km	16km	12.4km	7.9km	9.9km	
	Kadawatha	Kaduwela Kothalawala	Athurugiriya	Kottawa	Kahathuduwa	Gelanigama	Dodangoda	Welipenna	Kurundugaha	Baddegama	Pinnaduwa	Imaduwa	Kokmaduwa	Godagama
Kaduwela	100													
Athurugiriya	150	100												
Kottawa	150	100	100											
Kahathuduwa	200	150	150	100										
Gelanigama	250	200	200	150	100									
Dodangoda	300	250	250	200	150	150								
Welipenna	350	300	300	250	200	200	100							
Kurundugaha	400	350	350	300	250	250	150	150						
Baddegama	450	400	400	350	300	250	200	200	100					
Pinnaduwa	500	450	450	400	350	300	250	250	150	150				
Imaduwa	550	500	500	450	400	350	300	300	250	200	100			
Kokmaduwa	600	550	550	500	450	400	350	300	250	200	150	100		
Godagama	650	600	600	550	500	450	400	350	300	250	200	150	100	

Source: Expressway Operation Maintenance And Management Division,
Road Development Authority

Figure 4.4.10 Toll of Outer Circular and Southern Expressway (Category1)



Source: Ministry of Megapolis and Western Development

Figure 4.4.11 Regression Model for Expressway Toll (Category 1)

(4) Value of Time

Value of time is specified by income group as shown in Table 4.4.9, which is the same as in the CoMTrans and Megapolis Master Plan. The mean household income was estimated by the Home Visit Survey Results, and adjusted by the Household Income and Expenditure Survey 2012/2013. The value was converted to the worker's time value. Although averaged time value by purpose is used for economic analysis, worker's time value was used for the transport demand forecast. According to experience in other countries, the time value of transport mode and route choice is higher than their salary per unit of time.

Table 4.4.9 Value of Time for Traffic Assignment

Income Level	Mean Household Income (LKR)	Avg. No. of Workers in Household	Monthly Working Hours	Social Security Cost	Worker's Time Value (LKR/h)
Low	24,009	1.20	140	30%	186
Middle	56,810	1.72	140	30%	307
High	186,164	1.90	140	30%	909
All	70,366	1.36	140	30%	479

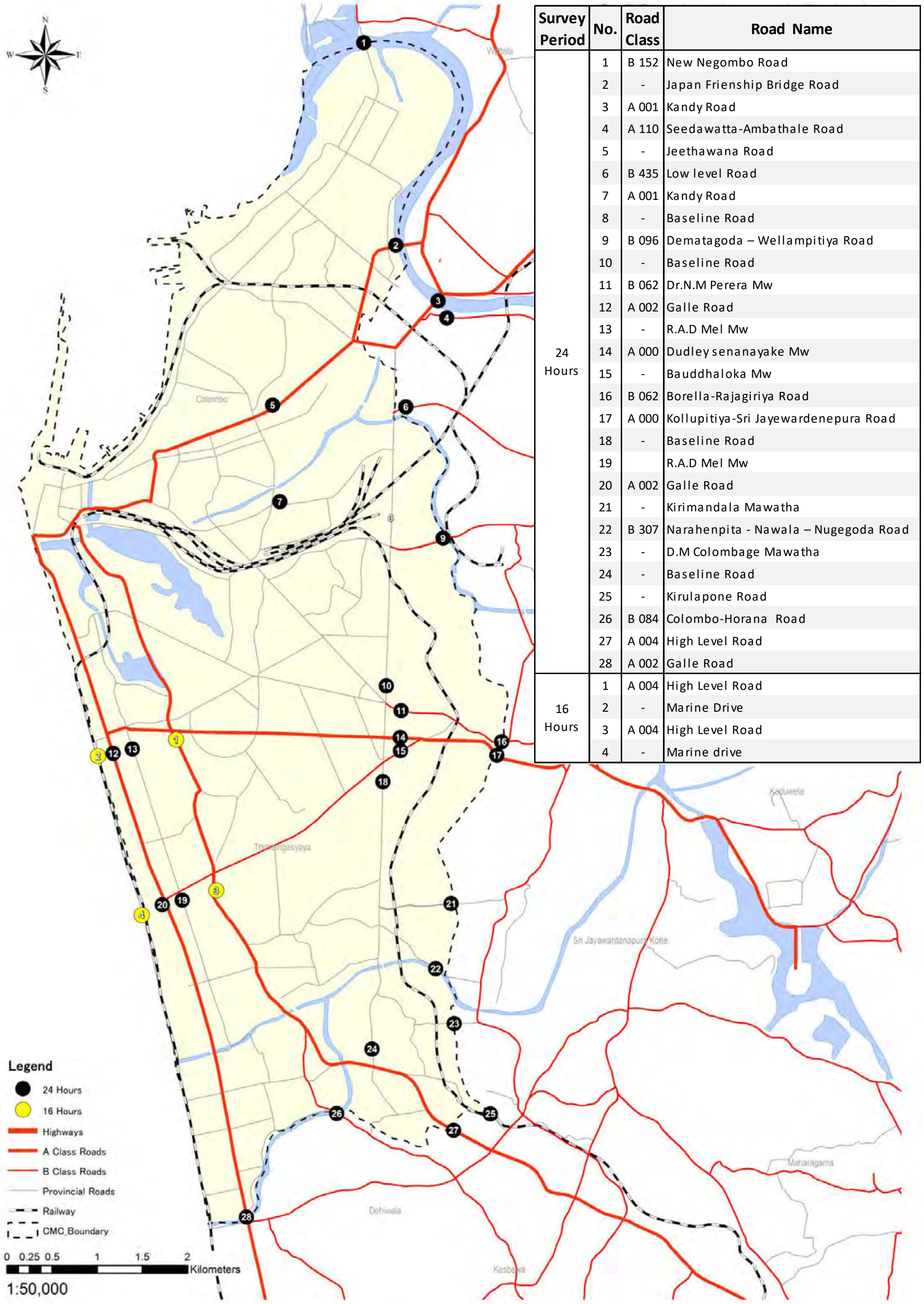
Note: "Avg." stands for "average".
Source: CoMTrans Study Team

(5) Daily and Peak Hour Traffic

Traffic assignment was conducted on a daily basis, taking data availability and accuracy into consideration. After the daily traffic assignment, peak-hour values were estimated by multiplying the daily volume by the peak-hour ratio. The peak-hour ratio is generally estimated by dividing the peak one hour passenger volume by the daily passenger volume.

The peak hour ratio in the Malabe Corridor in terms of passenger traffic is estimated in the range of approximately 10% to 13%, according to screen line survey of the CoMTrans Project conducted in 2013. Screenline survey site numbers 11, 14, 15, 16 and 17 depicted in Figure 4.4.12 are selected, and traffic volumes in vehicle unit and in passenger unit for peak hour are summarized in Table 4.4.10 respectively.

The peak hour ratio for JICA-LRT passenger demand estimation is assumed at 13%, which is the highest ratio among the observed survey sites in the Malabe Corridor.



Survey Period	No.	Road Class	Road Name
24 Hours	1	B 152	New Negombo Road
	2	-	Japan Frienship Bridge Road
	3	A 001	Kandy Road
	4	A 110	Seedawatta-Ambathale Road
	5	-	Jeethawana Road
	6	B 435	Low level Road
	7	A 001	Kandy Road
	8	-	Baseline Road
	9	B 096	Dematagoda – Wellampitiya Road
	10	-	Baseline Road
	11	B 062	Dr.N.M Perera Mw
	12	A 002	Galle Road
	13	-	R.A.D Mel Mw
	14	A 000	Dudley senanayake Mw
	15	-	Bauddhaloka Mw
	16	B 062	Borella-Rajagiriya Road
	17	A 000	Kollupitiya-Sri Jayewardenepura Road
	18	-	Baseline Road
	19		R.A.D Mel Mw
	20	A 002	Galle Road
	21	-	Kirimandala Mawatha
	22	B 307	Narahenpita - Nawala – Nugegoda Road
	23	-	D.M Colombage Mawatha
	24	-	Baseline Road
	25	-	Kirulapone Road
	26	B 084	Colombo-Horana Road
	27	A 004	High Level Road
	28	A 002	Galle Road
16 Hours	1	A 004	High Level Road
	2	-	Marine Drive
	3	A 004	High Level Road
	4	-	Marine drive

Source: CoMTrans

Figure 4.4.12 Screenline Survey Sites

Table 4.4.10 Peak Hour Traffic Volume on Malabe Corridor from Screenline Survey

Category	Survey Site No.	Road Name		Passenger Vehicle					Goods Vehicle			Passenger Vehicle			Total	Peak Hour Ratio
				Motorbike	3-Wheeler	Car, Jeep	Van	Pick-up	Med Truck	Large Truck (3+ axle)	Container Trailer	Minibus (-29seats)	Bus	Other		
Vehicle/Peak-hour/Inflow Dir.	11	B062	Dr. N. M. Perera Mw	721	353	688	180	17	16	0	0	10	118	0	2,103	10%
	14	A000	Dudley Senanayake Mw	435	241	1,384	159	47	17	1	0	32	64	1	2,381	10%
	15	-	Buddhaloka Mw	167	170	947	123	32	20	0	0	11	7	0	1,477	10%
	16	B062	Borella-Rajagiriya Rd	661	539	575	106	26	23	0	0	13	187	0	2,130	13%
	17	A000	Kollupitiya-Sri Jayawardenepura Rd	665	416	1,760	568	143	37	1	1	3	14	0	3,608	8%
Passenger/Peak-hour/Inflow	11	B062	Dr. N. M. Perera Mw	843	517	1,141	652	28	18	0	0	339	7,102	0	10,622	12%
	14	A000	Dudley Senanayake Mw	509	353	2,295	576	78	19	1	0	1,086	4,537	0	9,434	13%
	15	-	Buddhaloka Mw	195	249	1,570	446	53	23	0	0	373	496	0	3,382	12%
	16	B062	Borella-Rajagiriya Rd	832	933	942	261	43	26	0	0	203	9,085	0	12,299	13%
	17	A000	Kollupitiya-Sri Jayawardenepura Rd	778	609	2,918	2,058	237	42	1	1	47	680	0	7,327	10%

Note: Peak hour is during 7:00-8:00 am; Site 15 and 17 has no route bus operation
Source: CoMTrans Screen Line Survey 2013

(6) Passenger Car Unit (PCU)

Passenger car unit by major category of vehicles are listed in Table 4.4.11. The values are adopted from the road geometric design standards of the RDA.

Table 4.4.11 Passenger Car Units for Traffic Assignment

Car	1.0
Motorcycle	0.4
Three Wheeler	0.8
Bus	1.8
Medium Truck	1.7
Large Truck	2.8
Container Trailer	4.0

Source: Geometric Design Standards of Roads, RDA, 1998

(7) Average Number of Passengers

The average number of passengers was also estimated from various types of surveys, and are summarised in Table 4.4.12.

Table 4.4.12 Average Number of Passengers for Traffic Assignment

Car	1.71
Motorcycle	1.22
3 Wheeler	1.42
Bus	38.8
Truck	2.2

Source: Car, Motorcycle and 3 Wheeler; CoMTrans Home Visit Survey, 2013
Bus: CoMTrans Screen Line Survey, 2013
Truck: CoMTrans Cordon Line Survey, 2013

4.4.8 Results of Demand Forecast

(1) Summary of Passenger Volume

Based on the methodology and assumptions described in the previous section, traffic assignments were conducted. Table 4.4.13 shows the summary of demand forecast of JICA-LRT in 2020, 2025 and 2035. Daily passenger volume is expected to be increased to 498,000 passengers (pax.)/day in 2035. The Passenger per Hour per Direction (PPHPD) is calculated from the maximum daily section volume per direction multiplied by the peak ratio of 13%. The daily passenger flow would increase with operation of other RTS lines.

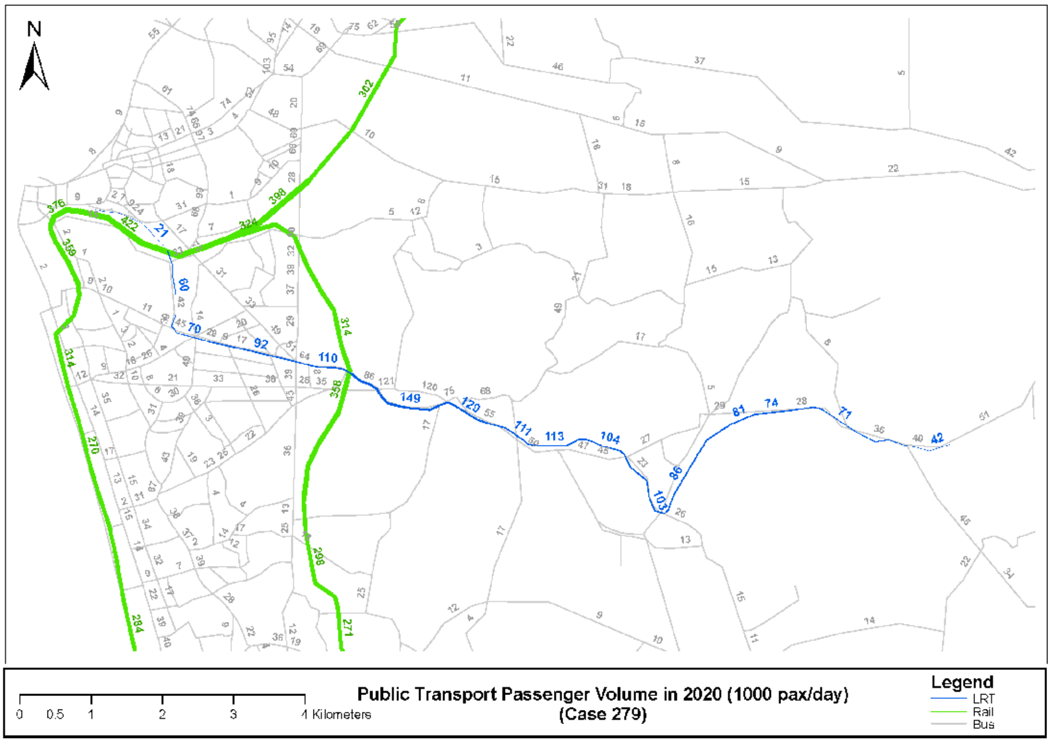
Table 4.4.13 Daily Passenger Volume Ratio

Indicator	2020	2025*	2035
PPHPD	11,500	14,300	19,800
Max Section	Cotta Rd. - Walikada	Cotta Rd. - Walikada	Cotta Rd. - Walikada
Daily Passengers	295,000	363,000	498,000
Daily Passenger-km	1,736,000	2,087,000	2,787,000

Note: Fare Level D
*: The demand of 2025 was calculated by linear interpolation of demand in 2020 and 2035.
Source: Survey Team

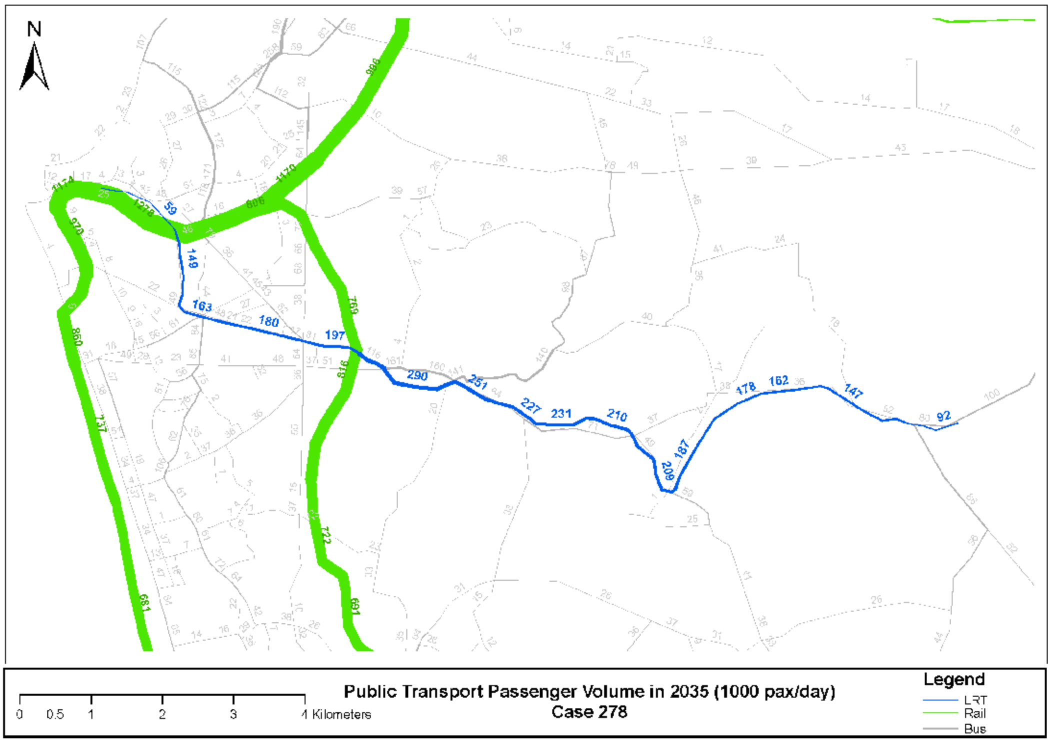
(2) Sectional Daily Volume

Figure 4.4.13 and Figure 4.4.14 show the sectional daily passenger volume of public transport in 2020 and 2035. The daily section volume of JICA-LRT is estimated to increase from 2020 to 2035, and the section volumes will be about 60,000~290,000 passengers/both direction in 2035. This suggests that JICA-LRT will be an option of transport mode for people living in the area south/east of Malabe to get to city centre or Sethsiripaya, by transferring Bus and JICA-LRT.



Source: Survey Team

Figure 4.4.13 Sectional Daily Passenger Volume of Public Transport in 2020

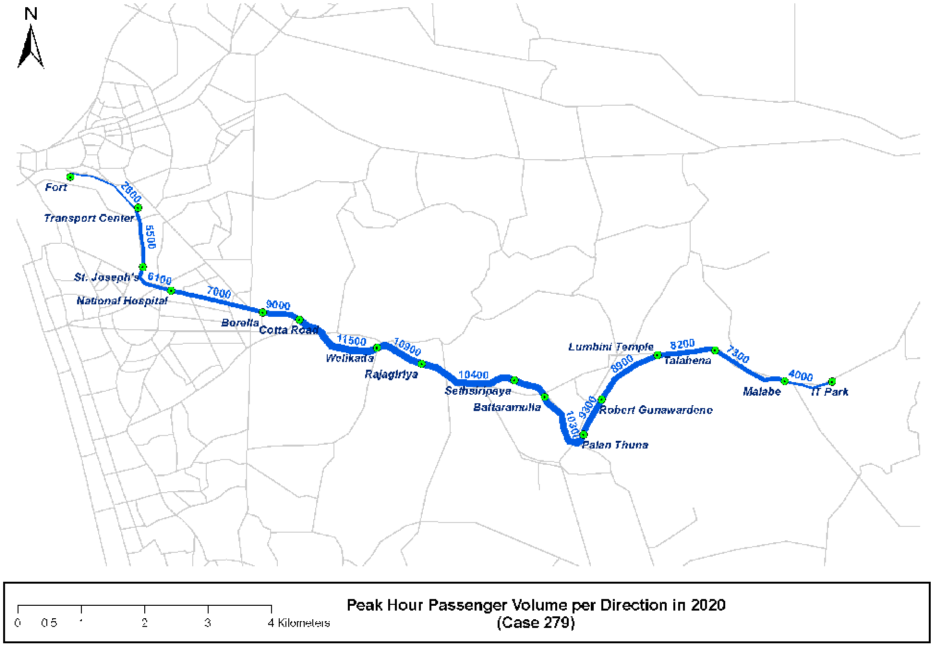


Source: Survey Team

Figure 4.4.14 Sectional Daily Passenger Volume of Public Transport in 2035

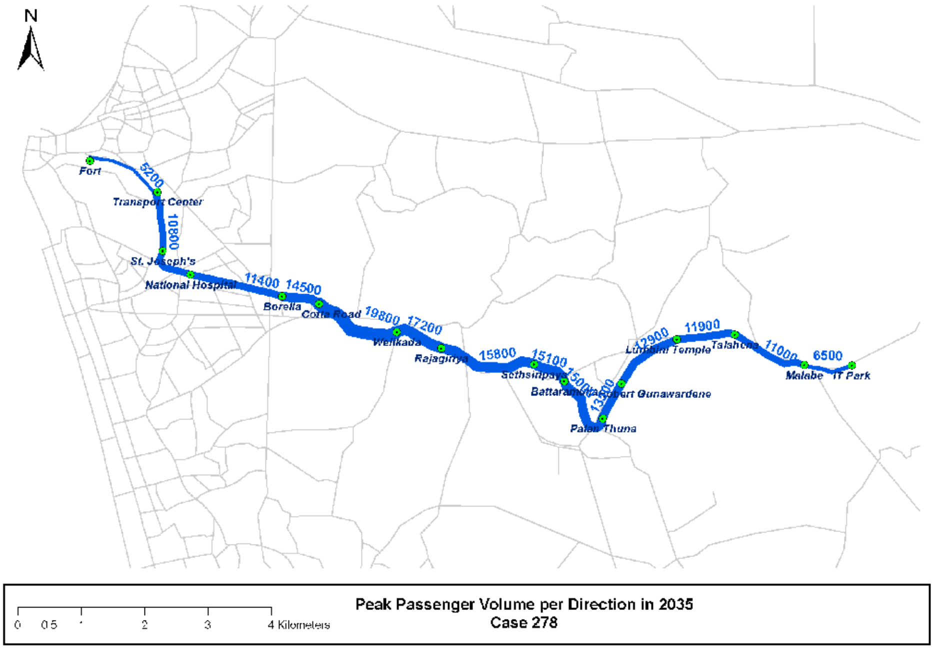
(3) Peak Hour Sectional Volume

Figure 4.4.15 and Figure 4.4.16 show the peak hour section volume in passenger/hour/direction in 2020 and 2035. The peak hour section volume in 2035, 19,800 passenger/hour/direction, is within the physical capacity of JICA-LRT.



Source: Survey Team

Figure 4.4.15 Peak Hour Section Volume of JICA-LRT in 2020



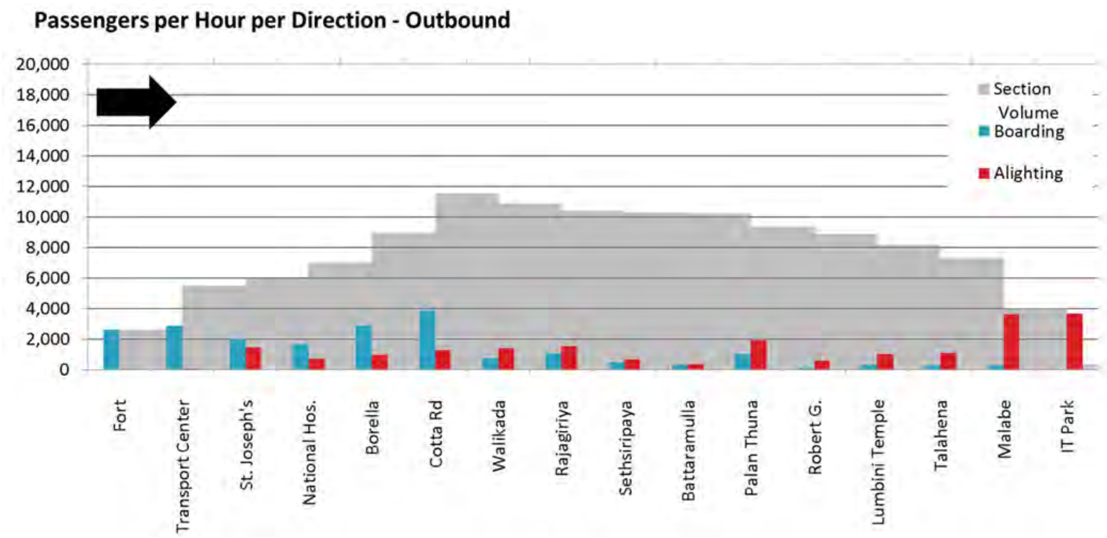
Source: Survey Team

Figure 4.4.16 Peak Hour Section Volume of JICA-LRT in 2035

(4) Peak Hour Boarding/Alighting Passenger Volume

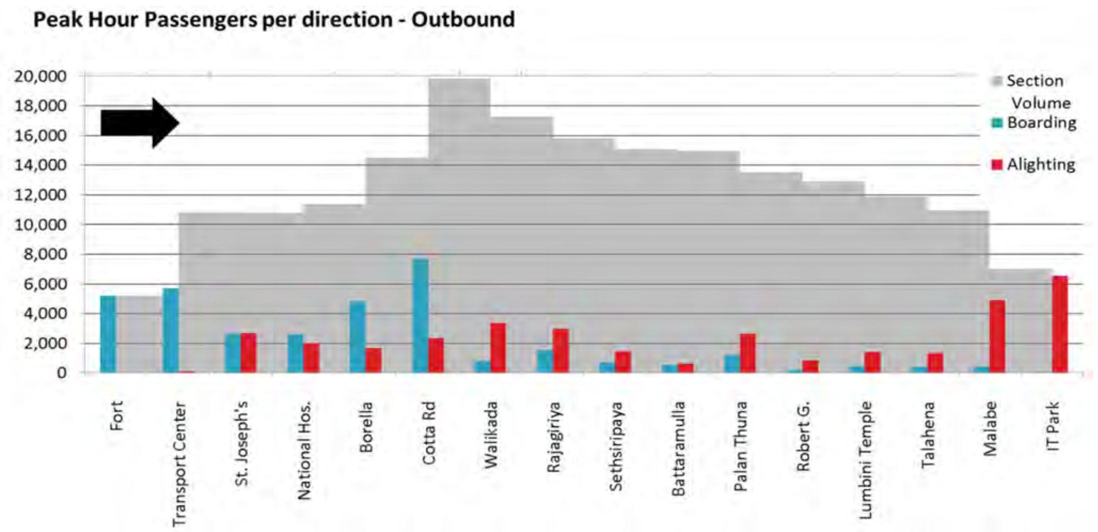
The peak hour boarding/alighting passenger volume and the section volumes in 2020 and 2035 are shown in Figure 4.4.17 and Figure 4.4.18. Based on the figures, the main stations can be identified as Fort, Transport Center, Borella, Cotta Road, Malabe and IT Park. Most of these main stations have transfer connections with railway or major bus lines.

Table 4.4.14 summarises the number of boarding/alighting passengers in peak hour and in a day, in 2035. This information was used for the station design in Section 4.11 in this report. While the boarding/alighting passenger volume in the inbound direction has some inconsistency between the neighbouring stations, adjusted variables are calculated based on the volume of the outbound direction.



Source: Survey Team

Figure 4.4.17 Peak Hour Passenger Loading by Station in 2020



Source: Survey Team

Figure 4.4.18 Peak Hour Passenger Loading by Station in 2035

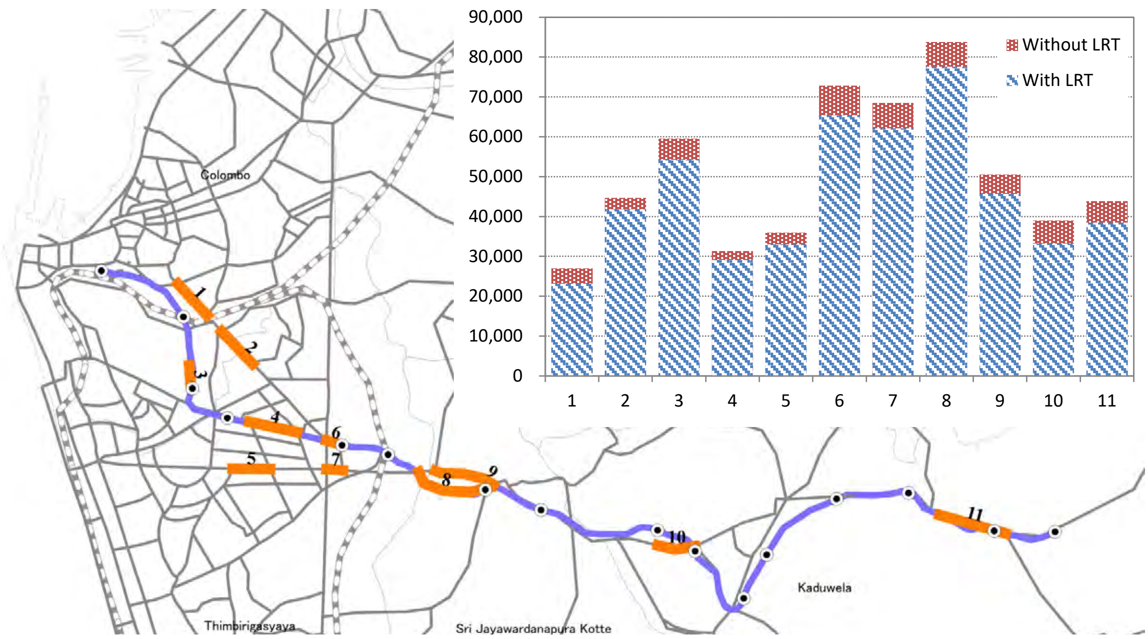
Table 4.4.14 Peak Hour and Daily Boarding/Alighting Passengers at each Station in 2035

Peak Hour				Daily Base	
Station	Boarding	Alighting	Total	Total	Total
	(Pax/Hour/dir)	(Pax/Hour/dir)	(Pax/Hour/dir)	(Pax/Day/dir)	(pax/day/both)
Fort	5,200	-	5,200	40,100	74,000
Transport Center	5,700	100	5,800	44,800	82,700
Union Place	2,700	2,700	5,400	41,100	75,900
National Hospital	2,600	2,000	4,600	35,300	65,200
Borella	4,800	1,700	6,500	49,800	91,900
Cotta Rd	7,700	2,300	10,000	77,000	142,100
Walikada	800	3,400	4,200	32,000	59,100
Rajagiriya	1,500	3,000	4,500	34,600	63,900
Sethsiripaya	700	1,500	2,200	16,600	30,600
Battaramulla	500	600	1,100	8,900	16,400
Palan Thuna	1,200	2,700	3,900	29,800	55,000
Robert G.	200	800	1,000	7,700	14,200
Lumbini Temple	400	1,400	1,800	14,400	26,600
Talahena	400	1,300	1,700	13,400	24,700
Malabe	400	4,900	5,300	41,000	75,700
IT Park	100	6,600	6,700	51,200	94,500

Source: Survey Team

(5) Reduction of Vehicle Volume on Road Section

Figure 4.4.19 shows the traffic volume of road sections along the JICA-LRT route in the with/without case scenarios. An approximately 7% to 11% traffic reduction is expected by the implementation of JICA-LRT. The reduction of total traffic of the 11 load sections is 10%. Generally, 10% traffic reduction significantly contributes to the mitigation of traffic congestion.

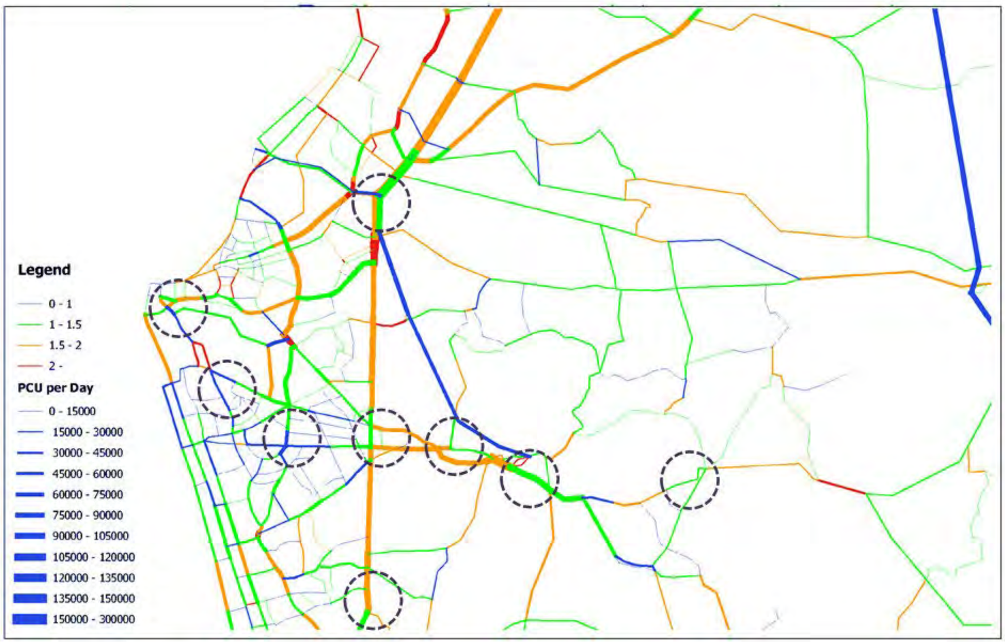


Source: Survey Team

Figure 4.4.19 Reduction of Vehicle Volume on Road Section in 2035

(6) Volume Capacity Ratio of Road Section

Figure 4.4.20 and Figure 4.4.21 show the level of road congestion by road section in the cases of With/Without JICA-LRT in 2035. The figures indicate that by the implementation of JICA-LRT, the road congestion will be mitigated not only in the Malabe Corridor, but also in the road section inside the city centre and Baseline Road, etc.



Source: Survey Team

Figure 4.4.20 Volume Capacity Ratio and Traffic Volume in 2035 (With JICA-LRT Case)

Source: Survey Team

Figure 4.4.21 Volume Capacity Ratio and Traffic Volume in 2035 (Without JICA-LRT Case)

(7) Travel Time and Speed by Mode

Table 4.4.15 shows the average travel time and average speed by mode between Fort-Malabe in the cases of With/Without JICA-LRT in 2020, 2025 and 2035. The travel speed of the section will be improved by the implementation of JICA-LRT. Regardless of the With/Without case, the JICA-LRT will be faster than the private mode speed. The speed was calculated in the daily traffic assignment, so the road speed will be much lower in the peak hour.

Table 4.4.15 Travel Time and Speed between Fort-Malabe Section

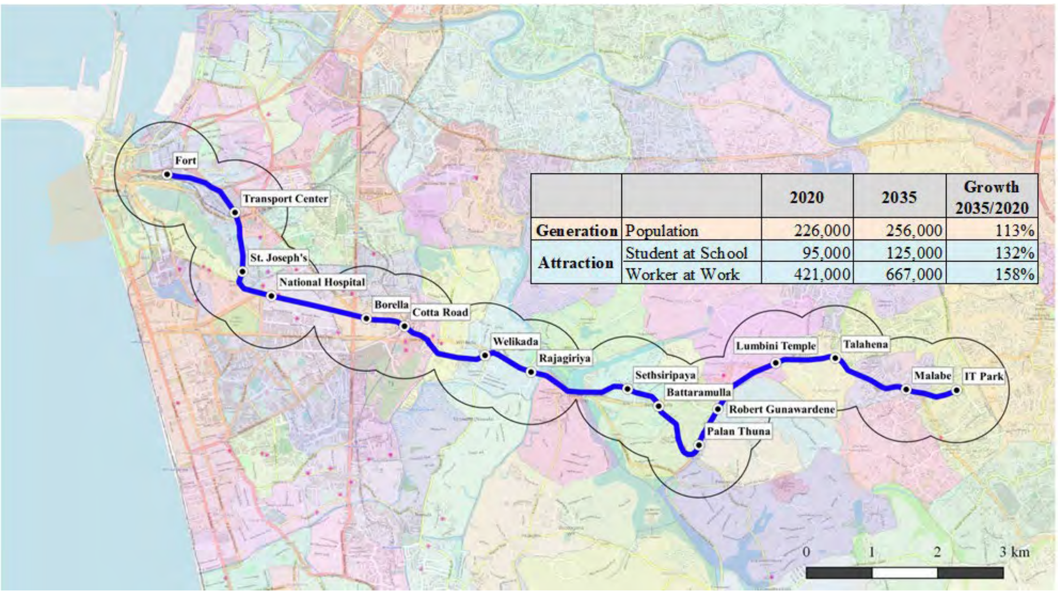
			2020	2025*	2035
Road (Without LRT)	Avg. Speed	(km/h)	21.6	19.4	15.0
	Avg. TT	(min)	39.4	45.2	56.7
Road (With LRT)	Avg. Speed	(km/h)	22.4	21.2	18.8
	Avg. TT	(min)	38.0	40.4	45.4
LRT	Avg. Speed	(km/h)	26.9		
	Avg. TT	(min)	32.5		

*: The demand of 2025 was calculated by linear interpolation of demand in 2020 and 2035.

Source: Survey Team

4.4.9 Population in the Catchment Area of JICA-LRT

Figure 4.4.22 shows the catchment area of the JICA-LRT stations, which is defined as circles of radius 1,000 meter from the station. The estimated population in the catchment area was calculated, using the zonal population and area of each zone inside the catchment area. The number of workers at work places shows a high growth rate, because of the estimated growth of employment in the city centre, Sethsiripaya, Welikada and Malabe areas. On the other hand, the growth of the population in the catchment area is not so high, because the major new residential area development is not assumed in the population framework of the Megapolis Transport Master Plan.



Source: Survey Team, the base map from OpenStreetMap

Figure 4.4.22 Estimated Population inside the Catchment area of JICA-LRT Stations

4.5 Civil Works

(1) Introduction

Based on the site condition survey and other information surveyed by this F/S together with the previous study on SKYTRAIN, the preliminary plan of civil works (structures for JICA-LRT) was conducted with sufficient accuracy for cost estimation. In addition, preliminary design drawings (plan-view, sectional-view, piling conditions, structural drawings) were also conducted.

(2) Civil Structures

Since almost the entire route is running along the road, a viaduct will be required. The suitable type of viaduct structure should be selected in consideration of safety, usability, economy, workability and landscape etc., to minimize negative environmental impacts along the route. The depot should be an elevated structure because its site is located at regulated pondage for flood control.

(3) Concept of Selection of Viaduct Structure Type

The selection of the viaduct structure will be selected by comparing the following evaluation items, based on the result of the geological survey and the site conditions.

Table 4.5.1 Evaluation Items for Selection of the Viaduct Structure Type

Evaluation Item	Points to be evaluated
Cost	Construction cost saving
Workability	Site condition (Right of Way, Access to site) Construction Method, Impact on road traffic, Utility diversion etc.
Environment and Landscape	Harmony with the surrounding environment, Measures for flood, Noise and Vibration etc.
Structure Specification	Durability etc.
Maintainability	Necessity, frequency, difficulty level etc. of maintenance etc.

Source: Survey Team

In the case of selecting the structure type, the most important factor is cost and workability. This includes construction cost, construction yard and maximum length/weight of the structural members, which is transportable to the construction site by road.

Viaduct structures for railway are available in many cities in Japan, United States and Europe and mainly concrete structures (Reinforced concrete: RC or Pre-stressed concrete: PC). The advantage of a concrete structure is relatively in lower cost, better maintainability and lower noise/vibration. Therefore, concrete structures have been used commonly compared to steel structures. On the other hand, while steel structures are more expensive than concrete ones, it can be more slender because of its high strength, and manufactured with higher accuracy and reliability by factory production. Furthermore, the construction period can be shortened and the construction method is simplified. As another type of structure, a composite structure having characteristics of both concrete and steel is often adopted.

It is desirable that a longer span of viaduct be selected from the viewpoint of smaller impact on the road traffic and surroundings during the construction period. However, longer span structures needs wider piers.

(4) Type of Structures for JICA-LRT

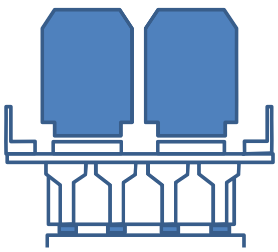
1) Girder (super-structure)

Structure type of the super-structure will be determined based on: the loading on the structure such live load; pier location (span); environmental issues; and local conditions of the construction technology. The common structure types which may be selected as the girder are following types:

- Precast Concrete I-Shape Beam with RC Slab
- Pre-stressed Concrete Box Girder
- Steel Box Girder with RC Slab (Composite Girder)

A comparison of girder type is shown in Table 4.5.2:

Table 4.5.2 Comparison of Girder Type

	Precast Concrete I-Shape Beam with RC Slab	Pre-stressed Concreate Box Girder	Steel Box Girder with RC Slab (Composite Girder)
Image			
Erection Method	By Crane or Girder	Assembling Precast Segment	By Crane
Applicable Span	15 to 30m	30 to 50m	25m or more
In Sharp Curve Section	Difficult	Most suitable	Suitable
Construction Period*	1 month/span (incl. slab work)	1 week/span	1 month/span (incl. slab work) However, manufacturing time in the factory and transportation time is required.
Maintainability	Less maintenance	Less maintenance	Re-painting is required every 10 to 15 years.
Cost* (Case of PC box is 1.0)	0.9	1.0	1.2
Recommendation	Not Recommended	Recommended	Recommended for special section such narrow road section area

*: Construction period and cost depends on erection method and site condition.
Source: Survey Team

Based on the comparison described above, Pre-stressed Concrete Box Girder in the standard section including the station is recommended. However, Steel Box Girder can be applied in special sections such as narrow road or wide road/lake/railway crossing.

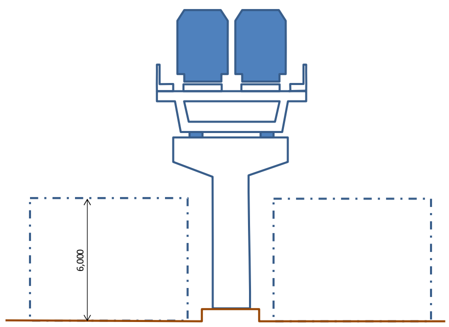
2) Pier (sub-structure)

The structure type of the sub-structure will be determined based on the load scale of the super-structure, supporting method, location and condition of the bearing layer, ground water level, environmental issues, and local conditions of the construction technology. Common structure types that can be selected for piers are the following two types:

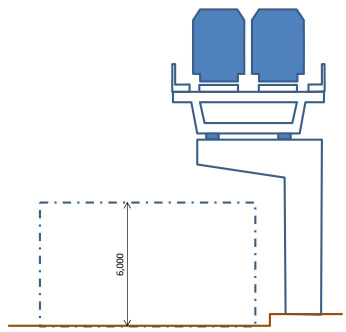
- Single Column Type Pier
- Portal Type Pier

<u>Single Column Type Pier</u>

The standard type of pier should be the single column type. For this project, the piers will be planned within the existing road area in principle. This concept does not affect the traffic lanes or sidewalks, can keep the construction yard and land acquisition area small, and does not interfere with the visual range of road traffic. Although the pier position is basically prepared in the centre of the road, where there is some particular condition such a narrow width of the road or needing to secure enough width, the pier may be arranged at the road side. Figure 4.5.1 shows the different single column type piers. The minimum clearance under the viaduct regulated by RDA is 6.0m.



(a) Standard Type



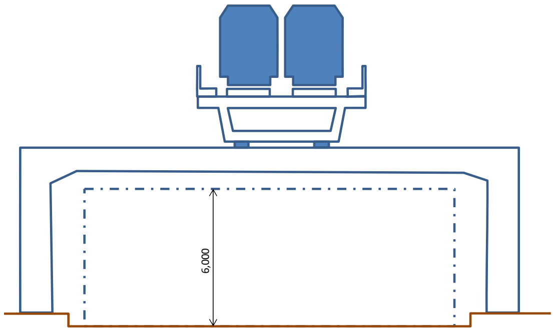
(b) Cantilever Type

Source: Survey Team

Figure 4.5.1 Single Column Type Pier

<u>Portal Type Pier</u>

If the centre of the girder is not aligned with the centre of the pier, an eccentric load that depends on the distance between the centres (the girder and the pier) will occur at the joints of the pier head and pier body, foundation and piles. Especially with existing roads that have a wider width, the distance between the centres tends to be larger and results in an increased eccentric load. Therefore, there may be places where the adoption of the single column type pier is structurally difficult. In this case, the portal type pier can be used (refer to Figure 4.5.2).



Source: Survey Team

Figure 4.5.2 Portal Type Pier

The pier structure will be made using cast-in-place reinforced concrete or steel, which can respond flexibly to the design and construction of the site condition. Steel structure has higher cost and less maintainability due to requiring re-painting every 10 to 15 years; however, the advantage of a steel structure is faster construction on-site and a slimmer shape.

In this Project, the pier size is 1.6 to 1.8 square meters of concrete structure and 1.2 to 1.4 square meters of steel structure. These should be used properly depending on site conditions and road width.

3) Foundation/Pile

The followings are two types of foundation (pile) structures to be considered in this Project:

- Cast in-situ (Bored) Pile
- Screwed Steel Pile

The standard type of pile is the cast in-situ (bored) pile; it is conventional method and easy to construct and is an economical type. However, since the footing foundation size is big, road occupancy space will also be bigger and occupancy time will be longer. The screwed steel pile has the advantage of working space, ecological-safety construction and rapid construction. However, construction cost is higher than bored pile. On the other hand, the screwed steel pile has a characteristic that piling work can be constructed even in a narrow space.

The comparison of foundation (pile) structure is shown below:

Table 4.5.3 Comparison of Piling Work

	Cast in-situ (Bored) Pile	Screwed Steel Pile
Feature	Construction method to build a reinforcing bar cage inside a hole and finish concrete after completion of excavation by earth drilling etc.	Construction method in which the steel pipe with the blade at the tip is rotated and is penetrated into the ground by excavating the ground.
Surplus Soil	Approx. 1.2 times the excavation volume	No surplus soil
Amount of cement	Quite a lot	Does not use cement
Noise and Vibration	Low noise and vibration	Low noise and vibration
Construction Vehicles	Many	Few
Confirmation of Bearing Layer	By sampling	By torque
Vertical and Pull-out Bearing Capacity	Large	Larger than bored pile
Size of Footing (Case of viaduct span 40m)	$5.0m^2$	$4.0m^2$ to $4.8m^2$
Width of Working Space on the road	10 to 15m	6 to 10m
Construction Time	Long (one pile per day)	Short (four piles per day)
Relative Piling Construction Cost (Case of bored pile is 1.0)	1.0	1.1 to 1.4

Source: Survey Team

Therefore, it is recommended that the bored pile should be used in sections where the road is sufficiently wide. And with the narrow road sections, the screwed steel pile can be applied.

The construction plan of the viaduct is described in Chapter 4.12.

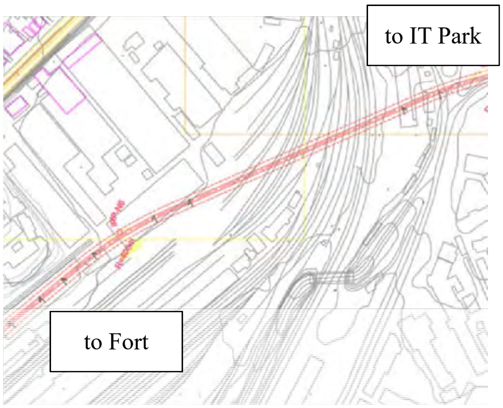
4) General Drawings of Viaduct

The general drawings of the viaduct structure (PC box girder and single column pier) are shown in Appendix 5.

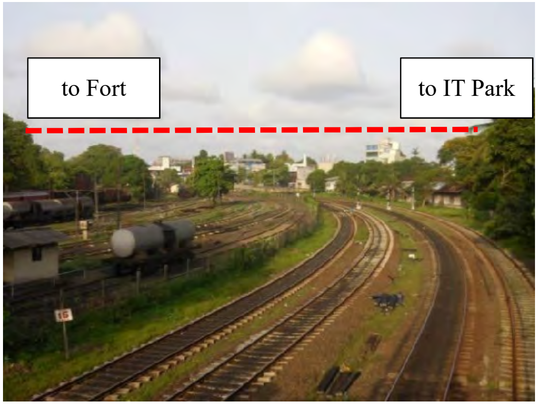
(5) Concerned Points for Technical Considerations of Civil Works

1) Bridges Crossing Sri Lanka Railway

The JICA-LRT route crosses SLR at two points, one point is located near the Transport Centre Station (Maradana) and the other one is located near Cotta Road Station. Particularly in Maradana, a special bridge structure (long span) crossing the railway yard will be required. In order to reduce impact on the existing railway tracks and future redevelopment projects, it is important to reduce the number of bridge piers to be constructed as much as possible in SLR's ROW. Therefore, when planning the bridge, detailed discussion and approval by SLR is required regarding bridge structure type, pier locations, and construction method under train operation. The alignment plan and site photo of the crossing point over the SLR Lines at Maradana is shown in Figure 4.5.3.



(a) Alignment Plan



(b) Site Photo

Source: Survey Team

Figure 4.5.3 Crossing Point over the SLR Lines close to Transport Center St. (Maradana)

2) Bridges Crossing Diyawanna Lake

The JICA-LRT route was planned to cross Diyawanna Lake between Rajagiriya Station and Sethsiripaya Station. For the selection of the bridge structure type at this section, it is important that the piers should not interfere with water flow, and activities on the lake such as recreation and rowing races should not be interrupted.

The bridge structure type will be selected with the considerations of above mentioned issues and landscape.

4.6 Rolling Stock

4.6.1 Recommended Rolling Stock Specification for JICA-LRT

In general, the rolling stock specification items are listed as follows:

- Maximum speed
- Gauge size
- Traction power supply
- Train formation
- Standard Passenger Capacity
- Capacity of a train
- Major dimension (length, width)
- Weight per train
- Body Materials
- Saloon design (door, seat type)
- Special facilities
- Traffic performance (acceleration/deceleration)
- Propulsion system
- Brake control system
- Others (bogies, signal system, etc.)

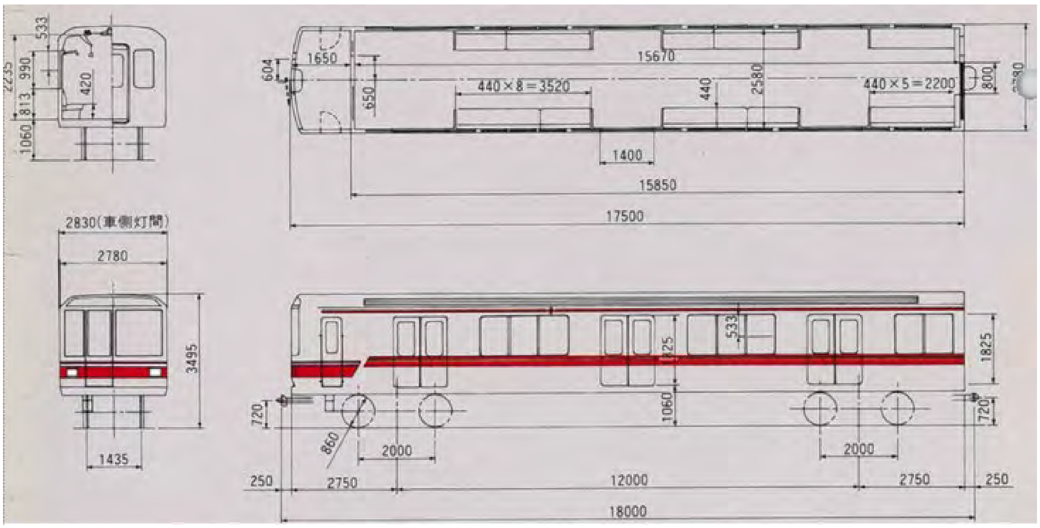
Based on the technical specification for JICA-LRT prepared by the Survey Team, series of discussion were made with PMU-MMWD for the applicability of these specifications together with the design principle (comfort, safety and reliability), estimated passenger demand, route plan and natural and cultural conditions in Colombo. In addition, through the experience on riding various types of rolling stock in Tokyo and Osaka area during the invitation program in Japan in September 2017 for GoSL officials, the proposed specifications were confirmed with the actual size and riding comfort. Table 4.6.1 shows the recommended specifications for JICA-LRT to meet the first urban railway in Sri Lanka. There are descriptions of the discussion results for the specifications in following section.

Table 4.6.1 Recommended Specifications for JICA-LRT

Technical Parameters		Specifications		
Maximum Speed		80km/h		
Gauge		1,435mm (Standard gauge)		
Traction Power Supply		Third Rail System		
Train Formation *Tc: Trailer Car with driver's cab,* *M: Motor car*		2M2T (Tc+M+M+Tc)		
Standard Passenger Capacity		Seated	Standing (3.3 persons/m^2)	Total
	Lead Car	42	86	128
	Intermediate Car	52	84	136
Capacity of a Train (4 car-sets)		Per Car	Nos. of cars	Total
	Lead Car	128	2	256
	Intermediate Car	136	2	272
	Total Passengers (3.3 persons/m^2) Including Seated passenger			528 (seated : 188)
	Total Passengers in different AW (Added Weight due to standing passenger)			
	AW-4: stand (4persons/m^2) + seat	600		
	AW-6: stand (6persons/m^2) + seat	806		
Major Dimension				
	Leading Car Length	18,000mm		
	Intermediate Car Length	18,000mm		
	Body Width	2,650~2,850mm		
Weight per Train (tare)		120t		
Body Materials		Light weight stainless steel or Aluminium		
Saloon Design				
	Door Ways	3 doorways each side of car		
	Door Type	Double slide doors 1,300 ~ 1,400mm width		
	Seat type	Longitudinal seat type		
Special Facilities				
	Wheel Chair Space	Equipped		
	Baggage Space	Not Equipped		
	Toilet	Not Equipped		
Traffic performance				
	Acceleration	3.2 km/h/s (0~30km/h)		
	Deceleration	Service 4.0 km/h/s		
		Emergency 5.0 km/h/s		
Propulsion System				
	Power Collection System	DC 750 V, Collector shoe, (2 set / 1 Bogie)		
	Control System	Variable-Voltage/Variable-Frequency (VVVF) inverter with Insulated Gate Bipolar Transistor (IGBT), (1 unit / M car)		
	Brake Control System	All electric command electro-pneumatic brake		
Bogies		Bolster-less type (air suspension)		
Air Conditioning Equipment		Roof top type		
Auxiliary Power Supply Equipment		SIV: 3-phase inverter with IGBT		
Inter communication system		Communication system between front and rear cabin		
Passenger Information System		Public address system via loudspeaker Visual information system via Liquid-Crystal Display (LCD) screens		
Security camera		Several security cameras are installed in each Rolling Stock.		
Signal System		ATP, Centralised Traffic Control (CTC), Automatic Train Operation (ATO) CBTC or Track Circuit System		

Source: Survey Team

These specifications should provide satisfaction and good service level for all of JICA-LRT users, the project owner, and bidders. The following diagram shows a sample of a currently operated metro sized rolling stock as recommended above, equipped with a longitude type seat, interior security camera and digital signage.



Source: Survey Team

Figure 4.6.1 Sample of Recommended Rolling Stock

Source: Survey Team

Figure 4.6.2 Interior of the Recommended Size for JICA-LRT

As described in Table 4.6.1, a sample of Passenger Information System, Visual Information System via LCD screen is shown in Figure 4.6.3.

Source: Survey Team

Figure 4.6.3 Sample of Digital Signage in a Car

On the alignment of JICA-LRT route, there are more steep curves on the alignment than the one on Japanese commuter railway alignment. Therefore, it is recommended to apply the bogies with short wheel base type, light weight with arc wheel profile bogie, and easy maintenance type. A sample of this bogie type is depicted in Figure 4.6.4.

Source: Survey Team

Figure 4.6.4 Sample of Bolsterless Bogie with 3rd Rail Collector

4.6.2 Passenger Capacity of Rolling Stock

Demand forecast for 2025 between Cotta Road and Welikada is 14,300 PPHPD, increasing to 19,800 in 2035. If 18 or 20 trains per hour are operated, the passenger capacity needed per train is about 715 to 790 persons in 2025, and about 1,000 to 1,100 persons in 2035. The platform length of the JICA-LRT is limited up to about 100 to 120m, due to limitations of keeping a straight line for track alignment. For this reason, the maximum number of trains stopping at a station is limited. For example, the passenger capacity of a train length of 108m (18m×6) with a width of 2.65m is about 950 persons; with a width of 2.8m is about 1,200 passengers; and with a width of 3.2m is about 1,450 passengers (6 passenger/m² in all cases). Considering that in 2035, a 1,000-person passenger capacity is needed for one train-set. Based on these conditions, a 1,200 passenger capacity per train-set is recommended for the JICA-LRT; this means that the JICA-LRT width is recommended to be 2.8m.

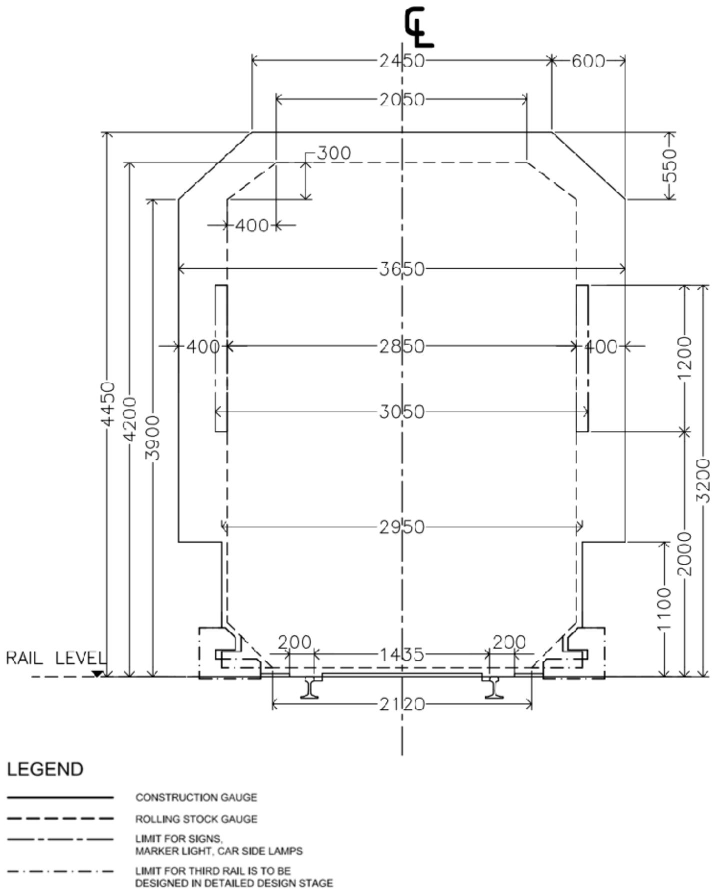
4.6.3 Required Space between Rolling Stock and Rail-Side Objects [Gauges]

The rolling stock gauge, structure gauge and third-rail gauge will be discussed in this Survey.

Rolling stock should not be interrupted by any rail-side objects when the train is running. Therefore, some space must be secured between the rolling stock body and rail-side objects, even when the rolling stock body is swaying. The structure gauge is set for preventing these collisions.

In addition, the conductor or train crew observe the outside, behind the window, to check the train or to find any trouble; it should be possible to do this safely without hitting any rail-side objects. To avoid these collisions, the secured distance between rolling stock gauge and structure gauge should be a minimum of 40 cm for both sides.

The gauges for rolling stock and structure are illustrated in Figure 4.6.5 below.



Source: Survey Team

Figure 4.6.5 Sample of Rolling Stock Gauge and Structure Gauge

4.6.4 Recommended Viaduct Width for JICA-LRT

1) Procedure for Recorded Viaduct Width

Based on the discussion on the various viaduct sizes of other projects in Chapter 3, the following viaduct width is proposed in preliminary design for the JICA-LRT. The width is considered based on a) rolling stock, b) required space between rolling stocks, and c) required space for both sides of rolling stocks as shown below.

2) Rolling Stock Gauge

As explained in "Recommended specification for JICA-LRT", the width of the car body is 2,800mm. Considering a manufacturing tolerance, it is better to set the rolling stock gauge width as 2,850mm for easier manufacturing and lower price of rolling stock.

3) Recommended Space between two Rolling Stocks on the Double Track

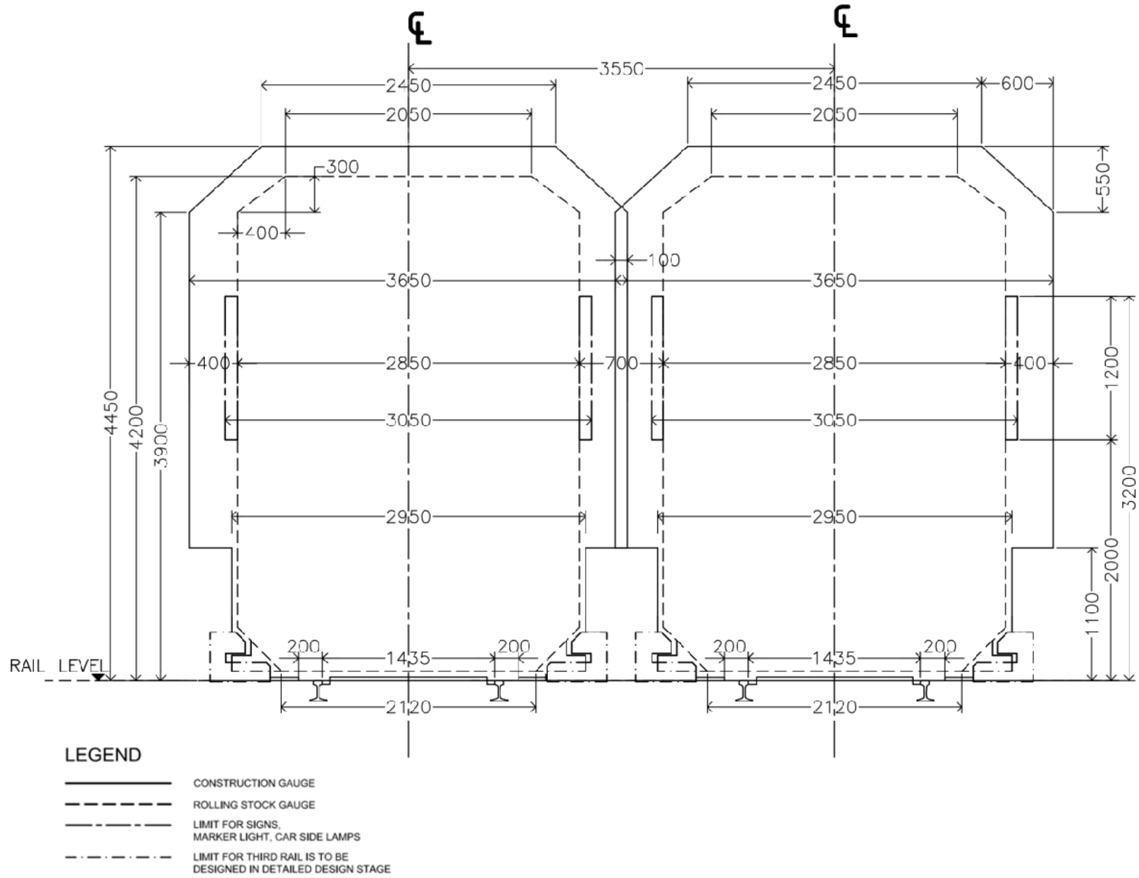
It is desirable for the space between two rolling stocks is over 80cm. However, it is very rare case for two trains to pass each other and have both conductors stick out their heads out of the window at 40cm, therefore colliding with each other. Therefore, 70cm space between each rolling stock gauge on double tracked sections is recommended as the minimum width.

4) Required Space of Inspection, Cable Parapet and Passenger Evacuation

When operator conducts inspection on track, third rail or equipment on the viaduct during the daytime, a 70cm walkway must be secured for inspector safety. Usually, there are many cables installed in the parapet along the track. The width of the parapet must be 30cm. Therefore, the width sum is up to 1.00m. When the train has problem and stopped on the viaduct for a long time, the passengers must be evacuated to the nearest station. In this case, the space can be utilized for the evacuation after cutting the electricity.

5) Recommended Viaduct Width

Based on the above discussion, with requirements for inspection walkway with parapet width (1,000mm), railway gauge (2,850mm) and space between rolling stock (700mm), 8.4m is the required width of the JICA-LRT in Colombo. Note that this is the case for straight sections; curvature sections require more space due to bogie and body length.



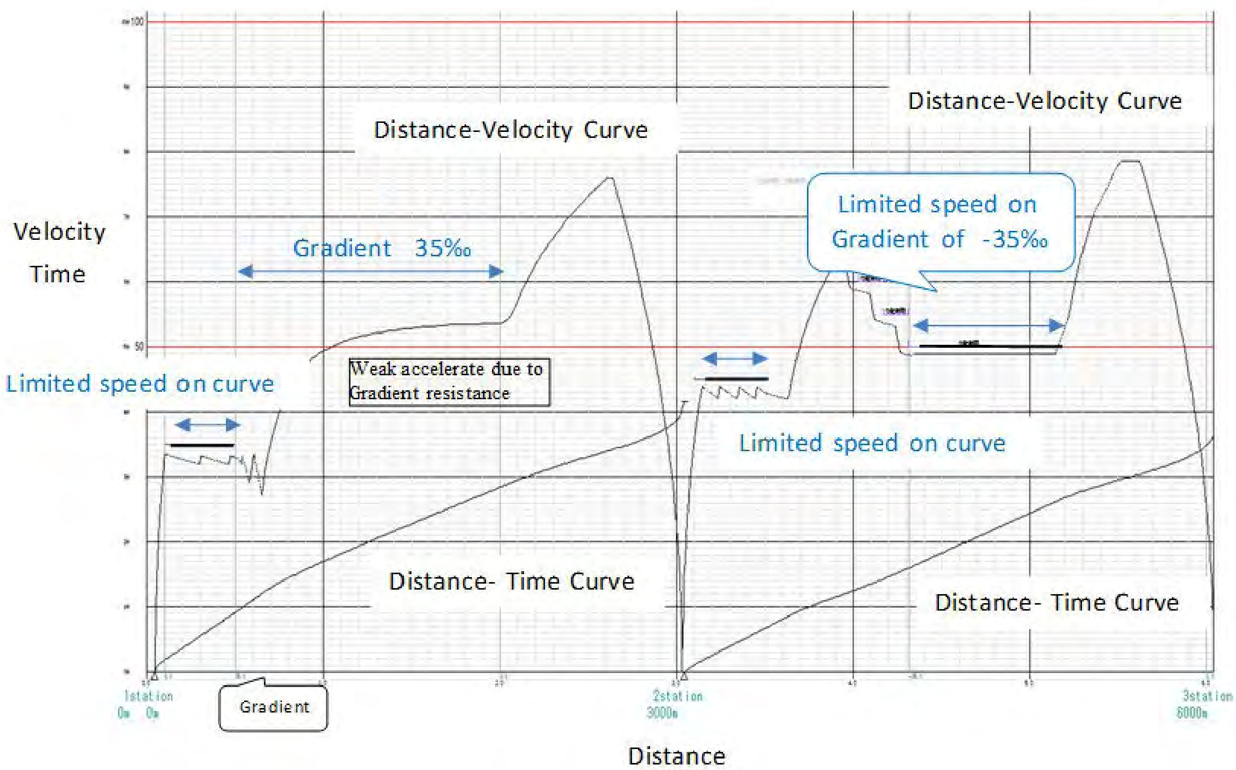
Source: Survey Team

Figure 4.6.6 Recommended Viaduct Cross Section for JICA-LRT

4.7 Train Operation Plan

4.7.1 Procedure for Operation Plan

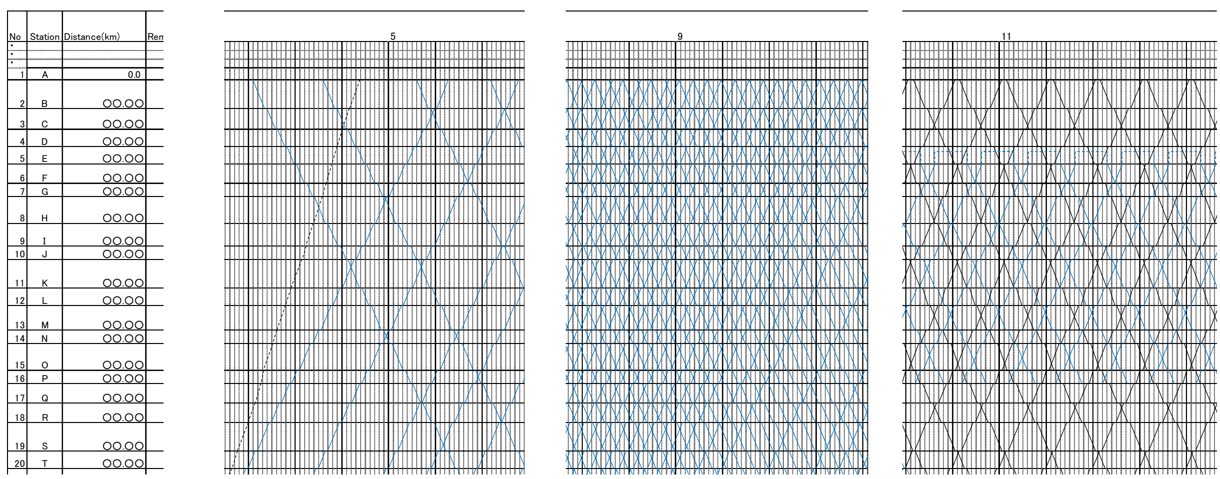
After fixing the alignment with station locations and various kinds of restrictions for speed, train travel time can be calculated by drawing the "train performance curve" that is depicted in Figure 4.7.1. This means that speed restriction sections and steep slopes affects the performance curve.



Source: Survey Team

Figure 4.7.1 Image of the Train Performance Curve

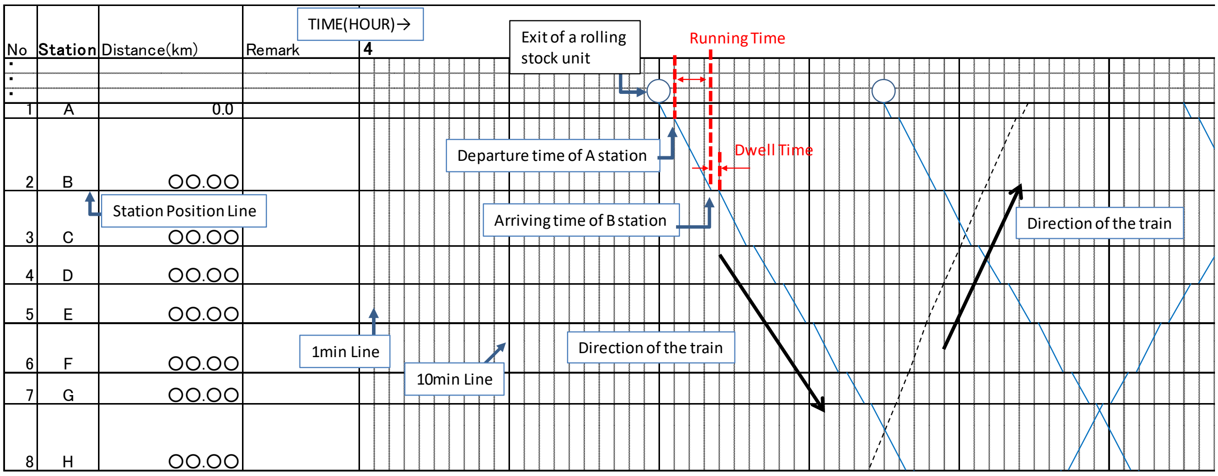
Once the distance-time curve is calculated by the performance curve, the "Train Diagram" can be drawn for both peak hours and off-peak hours. The horizontal axis shows the time (hours) and vertical axis shows the distance with station locations. The solid line on the diagram shows the train location at the time. Figure 4.7.2 shows the image of different patterns of train operation. The detailed explanation of the diagram is depicted in Figure 4.7.3.



Station list and distance | **Off-peak operatoin** | **Peak hour operatoin** | **Two different operation section**

Source: Survey Team

Figure 4.7.2 Image of the Train Diagram



Source: Survey Team

Figure 4.7.3 Description of the Train Diagram

Based on the above diagram, the required number of train-sets can be estimated to meet the schedule. Also, the total train kilometre and total train operation time can be calculated. In addition, the power consumption of a train from starting station to the terminal station is estimated by the train performance curve.

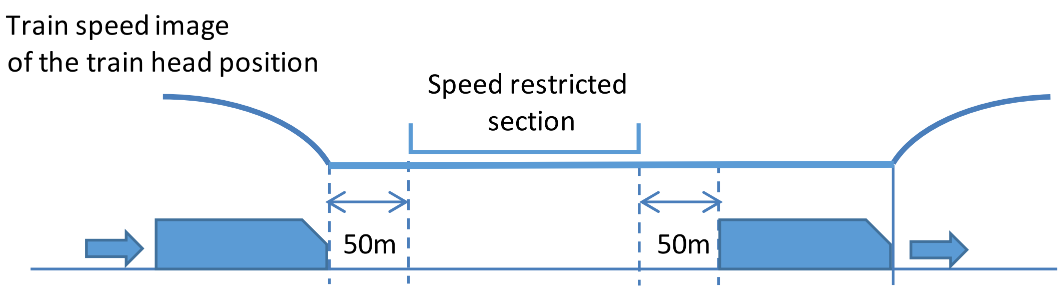
4.7.2 Required Information

In order to calculate the train performance curve, the following information is required:

- Maximum speed on the line: 80km/h
- Speed restrictions (gradient, curve, and degree of branching)

There are three speed restriction sections that reduce train speed (gradient, curve and degree of balancing). Figure 4.7.4 explains the speed calculation method when speed restriction sections exist.

- Train reduces its speed to less than the limit by 50m before the restricted section.
- The train can increase its speed from 50m plus the train length after the restricted section.



Source: Survey Team

Figure 4.7.4 Operating Conditions for Speed Restricted Section

1) Speed Restriction 1: Gradient

Table 4.7.1 shows the basic speed limit corresponding to the gradient. The downhill gradient rate is assumed as an average gradient value for each 1km length.

Table 4.7.1 Basic Speed Limit Corresponding to Gradient

Gradient	Speed Limit (km/h)
0-5‰	80
-10‰	75
-15‰	70
-20‰	65
-25‰	60
-30‰	55
-35‰	50

Source: Survey Team

Standard gradient is defined as the steepest uphill or downhill gradient (indicated per mileage) between average gradient of each 1 km length and between two adjacent stations and halts. However, if the distance between adjacent stations and halts is less than 1 km, the standard gradient is a gradient between the centres of stations and halts indicated per mileage. If the actual gradient is lower than the standard gradient, the standard gradient will be used.

2) Speed Restriction 2: Curve

Parameters to be considered are curve radius, curve position (Beginning of Transition Curve (BTC) and End of Transition Curve (ETC)). Table 4.7.2 shows the basic speed limit value corresponding to curve radius that is used for train performance curve. If the train curve performance value is lower than the basic speed limit, the corresponding value in the train performance curve should be applied.

Table 4.7.2 Basic Speed Limit on Curve

Curve Radius		Speed Limit (km/h)
Over	Less than	
350		80
300	350	75
250	300	70
225	250	65
200	225	60
175	200	55
150	175	50
125	150	45
100	125	40
	100	35

Source: Survey Team

3) Speed Restriction 3: Turnout/Switch: Degree of Branching, Position/Location

Table 4.7.3 shows the basic speed limit according to the degree of branching.

Table 4.7.3 Basic Speed Limit on Turnout

Degree of Branching	Basic Speed Limit (km/h)
8	30
9	35
10	40
12	55
16	70

Source: Survey Team

4) Signal Type

When creating the train performance curve, the signal type affects the calculation time. In this Survey, the signal type for calculation is assumed to be cab signals.

5) Train Specifications

In this Survey, a 6-car-train, which is the maximum number of cars in a train in 2035, is used for the calculation. Detailed information of rolling stock can be found in Section 4.6 Rolling Stock. Table 4.7.4 shows the summary of the rolling stock specifications applied to the train operation plan.

Table 4.7.4 Summary of Calculation Conditions

Design parameter	Specification
Maximum operation speed	80 km/h
Number of the cars in a train	6 cars
Train capacity	1,209 persons (in 6 cars), 806 persons (in 4 cars)
Train length	108m

Source: Survey Team

6) Dwell Time

The dwell time in an intermediate station is 30 seconds. In case the train is in deadhead condition at Malabe Station, a dwell time of 1 minute is applied, as for the time of inside train confirmation.

7) Alignment

Detailed information of the alignment, such as stations location, curve section, etc., is required for the train operation calculation.

8) Determination of Running Time

The running time is merged down every 10 seconds from the calculated running time.

4.7.3 Exercise on Different Running Time

(1) Exercise on Running Time due to Steep Curve

The JICA-LRT has several steep curves because it runs on roads in an urban area. In addition, based on the design principle described in Chapter 3, shortening the travel time is one of the important goals to provide for the urban rail-based public transport. Therefore, in this section, the Survey Team conducted an exercise on how much the speed limit affects to the operation time. The assumptions/conditions for this exercise are as follows:

- 1km length between stations
- Flat terrain
- Several types of speed limit applied: Curve radius = 100m, Speed Limit = 35km/h

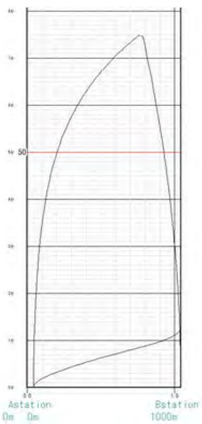
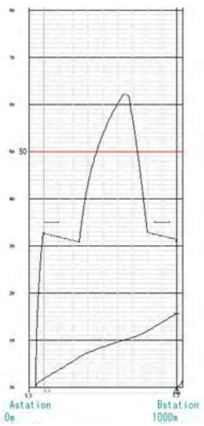
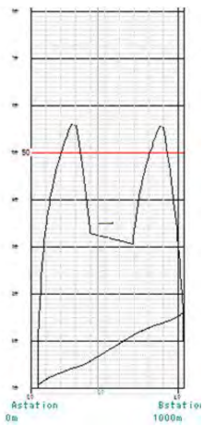
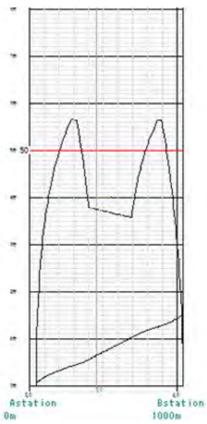
The results of various types of speed limit are shown in Figure 4.7.5.

If there is no speed limit, the running time is estimated as 1’20” to reach the next station, for which the result is depicted in graph (a).

When the speed limit is set near the stations, running time required is 1’50”, which is 30 seconds longer than that without restriction (graph (b)). As the total number of JICA-LRT stations is 16, if this situation occurs at all stations, the time delay is expected to be around 8 minutes for the entire route.

If the speed restriction is set in the middle of the station, it also affects the performance curve. In this simulation (graph (c)), the result (1’50”) is almost same as the graph (b). However, these graphs show that the travel time is dramatically extended when additional speed restrictions exist.

Note that a 5km/h increase of speed restriction improves travel time by 10 seconds (graph (d)).

			
Graph (a) **Without Ristriction** 1’20”	Graph (b) **Near Stations (35km/h)** 1’50”	Graph (c) **Middle of section (35km/h)** 1’50”	Graph (d) **Middle of section (40km/h)** 1’40”

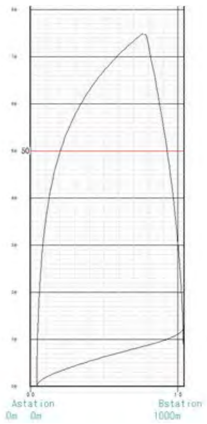
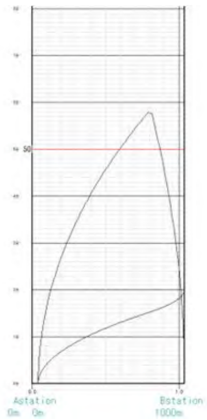
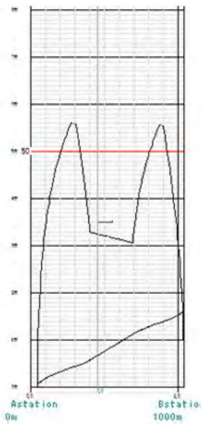
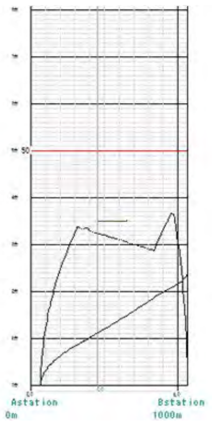
Source: Survey Team

Figure 4.7.5 Result of Simulation (Train performance of JICA-LRT: Difference due to various speed restriction point)

(2) Exercise on Running Time due to Public Transport Modes

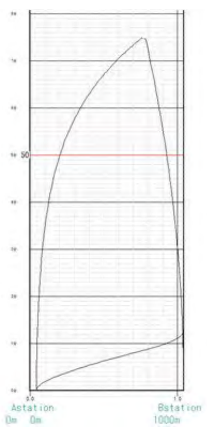
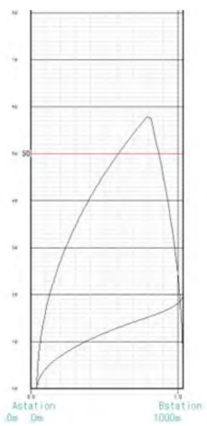
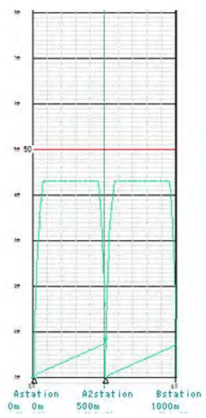
Data for acceleration and deceleration ratio in the Kelani Valley (KV) Line was collected to set the performance curve. In addition, the bus performance curve is assumed based on the catalogue basis. With the same length and conditions in the previous section, the trial simulation was done for comparison.

Figure 4.7.6 and Figure 4.7.7 show the results for JICA-LRT, KV Line and Buses. Around 40 seconds or more are required for the KV Line compared to JICA-LRT. Comparing with ideal bus operation (free driving without any congestion), only the driving time is similar to JICA-LRT, however if bus stopping time is added, JICA-LRT is the fastest mode.

			
JICA-LRT **Without Restriction** 1’20”	KV-line **Without Restriction** 2’00”	JICA-LRT **Middle of section (35km/h)** 1’50”	KV-line **Middle of section (35km/h)** 2’30”

Source: Survey Team

Figure 4.7.6 Result of Simulation (Train performance of JICA-LRT: Comparison between LRT and KV-line)

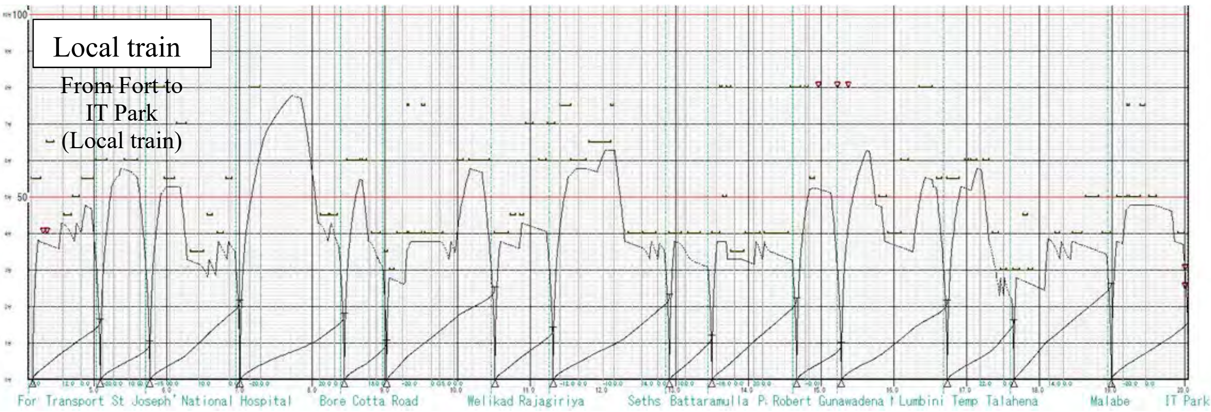
		 Note that the bus stop is assumed at every 500m, not included the bus stooping time at the bus station.
JICA-LRT **Without Ristriction** 1’20”	KV-line **Without Restriction** 2’00”	Bus **Max. speed (45km/h)** 1’40”

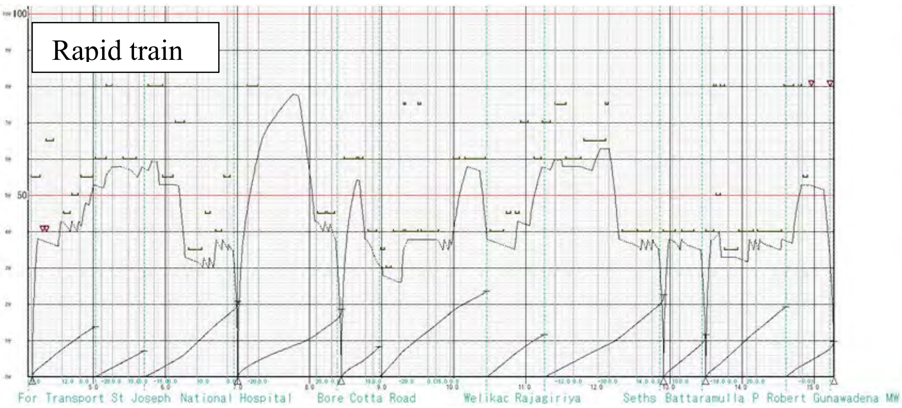
Source: Survey Team

Figure 4.7.7 Result of Simulation (Train performance of JICA-LRT: Difference of LRT, KV-line and Bus)

4.7.4 Result of the Traveling Time

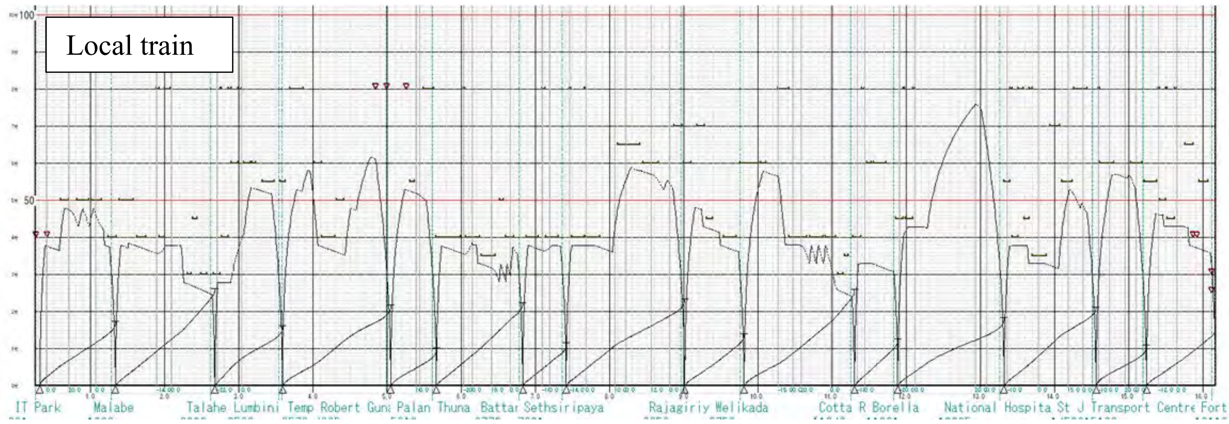
The terms "local train" and "rapid train" are used in this section. Local train is defined as the train stopping at every station. Rapid train is understood as a train that stops only at specific stations (main stations with high passenger demand). The outline of the local train and rapid train performance curve from Fort to Malabe is shown in Figure 4.7.9. A detailed diagram of train performance curve is attached in Appendix 6.

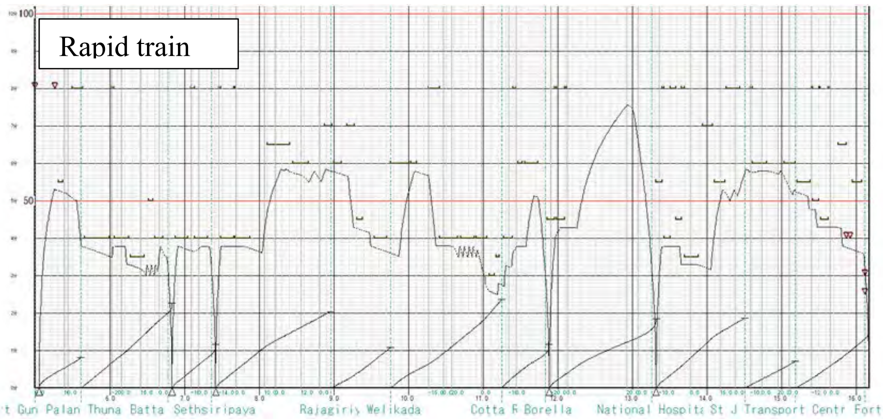




Source: Survey Team

Figure 4.7.8 Train Performance Curve: From Fort to IP Park (Outbound)





Source: Survey Team

Figure 4.7.9 Train Performance Curve from IP Park to Fort (Inbound)

Based on the performance curve, a summary of the comparison for travel time between local train and rapid train is shown in Table 4.7.5.

Table 4.7.5 Comparison of Travel Time at Major Sections

Direction	Rapid Train Travel Time	Local Train Travel Time
Fort – Sethsiripaya	14 minutes 20 seconds	18 minutes 10 seconds
Fort – Robert Gunawadena	19 minutes 50 seconds	24 minutes 30 seconds
Fort – Malabe	28 minutes 10 seconds	32 minutes 50 seconds
Fort – IT Park	30 minutes 30 seconds	35 minutes 10 seconds
Malabe – Sethsiripaya	13 minutes 20 seconds	14 minutes 20 seconds

Source: Survey Team

Detailed travel time information for both local train and rapid train at each station is depicted in Figure 4.7.10.

Traveling Time (5(Fort)→20(ITPark))									Station	Distance (km)	Distance of adjacent stations (km)	Traveling Time (20(ITPark)→(5(Fort))							
Rapid train				Local train								Rapid train				Local train			
Running time	Dwell time	Traveling Time	Pattern of stops	Running time	Dwell time	Traveling Time	Pattern of stops					Pattern of stops	Running time	Dwell time	Traveling Time	Pattern of stops	Running time	Dwell time	Traveling Time
			•				•	5	**Fort**	4.100		•			0:30:00	•			0:35:10
01:30				01:40							0.932		01:30				01:40		
		0:01:30			00:30	0:01:40	•	6	Transport Centre	5.032					0:28:30	•		00:30	0:33:00
00:50				01:10							0.680		00:50				01:10		
		0:02:20			00:30	0:03:20	•	7	St Joseph's	5.712					0:27:40	•		00:30	0:31:20
02:10				02:20							1.241		02:00				02:10		
	00:30	0:04:30	•		00:30	0:06:10	•	8	National Hospital	6.953		•		00:30	0:25:10	•		00:30	0:28:40
01:50				01:50							1.434		02:00				02:00		
	00:30	0:06:50	•		00:30	0:08:30	•	9	Borella	8.387		•		00:30	0:22:40	•		00:30	0:26:10
01:00				01:10							0.583		01:10				01:20		
		0:08:20			00:30	0:10:10	•	10	Cotta Road	8.970					0:21:30	•		00:30	0:24:20
02:30				02:40							1.490		02:30				02:40		
		0:10:50			00:30	0:13:20	•	11	Welikada	10.460					0:19:00	•		00:30	0:21:10
01:10				01:30							0.800		01:10				01:30		
		0:12:00			00:30	0:15:20	•	12	Rajagiriya	11.260					0:17:50	•		00:30	0:19:10
02:20				02:20							1.597		02:10				02:30		
	00:30	0:14:20	•		00:30	0:18:10	•	13	Sethsiripaya	12.857		•		00:30	0:15:10	•		00:30	0:16:10
01:20				01:20							0.585		01:10				01:10		
	00:30	0:16:10	•		00:30	0:20:00	•	14	Battaramulla	13.442		•		00:30	0:13:30	•		00:30	0:14:30
02:10				02:20							1.166		02:20				02:20		
		0:18:50			00:30	0:22:50	•	15	Palan Thuna	14.608					0:11:10	•		00:30	0:11:40
01:00				01:10							0.615		00:50				01:10		
	00:30	0:19:50	•		00:30	0:24:30	•	**16**	**Robert Gunawaden**	15.223		•		00:30	0:09:50	•		00:30	0:10:00
02:20				02:20							1.459		02:10				02:20		
	00:30	0:22:40	•		00:30	0:27:20	•	17	Lumbini Temple	16.682		•		00:30	0:07:10	•		00:30	0:07:10
01:40				01:40							0.914		01:40				01:40		
	00:30	0:24:50	•		00:30	0:29:30	•	18	Talahena	17.596		•		00:30	0:05:00	•		00:30	0:05:00
02:50				02:50							1.339		02:40				02:40		
	00:30	0:28:10	•		00:30	0:32:50	•	19	Malabe	18.935		•		00:30	0:01:50	•		00:30	0:01:50
01:50				01:50							0.722		01:50				01:50		
		0:30:30	•			0:35:10	•	20	**IT Park**	19.657		•				•			
0:26:30		12:30:30 AM		0:28:10		12:35:10 AM			Total				12:26:00 AM		12:30:00 AM		12:28:10 AM		12:35:10 AM

Source: Survey Team

Figure 4.7.10 Estimated Travel Time between Stations

(1) Conditions and Assumptions for Train Operation Plan

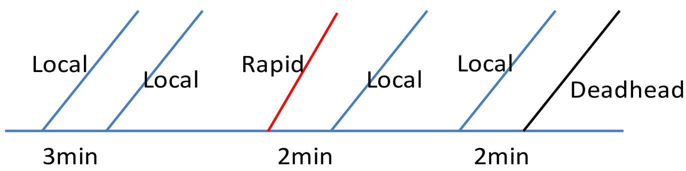
1) Turn Back Operation:

The minimum turn back operation time is set 2 minutes 00 seconds. This time is only for cab shifting purpose without any train shunting.

2) Headway:

The minimum headway between trains is set as follows (shown in Figure 4.7.11):

- Local train – Local train: 3 minutes 00 seconds
- Rapid train – Local train: 2 minutes 00 seconds
- Local train – Deadhead train: 2 minutes 00 seconds



Note: Deadhead train is a train which is in "not in-service" condition
Source: Survey Team

Figure 4.7.11 Minimum Headway Time Interval

- Headway is limited by crossover structure: Crossover structure is expected to be located at IT Park and Fort Station. If there is crossover structure at a station, 2 minutes 00 seconds of headway is applied as shown in Figure 4.7.12.

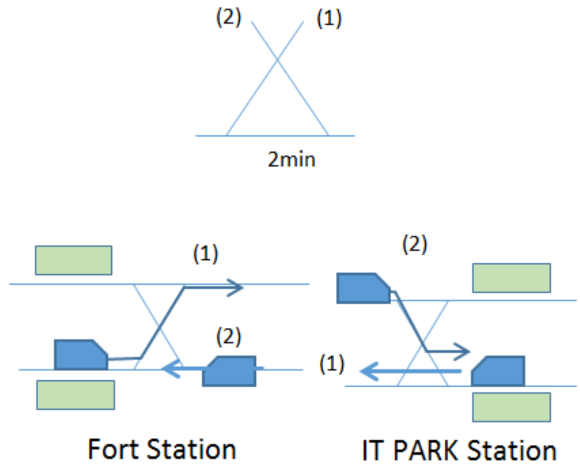


Figure 4.7.12 Headway Limited by Crossover Structure

3) Number of Rolling Stock:

The required number of train-set should meet its load factor to be not more than 100% under the PPHDP of demand forecast for 2025 and 2035. Also, in order to ensure operating trains safety, the minimum headway should be more than three minutes during the peak hour. The following equation is used to calculate the number of train at peak hour:

Number of train for peak hour = PPHPD/Train capacity

Based on the demand forecast, the number of trains at peak hour is:

2025: 14,300 (PPHPD)/806 (persons/4-car-train) = 17.7 = 18 (trains) with average operation interval time of 3 minutes 20 seconds.

2035: 19,800 (PPHPD)/1,209 (persons/6-car-train) = 16.4 = 17 (trains) with average operation interval time of 3 minutes 31 seconds.

The number of trains operating at peak hour should not be reduced in order to prevent and maintain required service level. In this Survey, 18 trains are set as the required number of rolling stock at peak hour in both 2025 and 2035.

Number of rolling stock at peak hour: 2025: 18 trains (4-car-train) 2035: 18 trains (6-car-train)

4) Operation plan for Peak Hour and Off-Peak Hour

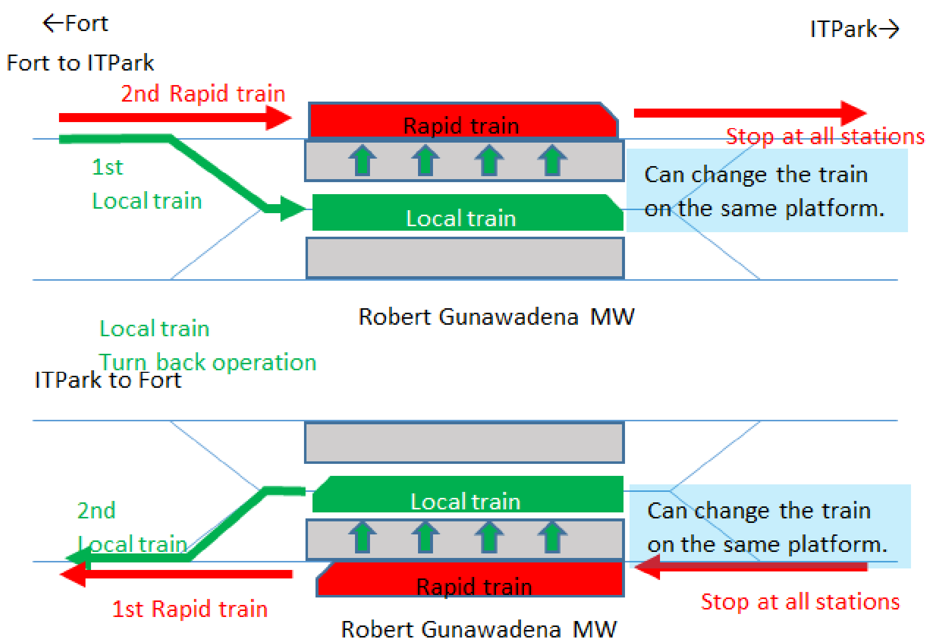
- First train: 4:30 (departure)
- Peak hour: 7:00 – 9:00, 17:00 – 19:00
- Last train: 23:40 (arrived)
- During the off-peak hours of 10:00 to 16:00, to reduce travel time between Fort and IT Park, a rapid train is operated when operation interval time is larger than 7 minutes. Table 4.7.6 shows the detailed stopping pattern of trains at off-peak hours.

Table 4.7.6 Train Stopping Pattern for Off-peak Hour

Station		5 **Fort**	6 Transport Centre	7 St. Joseph's	8 National Hospital	9 Borella	10 Cotta Road	11 Welikada	12 Rajagiriya	13 Sethsiripaya	14 Battaramulla	15 Palan Thuna	16 **Robert G. MW**	17 Lubini Temple	18 Talahena	19 Malabe	20 **IT Park**
Pattern of stops	Rapid train	●			●	●				●	●		●	●	●	●	●
	Local train	●	●	●	●	●	●	●	●	●	●	●	●				

Source: Survey Team

Passengers who plan to change from a rapid train to a local train and vice versa will be able to transfer at Robert Gunawadena St.. To reduce transfer time for passengers, the same platform should be used with the following train operation plan as shown in Figure 4.7.13.

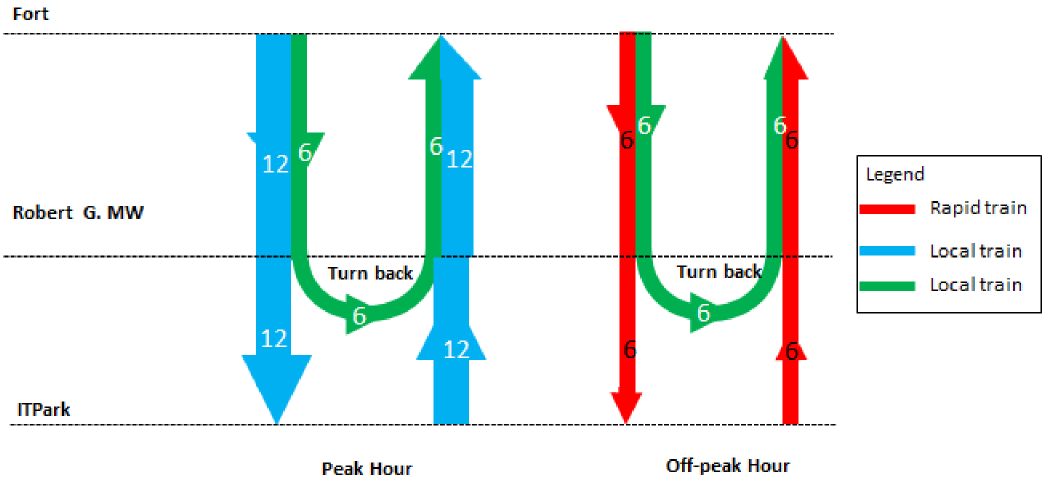


Source: Survey Team

Figure 4.7.13 Transfer between Local Train and Rapid Train at Robert Gunawadena St.

4.7.5 Result of Train Operation Plan

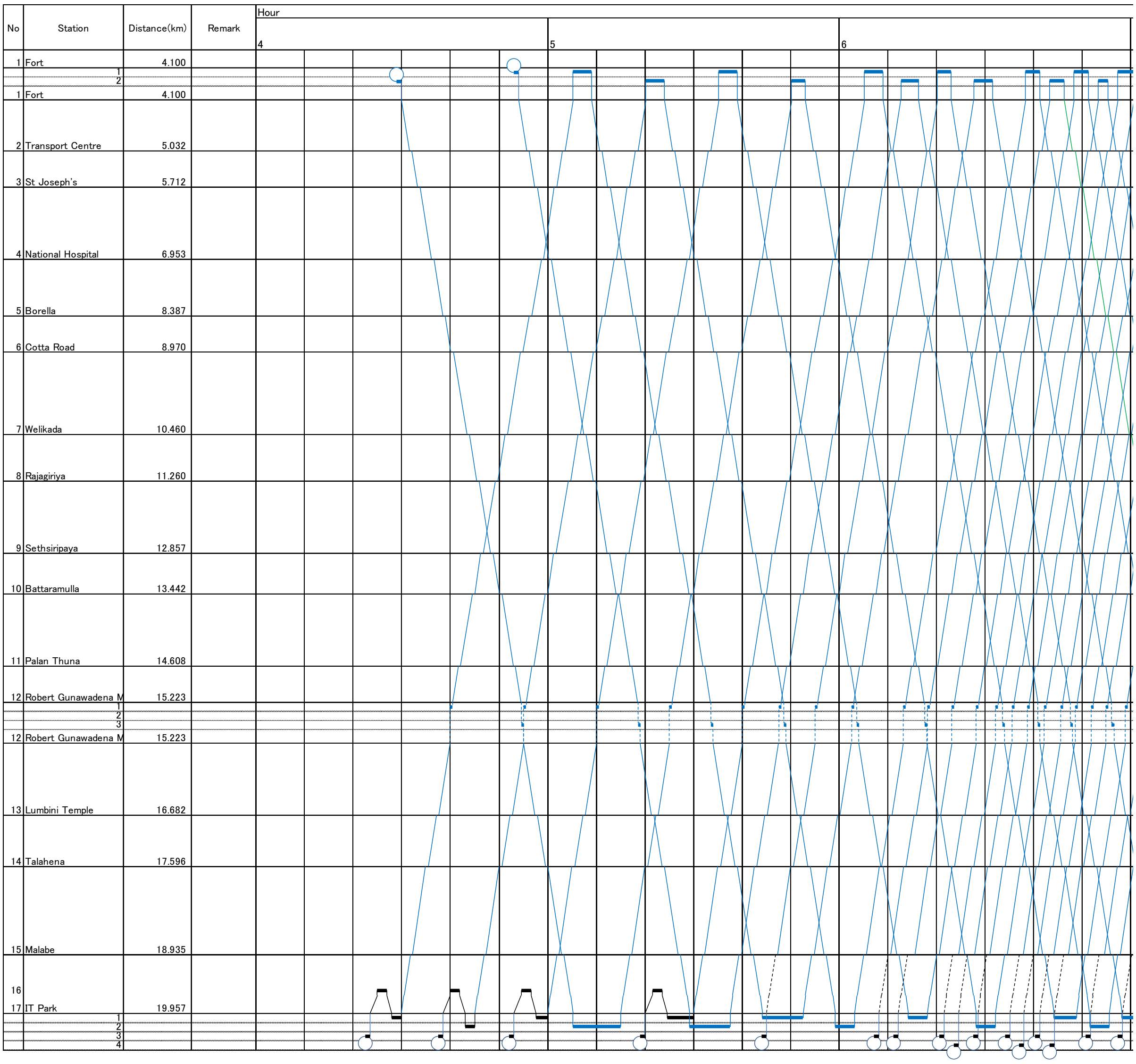
The summary of train operation in the peak hour and off-peak hour is described in Figure 4.7.14.



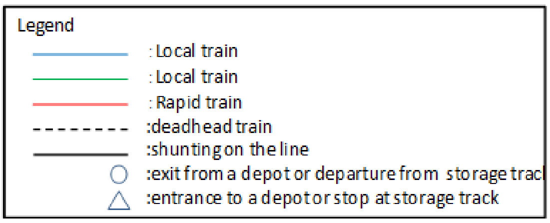
Source: Survey Team
Note: Presented numbers are number of train per hour (trains/hour)

Figure 4.7.14 Train Operation at Peak Hour and Off-peak Hour

The train operation diagram for 2025 and 2035 are summarized below in Figure 4.7.15, Figure 4.7.16 and Figure 4.7.17. Detailed information can be found in Appendix 6.

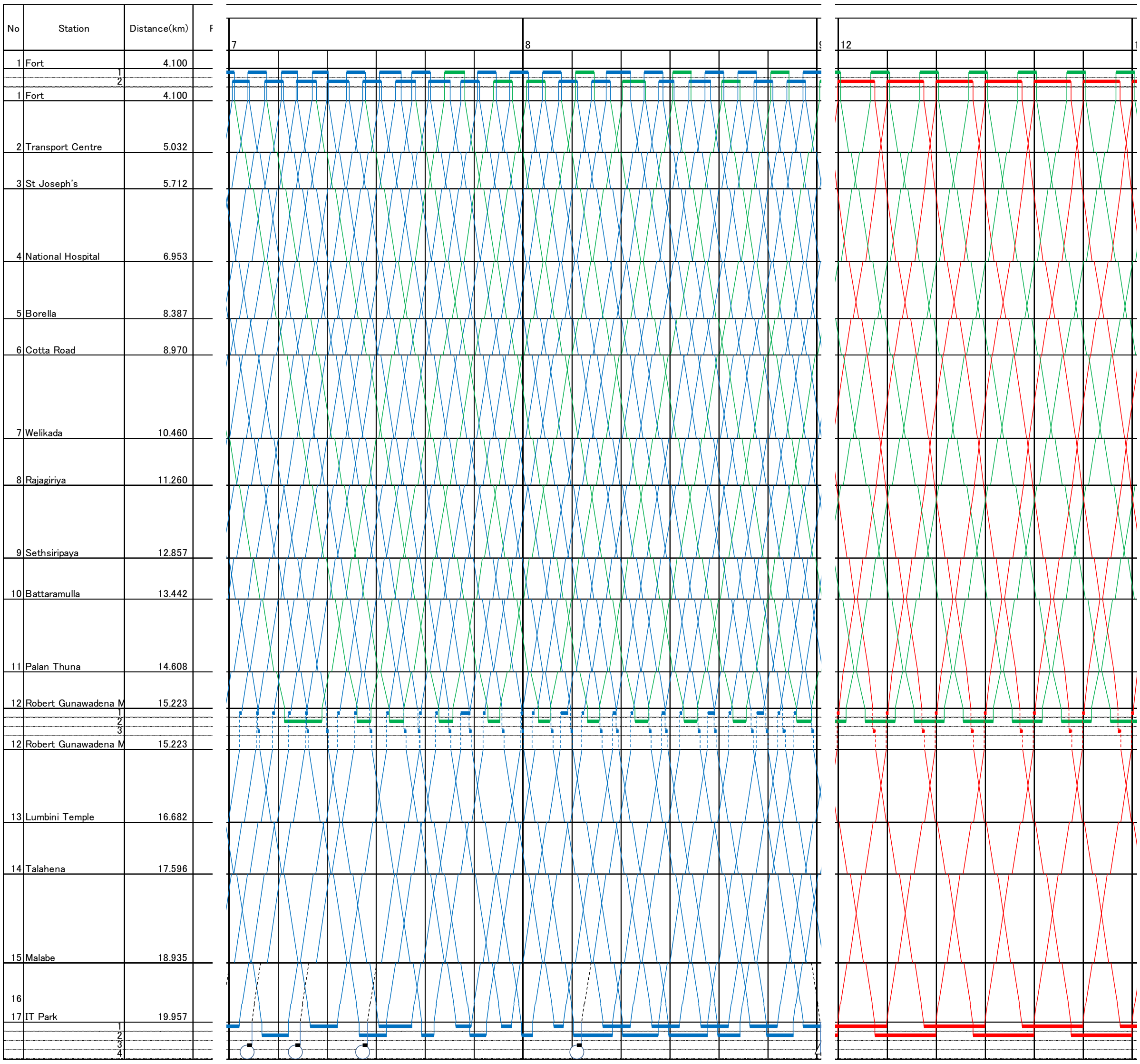


From first train (4:30) until morning peak operation (-7:00)

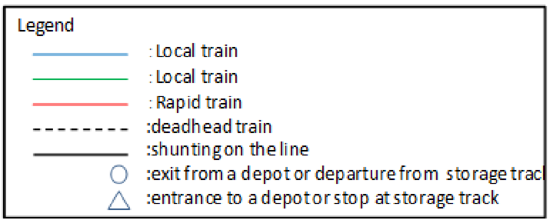


Source: Survey Team

Figure 4.7.15 Train Operation Diagram for 2025 and 2035 (1)

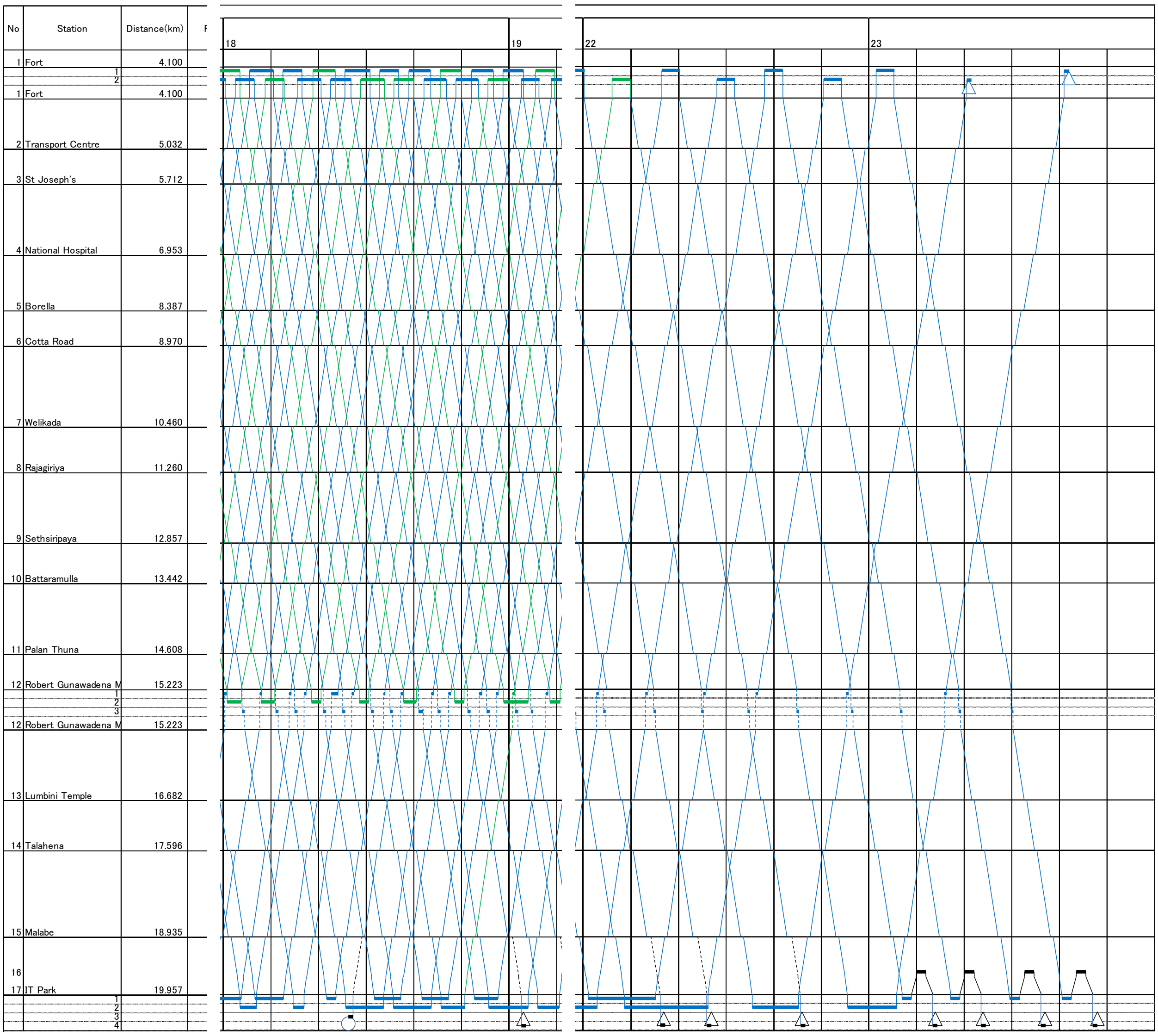


During morning peak (7:00-) and off peak (e.g. 12:00) Operation

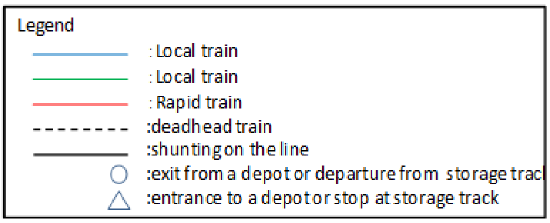


Source: Survey Team

Figure 4.7.16 Train Operation Diagram for 2025 and 2035 (2)



Evening peak (17:00-) and last train (23:40) Operation



Source: Survey Team

Figure 4.7.17 Train Operation Diagram for 2025 and 2035 (3)

The train operation plan is summarized as Table 4.7.7 below:

Table 4.7.7 Number of Rolling Stock and Key Factors of Operation Plan

No.	Key Factor for Operation Plan	Indicators
1	Number of cars in a train	4 cars (2025) , 6 cars (2035)
2	Number of operation trains in peak hour per direction from Fort to Robert Gunawadena MW (based on passenger demand data)	18 trains (2025 and 2035)
3	Regular train set for daily operation (trains)	22 train sets (plus 3 reserved train sets)
4	Total train km (km)/day	6,245.40 km/day
5	Total train operation hours (hh:mm:ss)	228:24:50
6	Total number of trains in service in a day in one direction between Fort St. and Robert Gunawadena MW St.	222 trains
	Total number of trains in service per direction per day from Robert Gunawadena MW St. to IT Park St.	147 trains
7	Transport capability at peak hour from Fort St. to Robert Gunawadena MW St.	In 2025 (4car: 806 persons) 14,508 (pax. /direction) In 2035 (6car:1,209 persons) 21,762 (pax. /direction)

Source: Survey Team

4.8 Depot

4.8.1 General

Since the railway transportation system has a significant social responsibility, it should be absolutely safe for handling huge amounts of passengers. Rolling stock for the railway is required to be kept in a condition such that they can be operated smoothly. In addition, the quality of rolling stock is sustained by preventive maintenance methods, because their sustainability and high safety are indispensable.

To carry this out, the depot is required as the place where trains are stabled, inspected, repaired and maintained including cleaning.

4.8.2 Depot Function and Facilities

(1) Introduction of Depot Function and Facilities

The depot has 4 functions:

- to stable train sets,
- to conduct inspections and preparations for the operation,
- to repair failures on the train set, and
- to overhaul rolling stock.

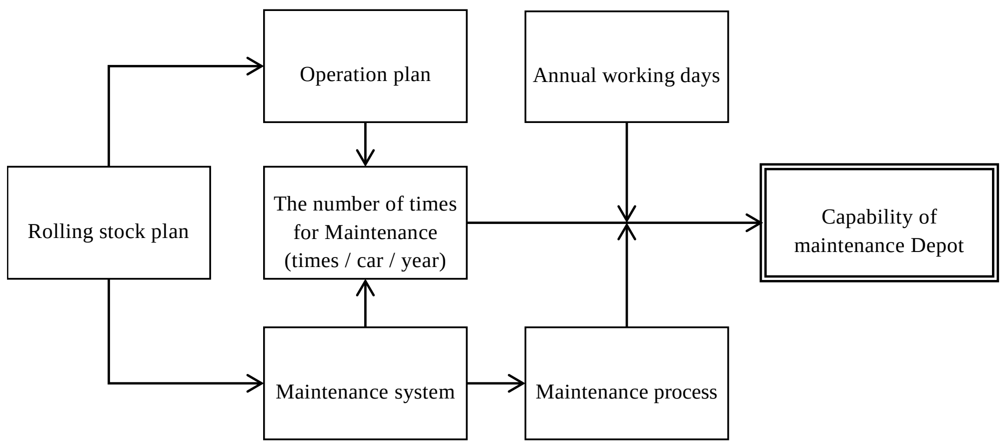
The depot is an essential facility to maintain the quality of train operations. “Inspection”, “repair”, and “preparation” for rolling stock maintenance should be planned at the same time as when rolling stock is examined.

In addition, it is necessary to consider the location for the maintenance depot based on the operation plan to increase the operation efficiency of rolling stocks. Generally, candidate site is location which is easy to conduct rolling stock maintenance and forwarding distance from a station is short. In this Survey, the preconditions for planning the maintenance depot are established in the operation plan.

Note that there are other facilities that are required for the operation of JICA-LRT including a headquarters (HQ) with Operation Control Centre (OCC) and a training centre for inspectors, drivers, and maintenance officers. Although these facilities are not necessary to locate at the depot area, the possibility of installing these facilities at the rest area of the depot was examined after the location of above four functions of depot are decided.

In the case of depot planning, the following conditions are required for an adequate level of design for the maintenance depot (Figure 4.8.1):

- Maintenance for rolling stock
  - Rolling stock type and number of cars in train sets
  - Maintenance system
  - Work flow of each maintenance task
- Operation plan
  - Required number of train sets for operation
  - Kilometric performance per day and train set
  - Section of train operation
- Number of working days
  - Annual working days in Sri Lanka



Source: Survey Team

Figure 4.8.1 Planning Flow for Maintenance Depot

(2) Maintenance System for Rolling Stock

Maintenance of rolling stock can be divided into 3 types: Preventive Maintenance, Breakdown Maintenance, and Train Preparation. An outline of these Maintenance Systems is shown in Table 4.8.1.

The required functions for maintenance in the Depot are proposed with the maintenance facilities/equipment.

Table 4.8.1 Maintenance System for Rolling Stock

Category			Maintenance Main Tasks	Period
Preventive Maintenance	Departure Inspection		Check conditions and functions to operate the train service.	Before Departure from Depot
Preventive Maintenance	Light Maintenance	Daily Inspection	Check consumables, Check conditions and functions, Check facilities for passengers.	Within 10 days
Preventive Maintenance	Light Maintenance	Monthly Inspection	Daily inspection items, Inspect conditions and functions.	Within 3 months
Preventive Maintenance	Heavy Maintenance	Semi Overhaul	Monthly inspection items, Overhaul significant equipment.	Within 4 years or 600,000 km
Preventive Maintenance	Heavy Maintenance	Overhaul	Semi-overhaul items Overhaul all equipment	Within 8 years
Preventive Maintenance	Wheel Re-profiling		Re-profile wheel set.	(Depends on Route alignment & Operation plan)
Breakdown Maintenance			Check conditions and functions, Repair failure on a train.	(When failure on a train occurs)
Train Preparation	Daily Cleaning		Pick up waste on a train, Clean interior of a train if dirty.	After operation
Train Preparation	Car-Body Cleaning		Wash car body by machine.	Every 3 or 4 days
Train Preparation	General Cleaning		Clean interior, Wash car body.	Within 30 days

Source: Survey Team

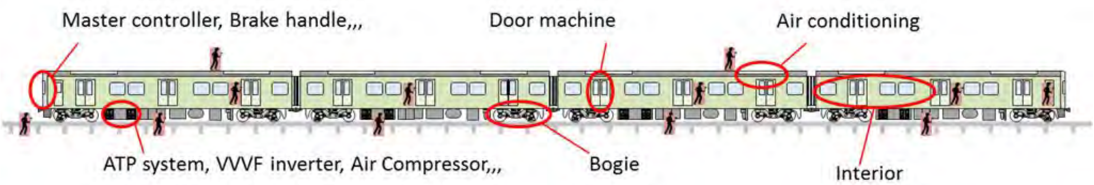
1) Preventive Maintenance

Preventive Maintenance is the most important to guarantee safe and reliable operation of rolling stocks. Without preventive maintenance, the conditions of rolling stock cannot be appropriately monitored, which may cause sudden breakdown of rolling stocks. Preventive maintenance is essential for continuous operation without sudden suspension of service. In severe case, railway operation will have to be stopped for passenger safety for a period of time.

In this part, the outline of each preventive maintenance type is described.

Light Maintenance

The main purpose of light maintenance is not to overhaul equipment, but to check or inspect the condition and the function of a rolling stock in operating condition (Figure 4.8.2).

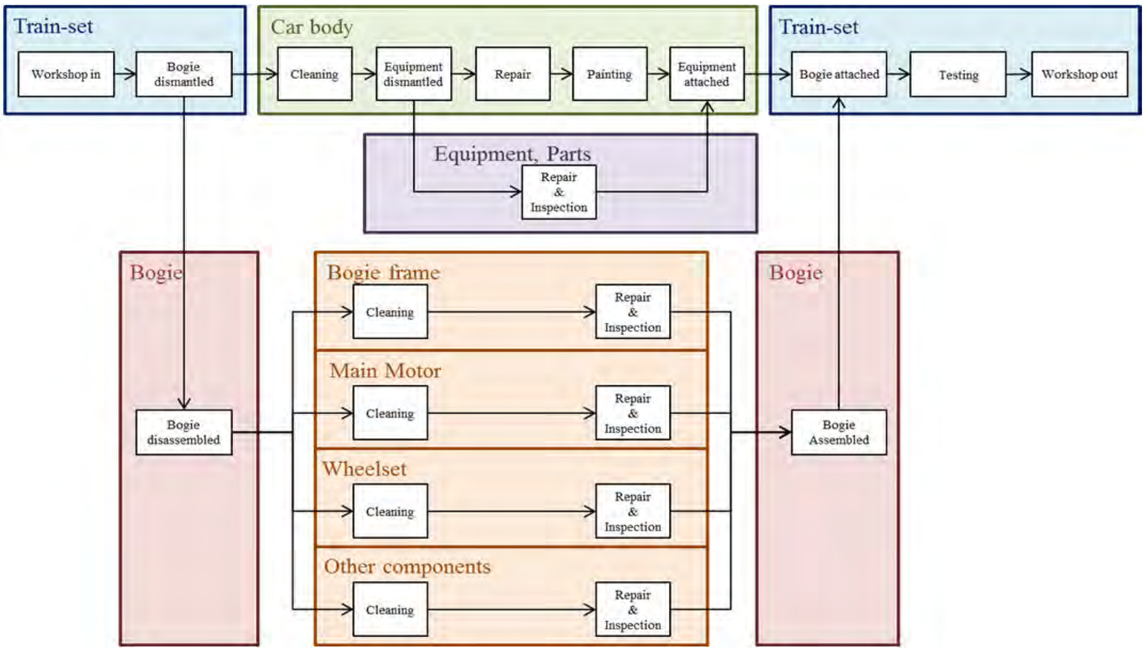


Source: Survey Team

Figure 4.8.2 Example Image of Light Maintenance

Heavy Maintenance

The main purpose of heavy maintenance is to overhaul the equipment. The work flow of Heavy Maintenance is shown in Figure 4.8.3.

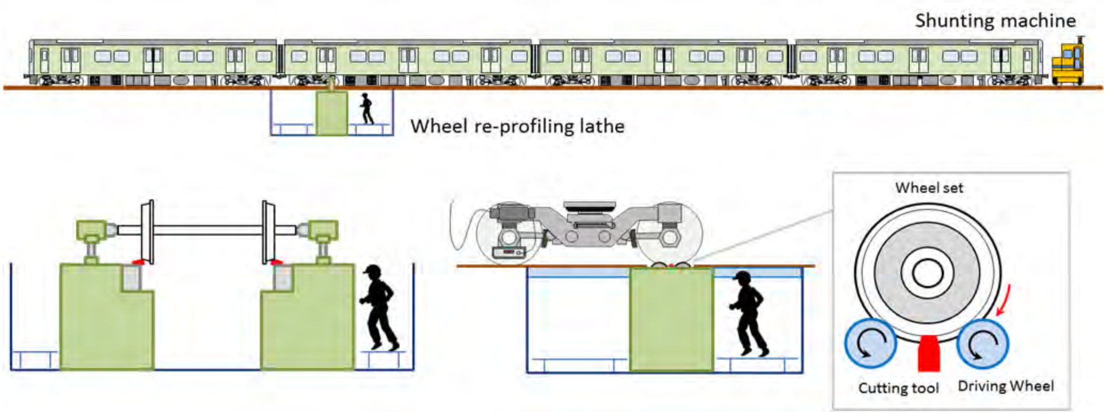


Source: Survey Team

Figure 4.8.3 Work flow of Heavy Maintenance

Wheel Re-Profiling

The main purpose of wheel re-profiling is to re-profile the wheel shape with the wheel re-profiling machine, in order to maintain riding comfort (Figure 4.8.4). The wheel re-profiling is conducted irregularly, depending on the condition of the wheel tread.

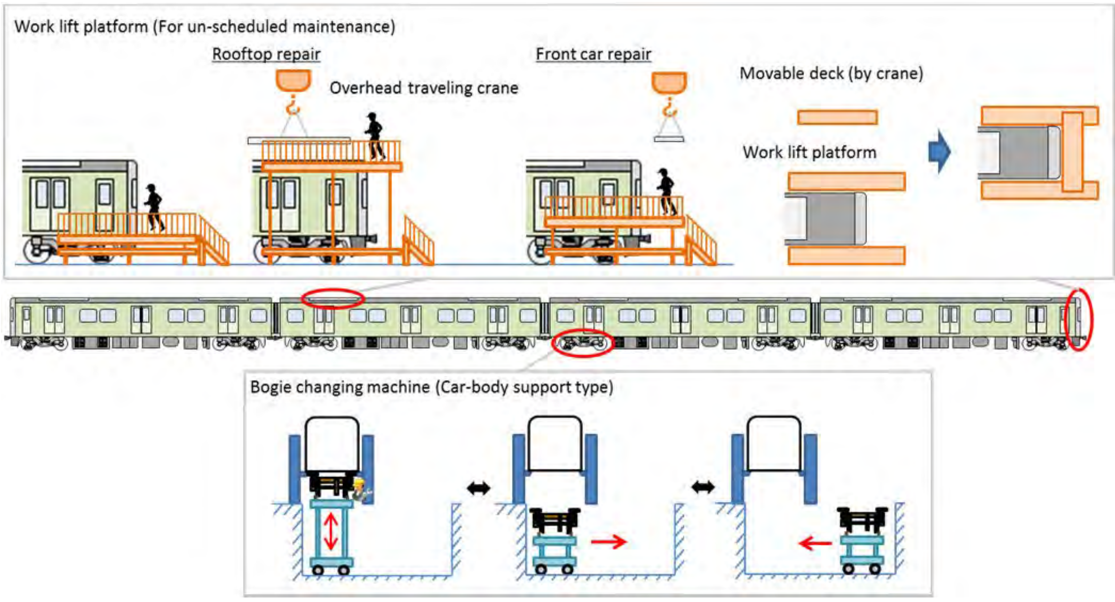


Source: Survey Team

Figure 4.8.4 Example Image of Wheel Re-Profiling

2) Breakdown Maintenance

The main purpose of breakdown maintenance is to repair a failure on a train. The train has various kinds of equipment on the roof, under the floor, and in the car (Figure 4.8.5). For this Survey, it is assumed that the exchanging of bogies is often conducted because the shape of the wheel tread is deformed due to route alignment (curves).

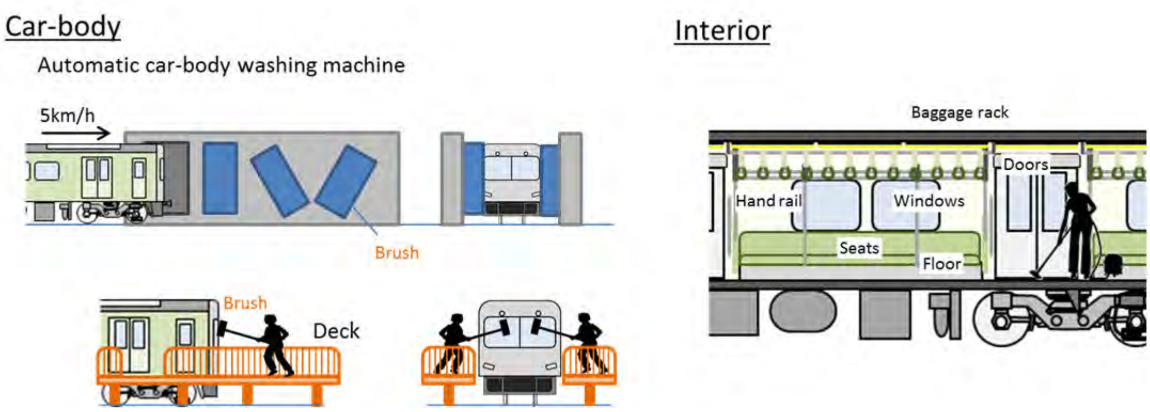


Source: Survey Team

Figure 4.8.5 Example Image of Breakdown Maintenance

3) Train Preparation

The main purpose of Train Preparation is to wash and clean a train for the purpose of comfort for passengers inside the train. Train Preparation is classified into 3 steps: cleaning after operation (every day); washing car bodies (every 3 or 4 days); and washing car bodies and cleaning all facilities such as lighting, seats, floor, windows, etc..



Source: Survey Team

Figure 4.8.6 Example Image of Train Preparation

(3) Existing Railway System in Sri Lanka

Train services in Sri Lanka have been operated by SLR since 1864. SLR has mainly 2 types of trains for passenger services - Locomotive and Carriage, and Diesel Multiple Unit (DMU) - as shown in Figure 4.8.7.

Locomotive

Carriage

DMU

Source: Survey Team

Figure 4.8.7 SLR's Rolling Stock for Passenger Service

The basic method of SLR's maintenance system is almost the same as the Survey Team's proposed maintenance system. SLR's maintenance can be classified into 2 types: light maintenance and heavy maintenance. However, there is a difference in the maintenance period. SLR's maintenance period is not unified, but the period depends on the rolling stock specification.

Heavy maintenance is conducted at the Workshop, while light maintenance is conducted at the Depot. The workshop has many facilities for overhauling all equipment; while the Depot has facilities for light maintenance, wheel re-profiling, breakdown maintenance, and train preparation. The facilities in the Survey Team's proposed plan are basically the same as the existing facilities, except for the facilities for maintenance works related to the engine, transmission, etc. (Figure 4.8.8 and Figure 4.8.9). Since SLR conducts their own maintenance, they have rich experiences in maintaining rolling stock.

Shed for Repairing Car Body

Work space for Inspecting Electrical Parts

Bogie shop

Wheel Lathe

Source: Survey Team

Figure 4.8.8 Facilities at Ratmalana Workshop

Shed for Light Maintenance

Wheel Re-Profiling Lathe

Shed for Breakdown Maintenance

Deck for Train Preparation

Source: Survey Team

Figure 4.8.9 Facilities at Hydraulic Locomotive Shed (Dematagoda)

Based on the facts of current SLR's maintenance activities and the human resource development in Sri Lanka about railway sector, the maintenance of the JICA-LRT can be managed by the Operator themselves within Sri Lanka if appropriate training are conducted to their staff.

(4) Required inspection capability of Maintenance Depot and Recommended Plan

Preconditions for the capacity calculation of the maintenance depot are as follows (Table 4.8.2, Table 4.8.3, and Table 4.8.4):

Table 4.8.2 Operation Plan

Year	Number of cars	Number of train set for operation	Total kilometric performance
2025	4 cars	22 train sets	6,246 km/day
2035	6 cars	22 train sets	6,246 km/day

Source: Survey Team

Table 4.8.3 Rolling Stock Plan

Item	Specification
Type	Electric Multiple Unit
Number of cars	2025 : 4 cars 2035 : 6 cars
Train length	4 cars : 72 m 6 cars : 108 m
Car length (including coupler)	18,000 mm
Car width	2,650 ~ 2,850 mm

Source: Survey Team

Table 4.8.4 Maintenance System, Required Time for Maintenance and Annual Working Days

Kind of Inspection	Period	Required Time	Work days
Daily Inspection	Within 10 days	1 hour	365 days/year, 24 hours/day
Monthly Inspection	Within 3 months	1 day	240 days/year, 8 hours/day
Semi Overhaul	Within 4 years or 600,000 km	17 days	240 days/year, 8 hours/day
Overhaul	Within 8 years	20 days	240 days/year, 8 hours/day
General Cleaning	Within 30 days	6 hours	240 days/year, 8 hours/day

Source: Survey Team

Based on the above, Table 4.8.5 shows the required inspection capability of the Maintenance Depot.

Table 4.8.5 Required Inspection Capability of Maintenance Depot

Year	Daily Inspection	Monthly Inspection	Semi Overhaul	Overhaul	General Cleaning
2025	2,000 trains	0.354 trains	0.224 trains	0.263 trains	1,229 trains
2035	2,000 trains	0.354 trains	0.224 trains	0.263 trains	1,229 trains

Source: Survey Team

Table 4.8.5 shows the number of train sets that can be maintained at one time. The number of train sets for overhaul in 2025 at the same time is 0.263 train sets. However, since electric multiple unit (EMU) works in a train formation, 0 or 1 train set can be in maintenance for overhaul at the same time. Furthermore, it is necessary to secure train sets for maintenance as train sets cannot be operated while in maintenance. The number of train sets in maintenance can be calculated based on Table 4.8.5. 25 train sets (22 train sets for operation, 2 train sets for maintenance, and 1 train set for stand-by) in 2025 are needed because the number of train sets under Heavy Maintenance is 1, and the number of train sets in monthly inspection is 1. The required number of rolling stock in 2035 can be calculated the same way.

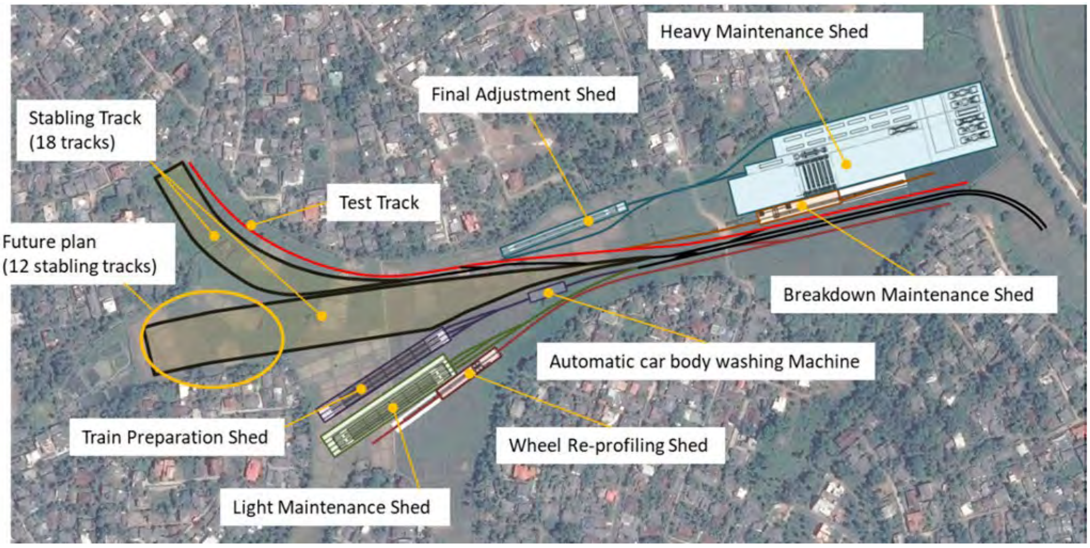
As a result of this examination, the recommended plan of the Maintenance Depot is shown in Table 4.8.6.

Table 4.8.6 Recommended Plan of Maintenance Depot (Number of Line Facility)

Facility	Stabling Track	Light Maintenance	Heavy Maintenance	Wheel re-profiling	Breakdown Maintenance	Train Preparation
Depot	18	3	1	1	1	3

Source: Survey Team

Based on this, the layout plan (Figure 4.8.10) is made to fit the candidate site. The candidate site is described in the following section.



Source: Survey Team

Figure 4.8.10 Layout Plan of Depot

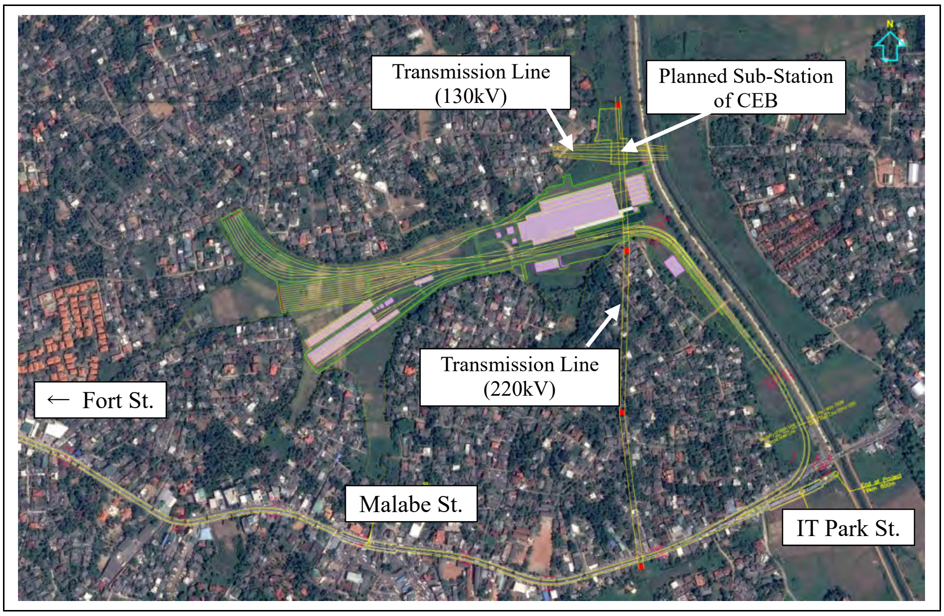
In the train operation plan, 21 train sets are stabled at this Depot. However, the number of Stabling Tracks on the layout (Figure 4.8.10 and Figure 4.8.11) is 18. Since 3 tracks for Train Preparation can be used for trains stabled, it is recommended that the number of Stabling Track on the layout be 18 to reduce the Depot area.

Moreover, in this plan, the future extension of 12 stabling tracks that are part of 18 stabling tracks is considered. If 12 tracks will be expanded in the future, more 12 train sets can be stabled at this Depot.

4.8.3 Location of Depot

The location of the depot should be not in the city centre, but at the other end of the line where a residential area is located nearby. In the morning, trains shall depart from the depot to the line. The direction of the trains will be going to the city centre, the same direction as the movement of the people commuting to work. Similarly, trains will go back to the depot when passengers return back to their residences in the evening.

Based on the alternative analysis shown in Chapter 3, the Malabe North-West area is considered as a feasible option.



Source: Survey Team

Figure 4.8.11 Location of Depot

4.8.4 Site Conditions

(1) Topology

The proposed depot area is located in the north of Malabe, and it is 950m long in the east-west direction and 90 to 380m long in the north-south direction. This area is an alluvial plain that is surrounded by hills in the north, west and south sides, and faces the canal in the east side.

The elevation of this area is lowest on the east side facing the canal and gradually increases towards the west side. The relative elevation between the east side and the west side is approximately 4m.

There are streams along both the north and south boundaries of the depot area. In addition, the watercourse flowing from the west to the east locates in the middle of the depot area.

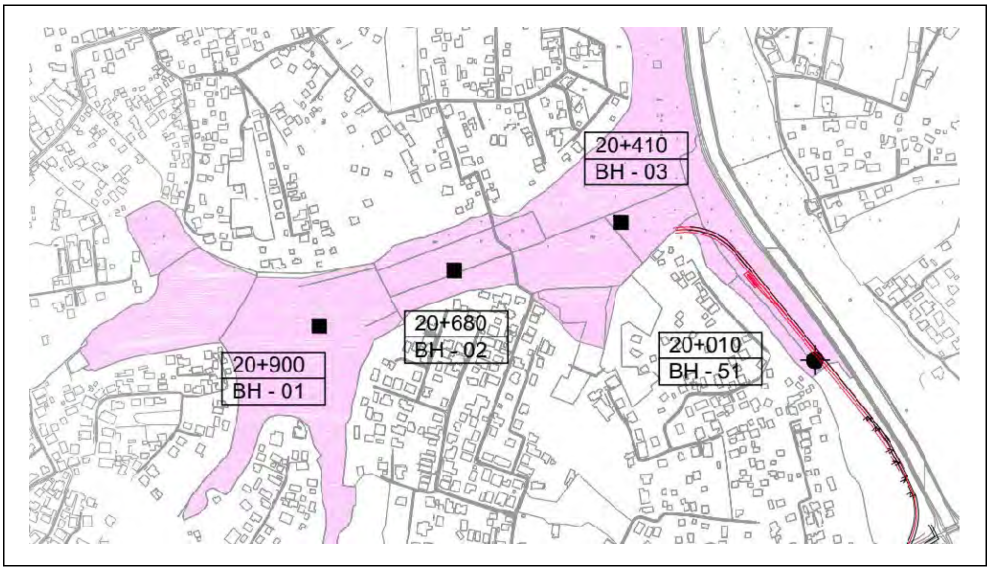
(2) Land Use

Most of this area is used as agricultural land; however, the east area is abandoned. The narrow paved road connecting the southern area with the northern area of the depot passes in the middle of the depot, and there are narrow pedestrian sidewalks in the west area.

A 220kV power line in the north-south direction crosses in the east side of the depot area. Another 132kV power line is located out of the north-east boundary of the depot. A new substation is planned on this power line close the depot area.

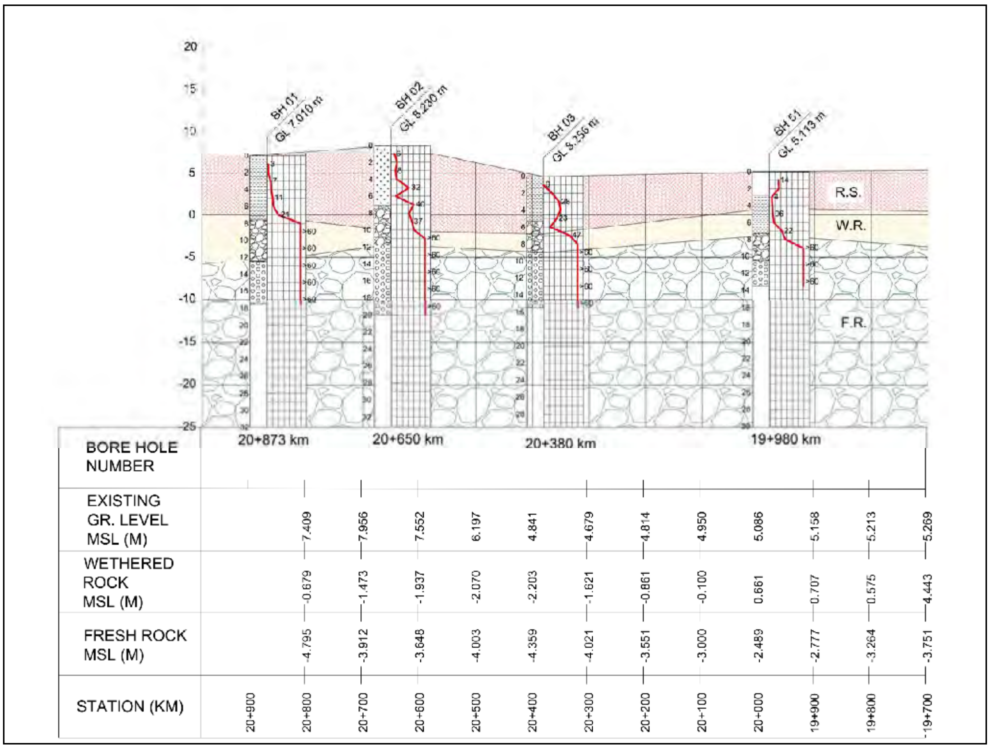
(3) Geotechnical Condition

A geotechnical survey was carried out around the depot area in the previous study. The location of boreholes and the soil profile in the depot area are shown below (Figure 4.8.12 and Figure 4.8.13).



Source: Survey Team

Figure 4.8.12 Location of Boreholes



Source: Survey Team

Figure 4.8.13 Borehole Logs

The soil in the depot area consists of sand or clay on rock. The N value of sand and clay is from 6 to 32 and from 3 to 30 respectively, therefore it is not soft ground. The fresh rock level is from 9 to 12.5m in depth from ground level, and there is 4 to 5m of thickness of highly weathered rock on the fresh rock.

The groundwater level is near the ground surface.

(4) Flooding

The depot area frequently suffers from flooding every rainy season. According to a hearing from residents living near the depot area, the water level from ground was 2 to 3m high when there was flood on May 2016. Not only the heavy rain around the depot area, but the backwater (flood lift) from the Kelani River down the canal also caused flooding in this area.

Based on the flood model by the SLLRDC, the flood level in the Depot Area for each return period is shown below (Table 4.8.7).

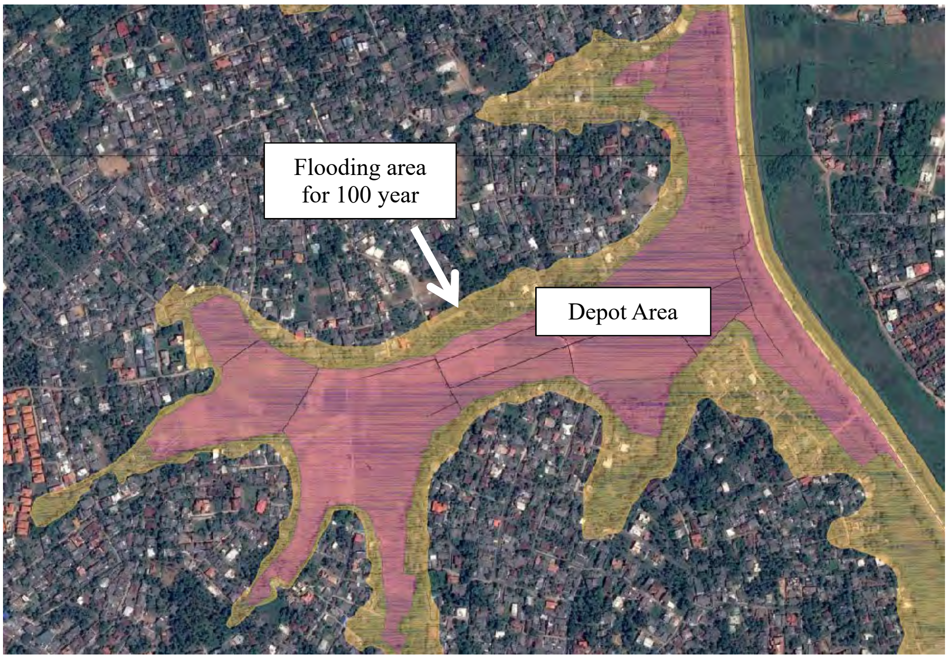
Table 4.8.7 Flood Level and Flood Recession Time in Depot Area

No	Scenario	Flood Level (m)			Remarks
		Without JICA-LRT MSL	With JICA-LRT MSL (m)	Backwater (Flood Lift) (m)	
1	Baseline-10 Year	4.62	**	**	**
2	Construction-10 Year	**	4.91	0.29	Backwater is considerable
3	Construction-10 Year with 3m wide peripheral canal	**	4.8	0.18	Backwater reduces with the proposed canal
4	Baseline-50 Year/100 Year	7.16/8.38	**	0.09/0.06	No backwater during the Operation Stage
5	Operational-50 Year/100 Year	**	7.25/8.42		

Source: SLLRDC, Survey Team

In addition, in case of a 100 return year flood, the flood level is estimated to be MSL +8.42m in the With JICA-LRT scenario.

Figure 4.8.14 shows the area for the 100 return year flood level. All of the depot area will suffer flooding; approximately 3m from ground level in the position close to the canal.



Source: Survey Team

Figure 4.8.14 Flooding Level in Depot Area

4.8.5 Civil Structure

(1) Elevated Structure

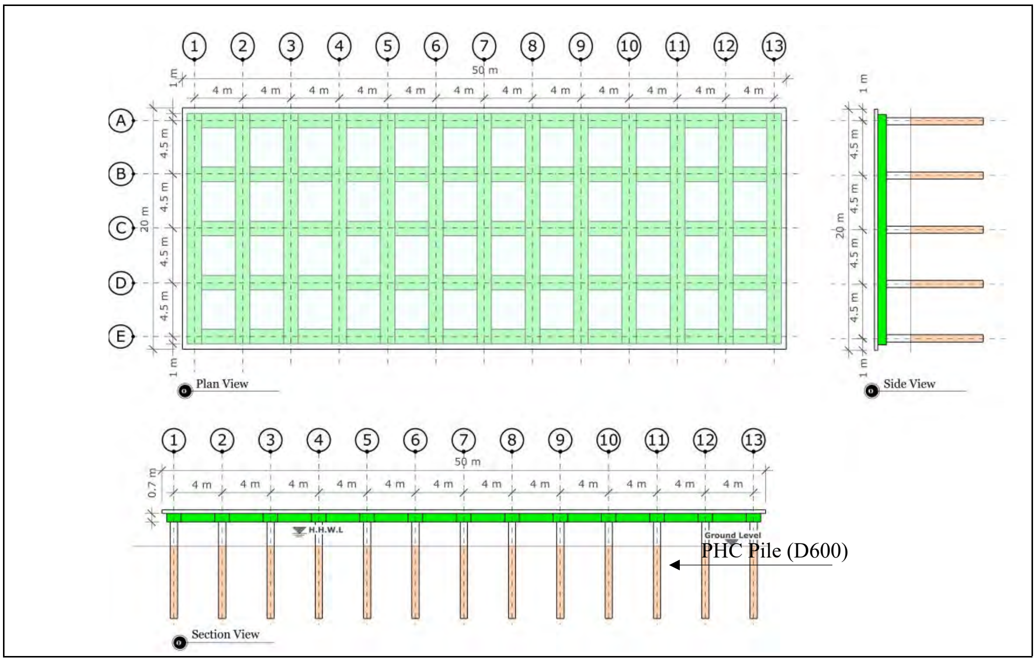
Since the location of the planned depot is in a marshy area that has a retarding effect during flooding, it is necessary to consider anti-flood measures. The depot will be built on an elevated structure consisting of the slab and pile foundation.

The height of the elevated structure from the ground level should be decided by clearance of the flood water level. The allowable clearance height is set as 0.5m, based on the anticipated water level from the flood model by SLLRDC.

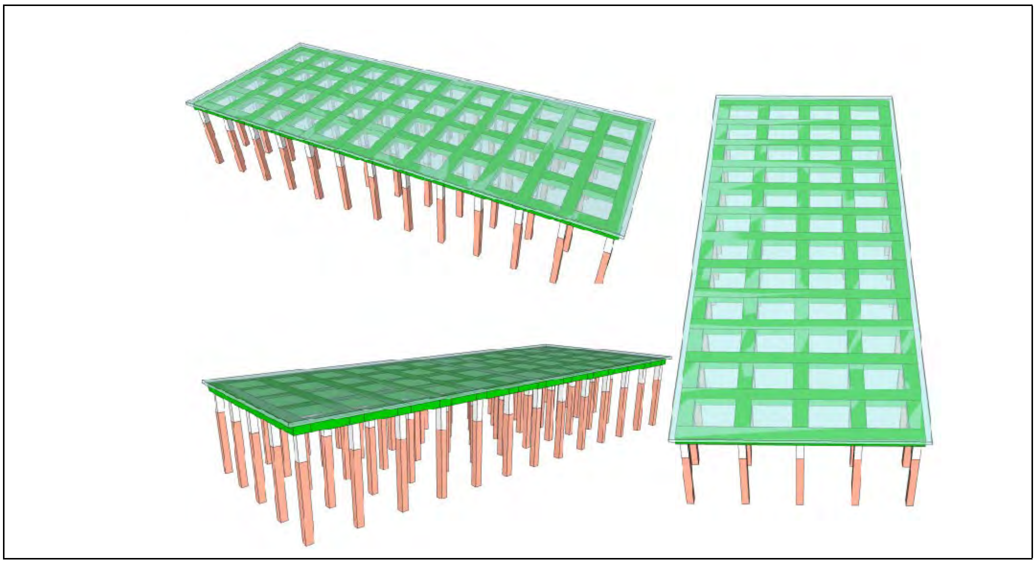
The elevated platform structure will be constructed with 50m x 20m units, depending on the track and facilities layout. The joint of each unit needs to be made with consideration of the shrinkage and expansion caused by temperature changes.

The diameter of the driven piles will be 0.6m, and the pile should be driven to a fresh rock.

The elevated platform structure is shown in Figure 4.8.15.



(a) 2D Model



(b) 3D Model

Source: Survey Team

Figure 4.8.15 The Slab and Pile Foundation

Major buildings (e.g. the heavy maintenance & breakdown shed, light maintenance shed and administration building) have independent foundations, and smaller buildings will be constructed on the slab.

The pit for equipment such as wheel profiling lathe, which will be located under the flood water level, should be required sufficient waterproof measures such as earth filling around the pit, rolling up the sheet and setting the drainage pumps.

An access track with double track to IT Park Station will be constructed with PC girders, in the same manner as the main line structures.

4.8.6 Track

Ballatless tracks will be applied in the depot, considering the cheaper installation cost and easier rearrangement of track and/or facilities layout rearrangement in the future.

The minimum horizontal curve radius is 100m in the same manner as the main line, and the gradient should be level, especially the tracks where the trains will be stabled. Turnouts to be used are 1:8.

4.8.7 Buildings

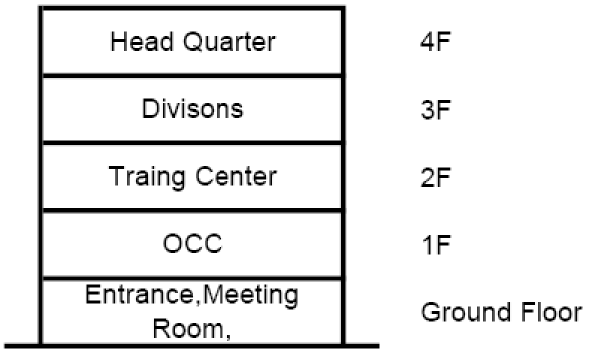
The building list for the Depot is shown below (Table 4.8.8).

Table 4.8.8 Building List of Depot

No	Name of Building	Building Area (m^2)	Structure and Stories
1	Final Adjustment Shed	1,600	Steel, 2-stories
2	Train Preparation Shed	2,700	Steel, 2-stories
3	Light Maintenance Shed	4160	Steel, 2-stories
4	Wheel Re-profiling Shed	700	Steel, 1-story
5	Oil Storage	40	RC, 1-story
6	Garbage Storage	30	RC, 1-story
7	Staff Cabin	60	RC, 1-story
8	Water Supply Facility	200	RC, 1-story
9	Pump House	15	RC, 1-story
10	Heavy Maintenance & Breakdown Maintenance Shed	15,120	Steel, 2-stories
11	Painting Shed	2,400	Steel, 1-story
12	Administration Building (incl. HQ, OCC, Training Centre)	1,000	RC, 5-stories
13	Wastewater Treatment Facility	100	Steel, 1-story
14	Emergency Vehicle Garage	200	RC, 1-story
15	Industrial Waste Storage	100	RC, 1-story
16	Oil/Paint Storage	100	RC, 1-story
17	Main Gate House	100	RC, 1-story
18	Sub Gate House	10	RC, 1-story

Source: Survey Team

The Administration Building will consist of the HQ, OCC, and Training Centre, etc. The floor image of the Administration Building and training centre facilities are shown below (Figure 4.8.16).



Source: Survey Team

Figure 4.8.16 Floor Image of Administration Building

(a) Train Simulator **(b) Control System Simulator**

Source: Survey Team

Figure 4.8.17 Training Centre Facilities

4.8.8 Other Facilities

(1) Water Supply

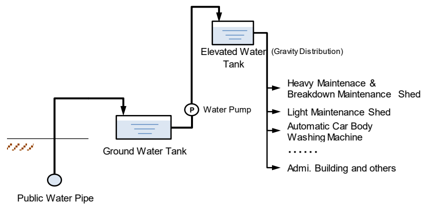
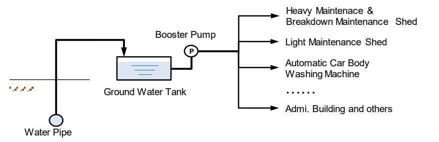
Water supply facilities provide the water used inside the depot area, such as water to wash rolling stock and equipment, drinking water for staff, and sanitary water for toilets.

There is no public water supply around the proposed depot area, however, a new water supply system will be completed by 2020, before starting depot construction. In case this water supply project is not expected to be on time, small water supply system for the depot will be required. Further information of the new water supply system is described as follows.

Comparison of Water Supply System in Depot

In general, there are two types of the water supply systems: "Elevated Water Tank System" and "Booster Pump Supply System", as shown below (Table 4.8.9).

Table 4.8.9 Comparison of Water Supply System in Depot

	Elevated Water Tank System	**Booster Pump Supply System**
		
Description	Distributing the water with gravity from elevated tank	Distributing the water from public water supply system
Advantage	• Water supply pressure is constant. • Water remaining in the elevated tank can be used even during the power failure or pump trouble.	• Construction and maintenance cost is less because the elevated tank is not required
Disadvantage	• Wider site for elevated tank is required. Also, construction cost is higher. • Maintenance cost is higher due to inspecting and cleaning the elevated tank periodically.	• Water cannot be distributed during a power failure or pump trouble • Equipment cost is higher due to requiring countermeasures for pump trouble because the complicated control of the pumps will be carried out by fluctuation of water use.
Recommendation	**Recommended**	

Source: Survey Team

The JICA Survey Team recommends the "Elevated Water Tank System" because of stable water supply in case of emergency.

Required Quantity of Water

The required quantity of water is estimated to be 125 m^3/day, which consist of 100 m^3/day for train maintenance operation and 25 m^3/day for sanitary/cleaning in the buildings.

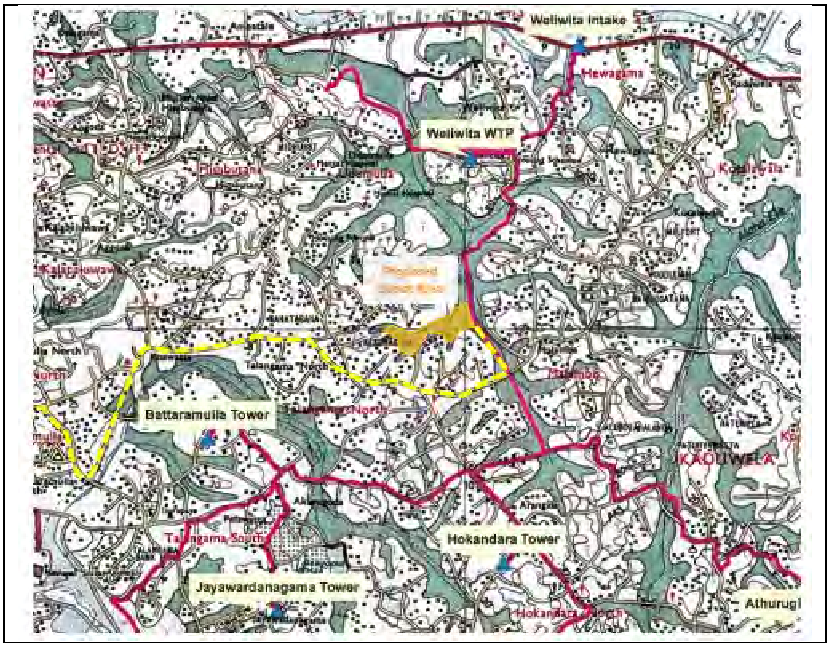
Water Supply Project

During operation in the depot, water will be used for train maintenance activities, sanitary (administration building etc.), and emergency purposes (e.g. firefighting).

Currently, there is no exiting water supply system implemented around the Depot area. However, there is a plan to implement new water supply network with proposed Weliwita water treatment plant (WTP) and new water supply line will be placed adjacent to the proposed depot area (Figure 4.8.18). For new water supply system, water will be withdrawn from the Kelani River, then send to WTP to treat to the desired water quality specifications. The water will then be supplied to the water supply network located south of the WTP. Approximately 180,000 m^3/day of water demand in the depot can be supplied by the WTP.

This new water supply project is currently planning stage as of the end of 2017. Operation of the Weliwita WTP is planned to start by 2020, before the commencement of depot construction.

In case that operation of the Weliwita WTP is not ready by the beginning of depot construction, installation of another water supply system, including construction of an independent water treatment plant in the depot as well as possibility of use of groundwater resource should be considered. In such case, the total construction cost will become higher.



Source: National Water Supply and Drainage Board

Figure 4.8.18 Potential Water Supply Source in Weliwita

(2) Rainwater Drainage

Rainwater on the RC slab and on the roofs of the building should be dropped on the ground under the RC slab. The drainage ditches should then be installed on the ground to collect the rainwater from the RC slab and the building roofs, and to discharge the collected water to a canal.

(3) Wastewater Treatment

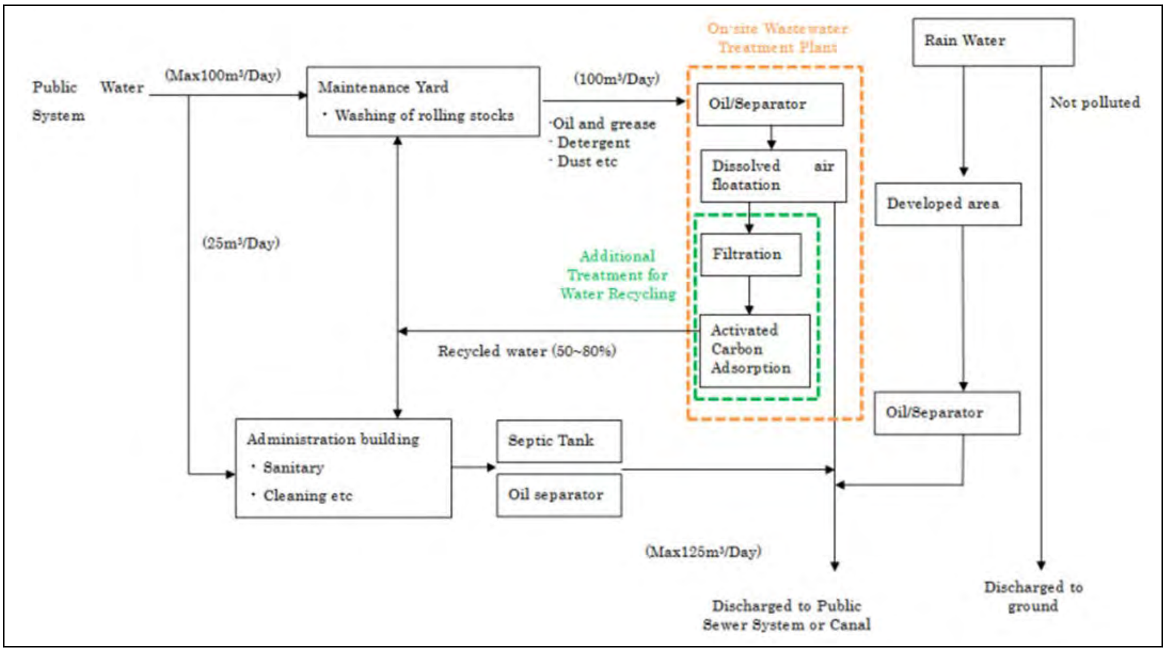
Wastewater will be released from the depot site where repair and maintenance work will be carried out. Wastewater will be generated from the administration building, such as from toilets and wash areas/sinks.

Wastewater from the depot area is generated from maintenance activities, such as carriage washing or parts cleaning. Approximately 100m^3/day of wastewater is expected to be generated from these activities. Wastewater generated may contain oil and grease, detergent, and dust possibly containing metal particles.

Conceptual Layout of the Proposed Wastewater Plant

A wastewater treatment system will be installed in the depot area. Figure 4.8.19 shows the water flow and treatment methods to be used. This system will mainly treat wastewater coming from the maintenance yard, and consists of an oil separator unit and a dissolved air flotation unit. Oil separators will be used to treat both wastewater from maintenance activities and potentially contaminated rainwater. In order to recycle some of the water and use as greywater for the maintenance yard and administrative building, additional units (filtration and adsorption) may also be included in the wastewater treatment system.

The plan is to recycle 50 percent, and up to 80 percent, of the wastewater generated. However, a higher recycle rate will result in a higher construction and operation/maintenance cost.



Source: Survey Team

Figure 4.8.19 Water Flow Diagram

The water treated will be discharged to the public sewer system or canal, satisfying the dischargeable water-quality regulations.

Sludge

A limited amount of sludge from the wastewater treatment system would be generated, depending on the amount of dirt, dust, oil/grease accumulated by the trains.

The final disposal of sludge should be contracted out to a registered industrial waste company. Sludge dewatering and drying equipment should be installed in the depot area, if required.

(4) Waste materials

Typical solid and liquid wastes generated at the depot and workshop area are listed in the table below (Table 4.8.10).

Table 4.8.10 Type of Waste from Depot Area

Type of Waste	Source
Lubricant oil	Air compressor and gear box
Sludge	Wastewater treatment plant (when cleaning train and its parts)
Brake shoe (brake pad)	Brake equipment
Metal scraps	Wheel re-profiling lathe, etc. (wheel re-profiling, and exchanging parts)
Rubber tube	Brake system (need to exchange every 8 years depending on its specs)

Source: Survey Team

Domestic waste from the administrative buildings in the depot area will be segregated. Recyclable materials (e.g. paper, glass) will be handed to registered recyclers. Non-hazardous wastes will be disposed to in accordance with relevant local regulations (e.g. disposal to designated disposal sites). Hazardous wastes (e.g. used batteries, light bulbs) will be collected and carefully stored. Treatment and disposal of these wastes will be contracted out to a registered industrial waste company.

These wastes should be collected and disposed regularly to prevent accumulation, which may cause pollution and safety risks.

(5) Fencing

Though the depot is an elevated structure, from the viewpoint of security, the area should be enclosed by a fence on the ground, in order to prevent unauthorized persons from entering the depot area. A security system such as electric wiring will be installed if required. Major buildings such as the administration building requiring a high security level should install a monitoring system by CCTV. The security guard staff stationed in the main gate house will monitor the security system.

4.8.9 Track Maintenance Depot

The Track Maintenance Depot will be located along the depot access track. This depot consists of the track material stock yard such as rail, the shed of the motor car (MC), the track maintenance department office, etc. The role of this depot includes maintenance of signalling and power supply system along the track.

This depot area is also on the RC slab as an anti-flooding measure.

In addition, the stabling track for the MC is located at Fort Station.

4.8.10 Landscape

Since the depot is located in a residential area, landscape consideration should be required. A green buffer zone should be set along the depot area boundary to harmonize with the surrounding landscape. The width of green buffer zone will be 2 to 3m.

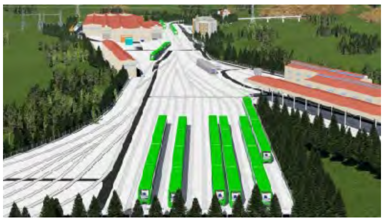
4.8.11 Road Diversion

There is a road crossing the depot area in the north-south direction. This road will be diverted to pass under the depot structure. Since it is expected that the road floods in the rainy season, the sign board for flooding notice should be installed at the entrances of the depot area.

During construction, especially civil work, a detour route should be provided and all roads crossing the depot area should be closed.

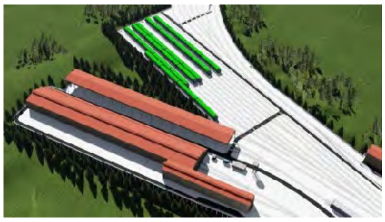
4.8.12 Depot Layout/Image

The 3D images of the Depot are shown as Figure 4.8.20; The Depot layout is shown in Appendix 7.



View from West, (Stabling Yard)

Administration Office and Heavy Maintenance Facility



Light Maintenance and Stabling Yard

Source: Survey Team

Figure 4.8.20 3D Image of Depot

4.9 Signal and Telecommunications

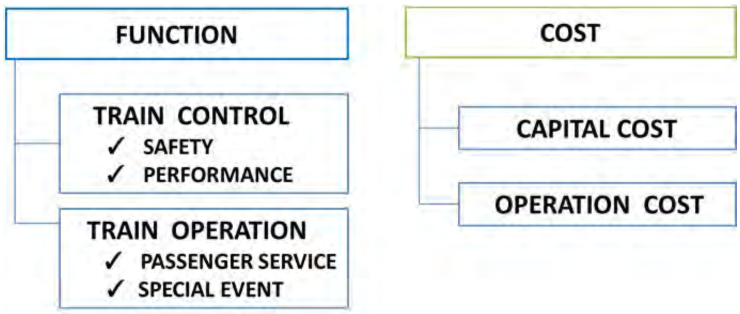
4.9.1 Planning Principle

With planning principle on appropriate Signalling & Telecommunications (S&T) for the first full-elevated LRT in Sri Lanka, the essential factors, as shown below in Figure 4.9.1, will be taken into consideration.

Firstly, as for the functions of both train control and train operation, it is desirable that its safety and performance shall be to standard, and that countermeasures for restricted train operation should be provided for operation dispatchers; satisfactory or favourable services should be provided for passengers as well.

Secondly, as for the cost estimation, it is essential to examine not only the initial investment cost but also the maintenance cost for the selection of alternatives for S&T, and also technology obsolesce of the system, maintenance support and cost formula for spare parts.

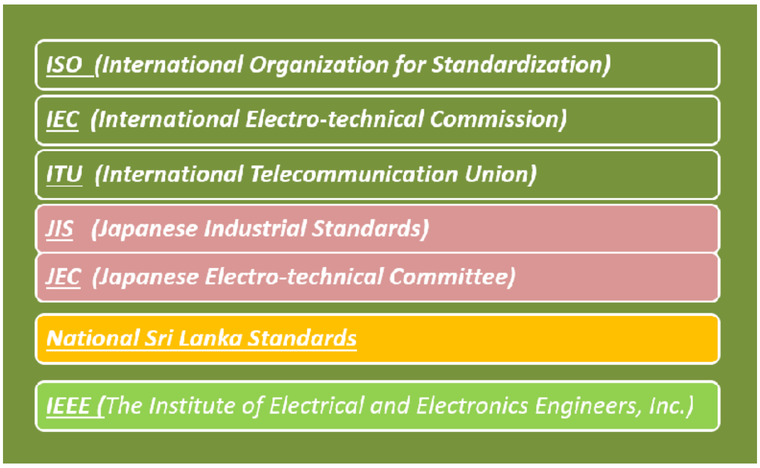
In addition, the life cycle of S&T equipment is assumed to range from 15 years up to 20 years.



Source: Survey Team

Figure 4.9.1 Planning Principle for Signalling and Telecommunications

Figure 4.9.2 shows the list of standards that are applied to the S&T in the JICA-LRT.



Source: Survey Team

Figure 4.9.2 Compliance with Standards

Next, main subjects for planning the Signalling for the JICA-LRT consist of the following four systems. The outline of these systems and their issues to be discussed are shown in the following section.

- Automatic Train Protection (ATP)
- Automatic Train Operation (ATO)
- Automatic Train Supervision (ATS)
- Centralized Interlocking System (CIS)

For the planning of Telecommunications, the selection of the types of transmission means as well as collecting & monitoring the types of events and information will be described in sub-sections below.

4.9.2 Automatic Train Protection

The automatic train protection system prevents train collisions by controlling distance between train, and it limits the speed on the basis of route and temporary work conditions.

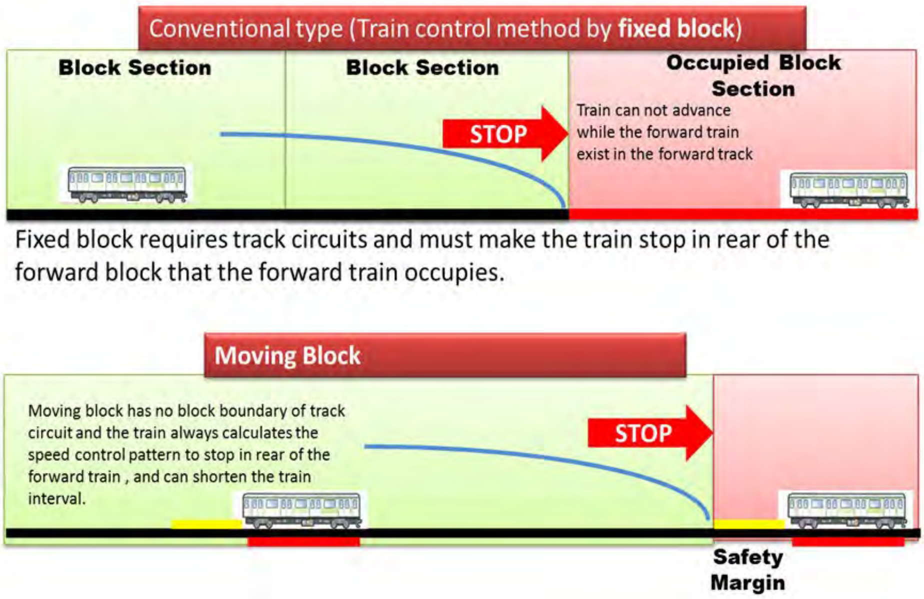
In order to implement an ATP system, there are two methods based on different train detection system for its location: "Fixed Block System with Track Circuits" and "Moving Block with Communications-Based Train Control (CBTC)".

1) Fixed Block System with Track Circuits

This is a conventional system used in railways worldwide as well as by Sri Lanka Railways, as shown in Figure 4.9.3 below.

2) Moving Block System with CBTC

This has been practically applied in recent years. As for its basic principle, train location is monitored continuously through communications between the train and ground facilities. In order to prevent a train collision without exception, the braking distance for the succeeding train should keep a safe distance between a preceding train and a succeeding train. If none of the above conditions have met, emergency braking would be applied.



Source: Survey Team

Figure 4.9.3 Image of ATP (Fixed Block and Moving Block System)

The comparison between Fixed Block System and Moving Block System is shown in Table 4.9.1. Regarding the alternatives of the two mentioned systems, discussion between PMU and the Survey Team was made during the Survey.

Table 4.9.1 Summary on Pros/Cons of each ATP System

Items	Fixed Block (Track Circuit)	Moving Block (CBTC)
Outline of System Merit	Reduction of operation headway with modification of facilities and its cost	Flexible control of train interval without modification of facilities
Safety	Safety Integrity Level 4 in International Electro-technical Commission (IEC)	No difference from the Left (Based on Safety Integrity Level 4 in IEC)
Reliability (Result)	Reliability specified in IEC	No difference from the Left (Based on Reliability in IEC)
Comfort of ride	Ordinary comfort of ride	No difference from the Left
Features of On-Ground Facilities and their Scale & Size	Ordinary Scale & Size With track circuits, signals and their cables Without on-ground radio facilities	Smaller Scale & Size as a whole Without track circuits, signals and their cables With on-ground radio facilities
Initial Investment Cost	Ordinary cost	Less than the Left
Simplicity of Maintenance Management	Ordinary system	Simpler than the Left
Maintenance Cost	Ordinary cost	Less than the Left
Others, if any	Nothing in particular	Different Interference Methods in CBTC

Source: Survey Team

As for the necessity of a rail breakage detection system, it is possible for the fixed block system with track circuits to detect the rail breakage in common use. However, in case of the moving block system with CBTC, it is required to install any detection system, if necessary. As a result, a partial redundant facility will be accommodated.

According to the explanation by a track work engineer in SLR, it seems that rail breakage occurs about once every 2~3 months. The conditions of train operation and rails of SLR in Colombo are quite different from that of the JICA-LRT. Therefore, the possibility of rail breakage seems to be less than that of Sri Lanka Railways due to its concrete bed structure, lighter axle weight and higher quality of rails, etc.

4.9.3 ATO

According to the International Association of Public Transport (UITP), the Grade of Automation (GOA) on ATO is classified into four types, as illustrated in Figure 4.9.4:

- GOA 4 is unattended train operation (UTO), where the starting and stopping, operation of doors and handling of emergencies are fully automated, without any on-train staff.
- GOA 3 is driverless train operation (DTO), where the starting and stopping are automated, but a train attendant operates the doors and drives the train in case of emergencies.
- GOA 2 is semi-automatic train operation (STO), where starting and stopping is automated, but a driver operates the doors, drives the train if needed and handles emergencies. Many ATO systems are GOA 2.
- GOA 1 is manual train operation, where a train driver controls starting and stopping, operation of doors and handling of emergencies or sudden diversions.

Grade of ATO	*Train Operation Type*	*Ensure Safe Movement Trains*	*Drive Train*	*Supervision Guide Way*	*Supervision of Passenger Transfer*	*Operation of Train*	*Operation during disruption*	
GOA 1	Non-Automatic Train Operation	Driver	Driver	Driver	Driver	Driver	Driver	ATP with diver
GOA 2	Semi-automatic Train Operation	Automatic	Automatic	Driver	Driver	Driver	Driver	ATP and ATO with driver
GOA 3	Driverless Train Operation	Automatic	Automatic	Automatic	Train attendant	Train attendant	Train attendant	
GOA 4	Unattended Train Operation	Automatic	Automatic	Automatic	Automatic	Automatic	Automatic	

Source: Survey Team

Figure 4.9.4 Grade of Automation on ATO

For all main tracks and the entry/departure sections of depot, the automatic operation system must allow the selection of automatic operation as required. This system consists of an on-board unit and a ground unit.

In the section between adjacent stations, the ground unit transmits information on the stop position, speed limit, etc. to the on-board unit. Receiving the information, the on-board unit generates the train operation speed pattern, and automatic operation is done on the basis of such information. At the same time, the on-board unit transmits the train location information in a given interval to the ground unit.

Inside the station yard, the on-board unit receives information each time the train passes over the ATO wayside coil, ensuring the train stop at the specified position. The on-board unit controls the opening and/or closing of doors automatically or manually through interlocking between them of the vehicle and platform, then allowing the train to depart automatically or manually.

In specific terms, three alternatives for the safety check of car door operation (door closing in particular) are as follows:

- Operation by Crew (Driver): This corresponds to GOA 2
- Operation by Staff on platform at station
- Operation by Crew (Guard)

Furthermore, if ATO (GOA 2, 3, 4) will be introduced into the JICA-LRT, a Platform Screen Door (PSD) system can be installed at the station.

The GOA 2 is recommended to be applied to JICA-LRT.

4.9.4 Automatic Train Supervision

Types of train operation management systems are classified into manual supervision in each station and centralized supervision in the OCC. The latter is divided into manual control type and automatic control type with Programmed Route Control (PRC).

Automatic train supervision with PRC is recommended to be applied to the JICA-LRT because of high density train operation in urban railway, and saving manpower and its expenditure.

The train operation management system linked with PRC, in combination with the signal and telecommunication system, power supply system and Centralized Information Monitoring system (CIM), has the basic function of ensuring smooth operation of train groups which includes train diagram control; operation record management; operation control and monitoring; route control; guidance display control; and information broadcasting for all trains on the main track and on the entry and exit sections to depots.

The detailed functions of train operation management are classified into a) monitoring position and condition based on train diagram information such as punctuality, and the delay of each train and automatically controlling the adjustment of train departure times, b) the designation of arrival and departure tracks, and c) instructions for departure sequence.

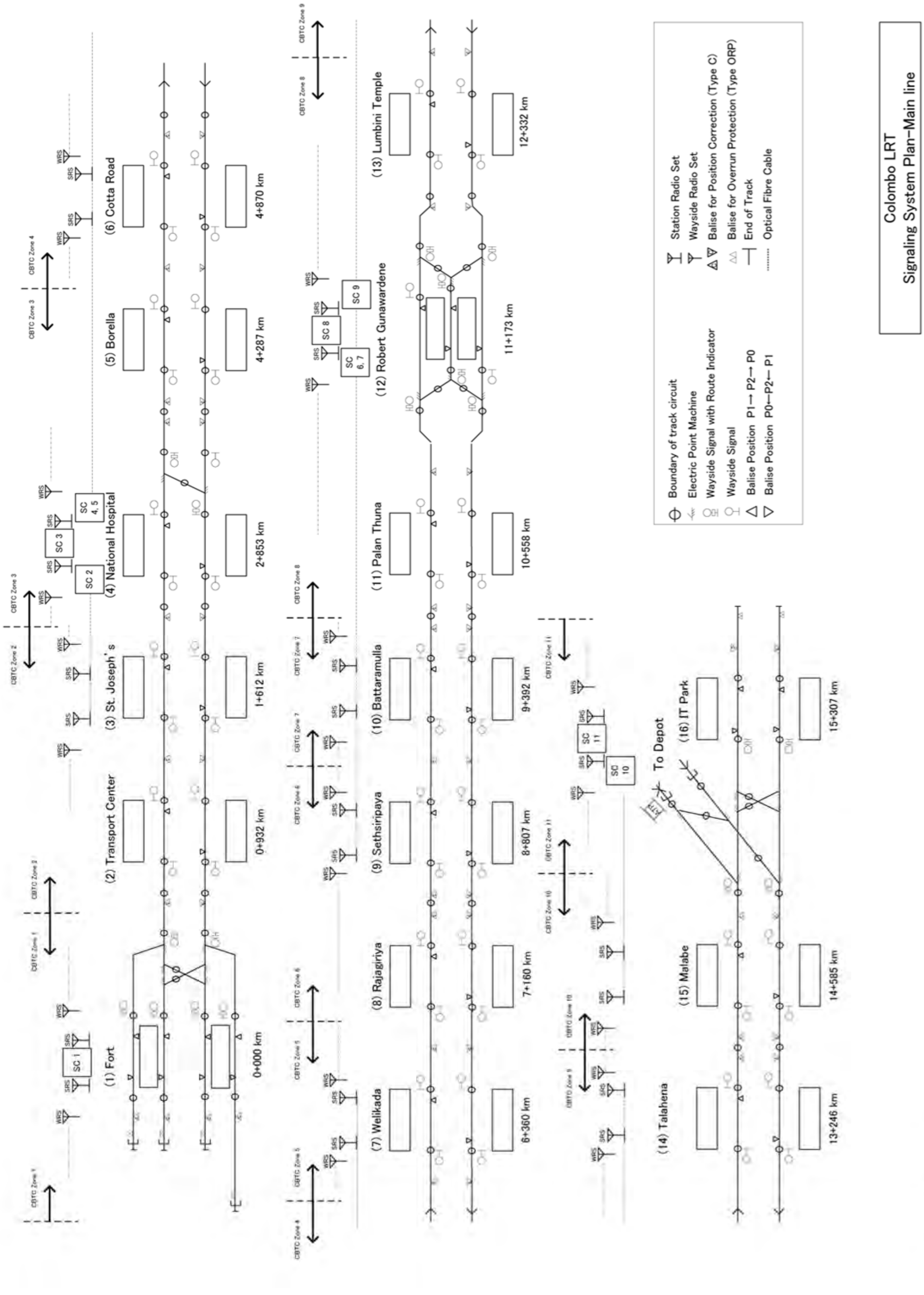
On the other hand, with the tentative change of the train diagram information, train dispatchers at the OCC are able to perform manual controls for any specific train or all trains from the traffic dispatching console, for such operations as changing departure time, changing arrival or departure track, and changing departure sequence.

Source: Survey Team

Figure 4.9.5 Image of OCC

4.9.5 CIS

The CIS is recommended to be provided at four stations, namely Colombo Fort, National Hospital, Robert Gunawardene, and IT Park on the main track, and at the car depot to secure the safety of route setting. Signal system plans at main line and at depot are described in Figure 4.9.6 and Figure 4.9.7.



Source: Survey Team

Figure 4.9.6 Signal System Plan on Main Line

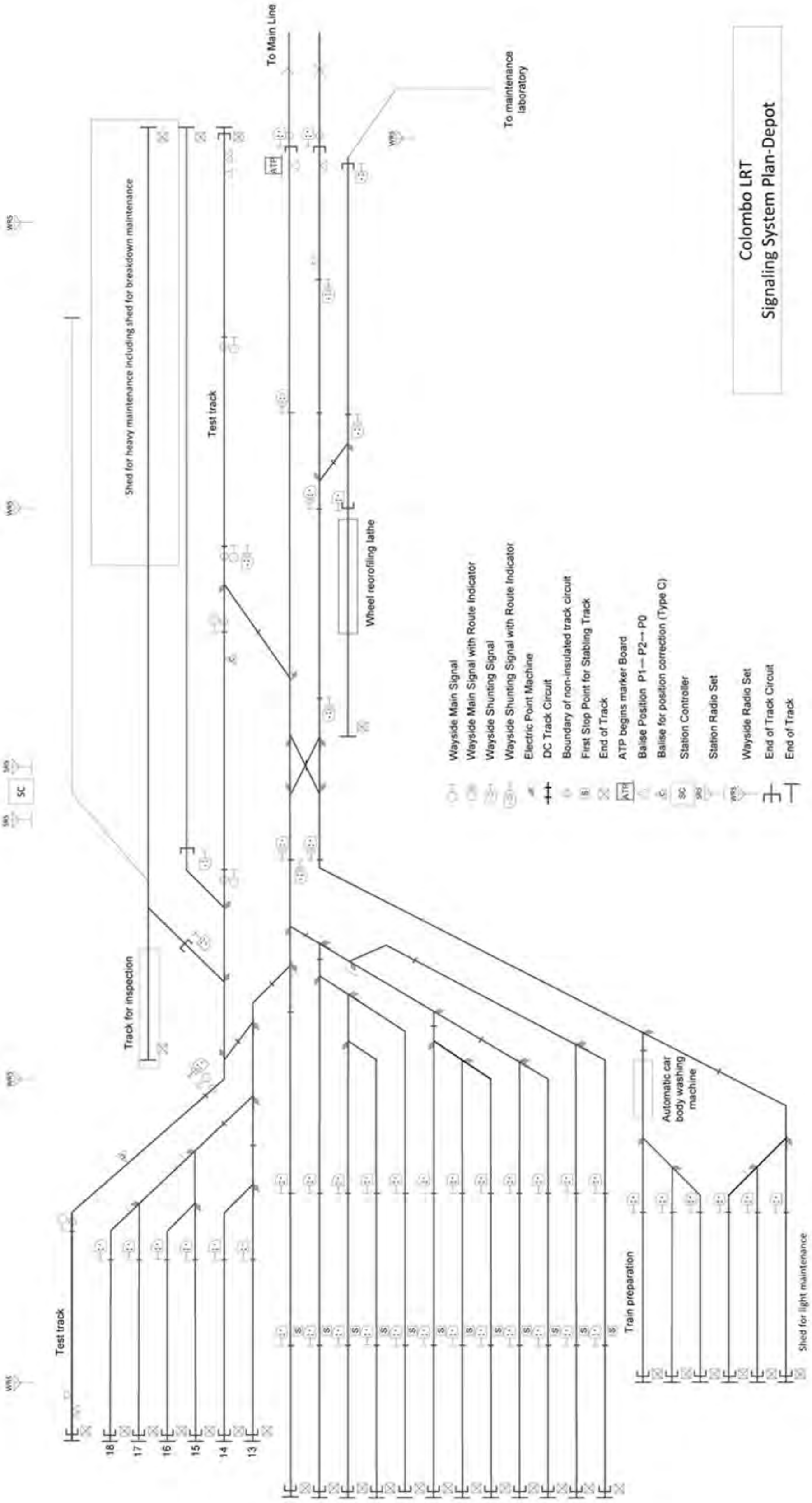


Figure 4.9.7 Signal System Plan at Depot

Source: Survey Team

4.9.6 Telecommunications

The telecommunication system is used to ensure a smooth and efficient execution of the train operation and maintenance work. This system also functions as a medium of communication to the passengers, drivers and dispatchers in case of recovery of train operation after an abnormality, special events and emergencies. The system's compositions and functions are shown in Table 4.9.2.

Table 4.9.2 Components of the Telecommunication System

Classification	Component
Train radio equipment	Train radio, maintenance radio, emergency warning, train information (Delay, train information in other lines, transfer)
Cable equipment	Dispatcher telephone, exchange telephone
Closed Circuit Television (CCTV)	Video monitoring
Optical transmission equipment, etc.	Optical fibre transmission, power supply
Passenger information display equipment, Public address equipment	Train operation guidance display (Train Delay Platform No. Departure time), guidance announcement (Train approach, door closing, abnormal event information)
CIM (Centralized Information Monitoring System)	Monitoring the conditions on the main equipment and the disaster preventive data

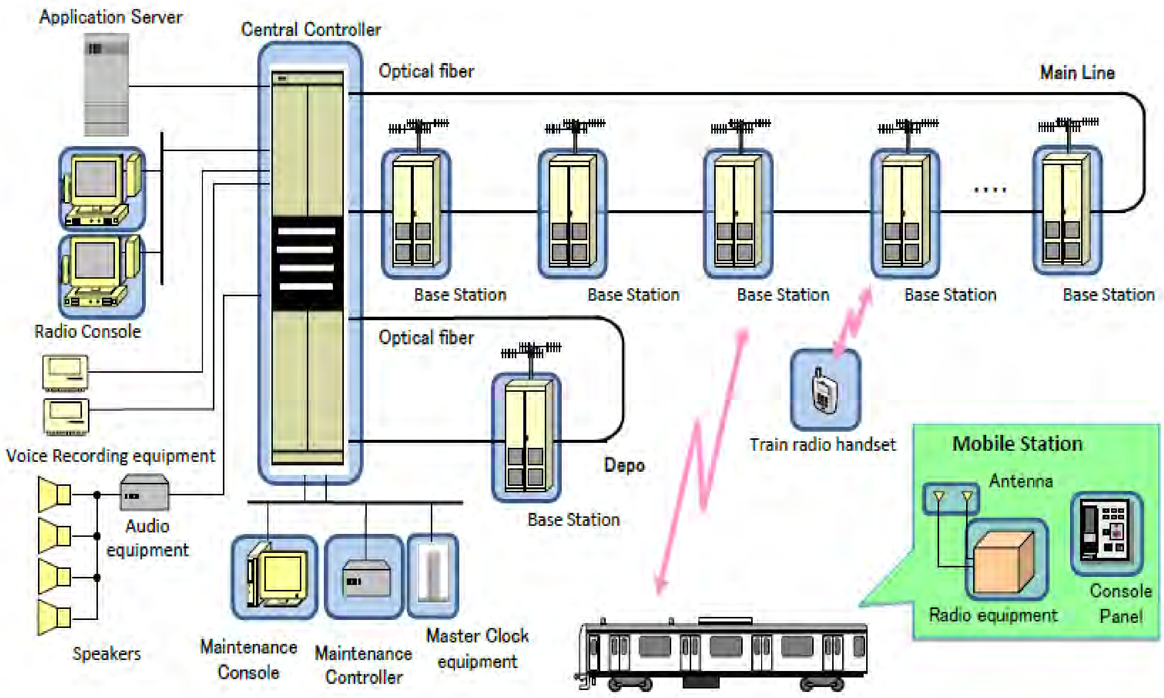
Source: Survey Team

1) Communication Methods between the OCC and Moving Trains

The train radio equipment establishes communications between the dispatching centres, trains on the main track, and vehicles inside the car depot. This enhances train operational safety and facilitates the performance of duties. The emergency alarm equipment has emergency warning and emergency train stop functions that can be used as emergency measures.

Recently, the usage of mobile phones in a public radio network is prevailing; however, exclusive radio circuits in VHF bands is desirable for a train radio system in the JICA-LRT, in viewpoint of keeping its availability in case of disaster and avoiding the interference with other radio frequencies as well. This is why the usage permission of exclusive radio frequency bands will be required through the official protocol to the Telecommunication Regulatory Committee (TRC). Figure 4.9.8 describes the configuration of the train radio system.

In addition, train operation information with Light Emitting Diode (LED) displays will be able to be provided to passengers in the train, through exclusive radio circuits.



Source: Survey Team

Figure 4.9.8 System Configuration of Train Radio

2) Optical Transmission Equipment

The optical transmission equipment needs to be installed in the OCC and in each station independently, securing a high degree of transmission quality and transmission speed.

The optical transmission equipment is a transmission circuit used to ensure efficient and high-quality information in the communication between the central dispatching centre and field organizations, and on the remote monitoring and control from the centre for a period of train operation and maintenance, even when there is a possibility of interference caused by lightning or electrical magnetic noise.

3) Closed Circuit Television equipment

The CCTV equipment for train operation includes CCTV cameras in the platforms and concourse of each station, which enables monitoring passengers getting on/off trains from the train cabin.

4) Centralized Information Monitoring System

CIM is installed to monitor the conditions on the main equipment and the disaster prevention data against wind and rain, via the optical transmission system at the console of the OCC. The major items of monitoring are as follows:

- Facility Failure and Status: Any abnormality in the main facilities is displayed and alarmed.
- Disaster Prevention against Wind and Rain: Displayed and alarmed at a time point when data from the anemometer (Figure 4.9.9) and pluviometer (Figure 4.9.10) exceeds the operation restricted limit.

Source: Survey Team

Figure 4.9.9 Image of Anemometer at the wayside

Source: Survey Team

Figure 4.9.10 Image of Pluviometer

5) Telephone Set and Interphone Equipment for Train Operation

The telephone set consists of an administrative telephone circuit via an exchange and a direct dispatcher telephone.

A direct dispatch telephone network accomplishes a core communication system of railway operation. And, it is used to communicate with the site and the OCC at the time of maintenance facilities inspection or the failure of the system used in railway operation. The dispatch telephone is used for train operation dispatching, electric power dispatching, telecommunication dispatching, signal dispatching, and facility dispatching. The interphone equipment is provided at the concourse and in the platform at each station, if necessary.

6) Passenger Information Display (PID)

This PID system provides information of train schedule, departure time, train number, and train type for passengers at the station, as well as at the concourse of the station.

Display panels are installed at each station platform and concourse. The main equipment is installed at the station equipment room, and LED indicated displays are installed at the station platforms and concourse.

Figure 4.9.11 Image of Passenger Information Display

7) Public Address (PA) Equipment

A PA system is the broadcast system installed at every station platform and at the concourse. This system provides guide information such as approaching train, door operation, and urgent information.

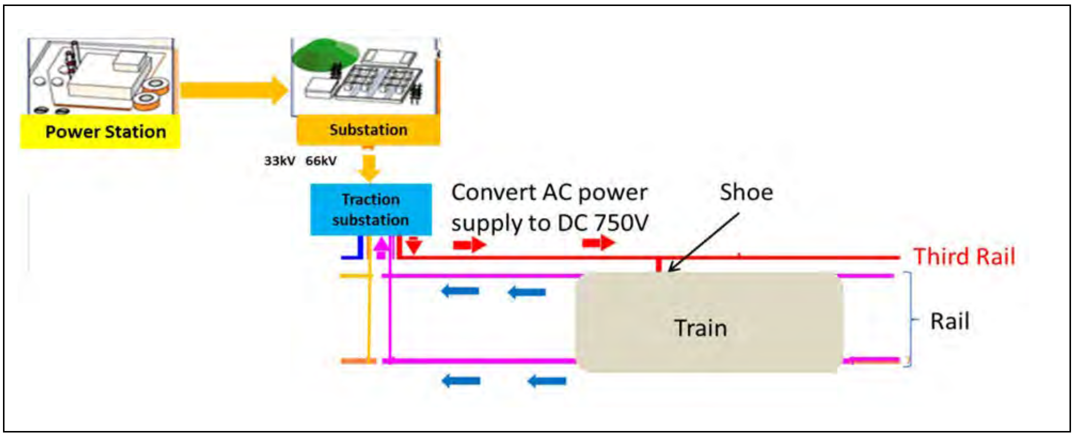
The approach of train is automatically announced when a signal is received from the signal system and other announcements are made by manual operation.

4.10 Electrical & Mechanical/ Power Supply

4.10.1 Electrical

(1) Power Supply System

As the third-rail power supply system is selected for JICA-LRT, Figure 4.10.1 shows the image of electricity flow for power supply to the JICA-LRT train. The alternating current (AC) power is distributed from the power station to the Receiving Substation (RSS) for the JICA-LRT system via grid lines of CEB, and then the RSS sends AC to the Traction Substation (TSS) that converts to direct current (DC) from AC. The TSS supplies DC 750V on the third rail to the motor in the JICA-LRT vehicle for traction.



Source: Survey Team

Figure 4.10.1 Image of Electricity Flow for JICA-LRT System (Third Rail)

In the F/S, one of the necessary tasks is to clarify the CEB's grid point location, and where the RSS and the TSS should be located.

The RSS requires a land area of 25m x 30m as base size. If the Traction Electric Room is included in the RSS, a larger area size is needed. The RSS is recommended to be located near the current grid line with enough capacity, which is around 40 Megavolt-ampere (MVA). The TSS requires a land area of 45m x 25m. The location of both the RSS and the TSS is decided with consideration to avoiding flooding and security.

The Service Substation (SSS) provides electricity to the electrical equipment in the station. Therefore, it should be installed inside of the station, or the nearest place in case there is not enough space inside the station.

For the station power supply, it is recommended to step down the voltage to 6.6 kV at TSS and to transmit power. A voltage of 6.6 kV is not common in Sri Lanka, but it is recommended to use 6.6 kV considering the current flowing through the line and the insulation distance. Especially since the station building cannot be enlarged and the ceiling is restricted to a low level, it is not possible to satisfy the insulation distance and the bending of cable at the typical 33 kV voltage in Sri Lanka.

Power transmission from the TSS to the SSS is carried out on two lines, and from the opposing TSS it is possible to transmit power to the SSS by two lines. Redundancy is provided as described above.

The Traction Electric Room is a room that supplies electricity to the track lines in the Depot, and has only the main switch for each line is arranged. The equipment is installed at the "Depot RSS". The main switches for each line are listed as Entry Track, Outgoing Track, Maintenance, Heavy Repair, Test Track, Stabling Tracks and Other Tracks.

The OCC Electric Room provides electricity for the operation control centre, which is installed at the ground floor of the OCC building where OCC and Power Supervisory Control and Data Acquisition (SCADA) are prepared. It equips two 33kV feeder lines transmitted from the RSS and an emergency generator.

The power supply system diagram described above is shown in Figure 4.10.3. Although capacitors for power factor improvement are not indicated, these are planned to be installed in the SSS.

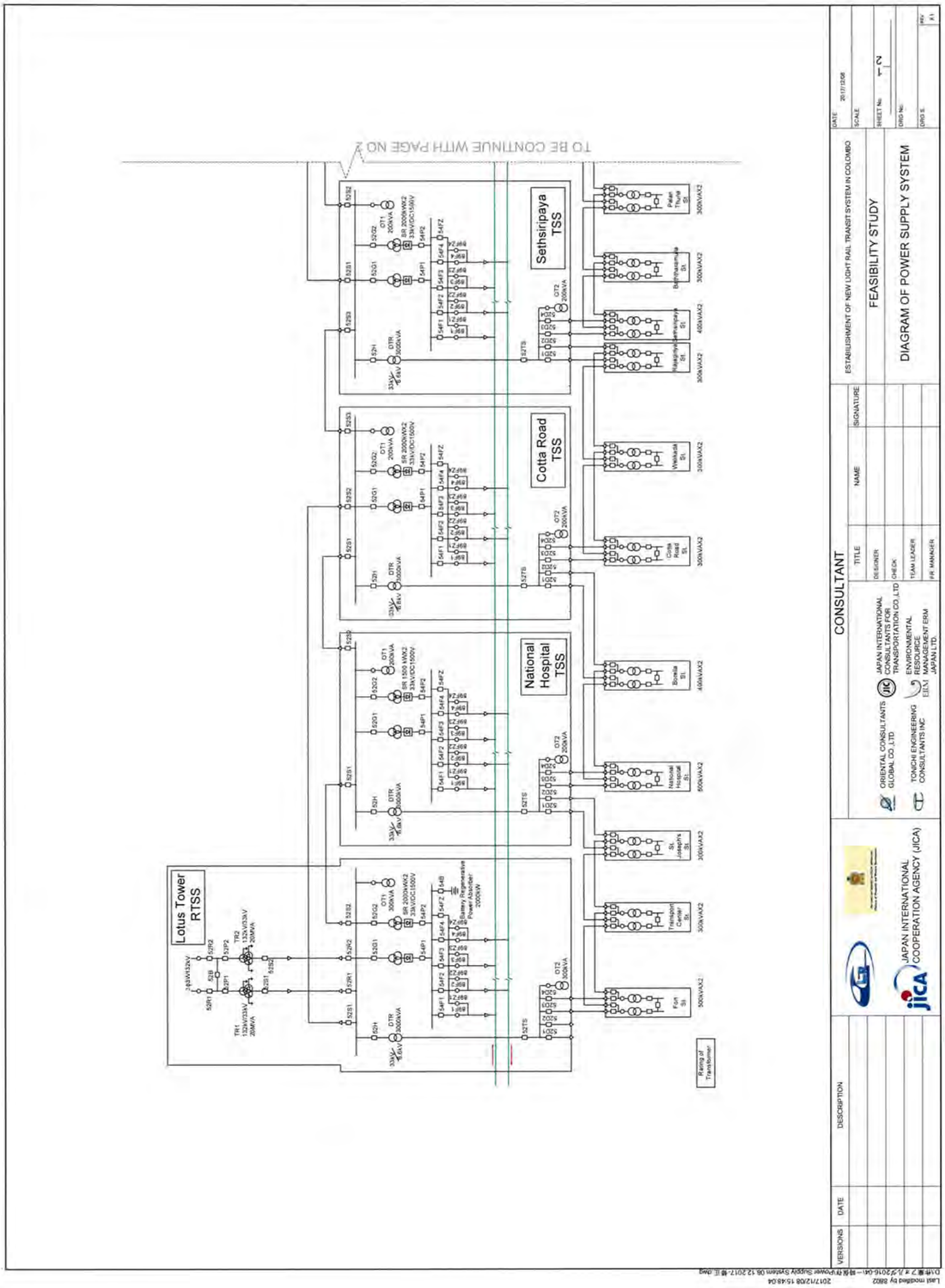
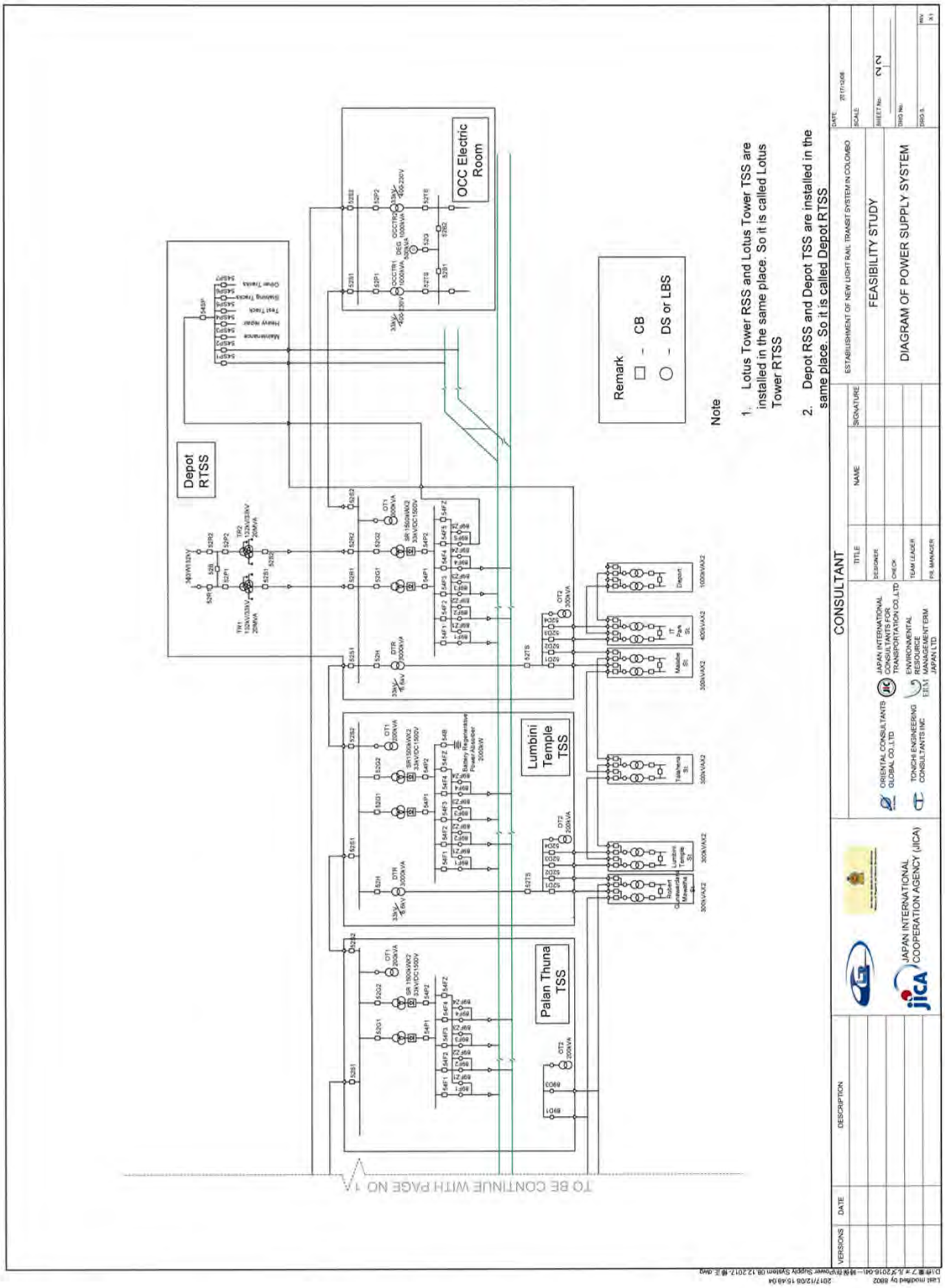


Figure 4.10.2 Power supply system diagram 1

Source: Survey Team



Source: Survey Team

Figure 4.10.3 Power supply system diagram 2

(2) Required Capacity for RSS and TSS

1) Required Capacity for TSS

The JICA-LRT is planned to be opened in 2025, and will initially be operated by 4-car trains of 2M (motor car) + 2T (trailer). In 2035, ten years after the start of operation, it is expected to operate 6-car trains of 4M + 2T at 3 min 20 sec intervals, as explained in Section 4.6 and Section 4.7. Because of the difficulties of upgrading within short-term after operation, it is recommended that the substation capacity should be designed for 6-car trains of 4M + 2T, and at 3 min 20 sec intervals.

Since there are no TSS between the Sethsiripaya TSS and Lumbini Temple TSS, the capacity of these two TSS is estimated to be larger value than other TSS in Stage 2 of the F/S. Although only operation of the original two TSS's with large capacity is possible, a large capacity of the rectifier is required, meaning that the circuit breakers for protecting these TSS are not compatible with other TSS. As a result, many types and numbers of spare parts for the circuit breakers are required, meaning that the substations are not well balanced.

With the situation above, it is recommended that the additional substation should be located between the Sethsiripaya TSS and Lumbini Temple TSS named as "Palan Thuna TSS".

Table 4.10.1 shows the calculation results after adding one TSS substation with their required capacity of rectifiers.

In consideration of the future extension to Kollupitiya, it is difficult to increase the capacity of the rectifier and its replacement. Therefore, it is recommended that the capacity of the rectifier with the future requirement should be provided as well. Calculated results are shown in Table 4.10.1.

Table 4.10.1 Required Capacity for TSS Substation

Name	(Kollupitiya TSS) (future)	Lotus Tower TSS	National Hospital TSS	Cotta Road TSS	Sethsiripaya TSS	Palan Thuna TSS	Lumbini Temple TSS	Depot TSS
Calculated value (kW)	L/A (3,634)	2,149 3,516	2,104	3,752	3,851	2,673	2,813	2,982
Required Capacity for Rectifier (kW)	(4,000)	4,000	3,000	4,000	4,000	3,000	3,000	3,000

Source: Survey Team

<u>**Number of Rectifier at TSS**</u>

It is recommended that rectifiers, which consist of transformers for rectifiers and the rectifiers themselves at the TSS, should be installed by two (2) banks at each TSS. The reason is that the limit of capacity of one rectifier is up to 3,000 kW with the capacity of the circuit breaker; this requires 2 banks of rectifiers. In general, the maximum capacity of the DC High Speed Circuit Breaker (HSCB), is regulated as 6,000A, and the rectifier of 3,000 kW for DC 750V, corresponding to the limit of its circuit breaker, which are considered at 150% of overloading with 2 hours duration in Japanese standards (D-type).

The rated current of the rectifier (Ir) is calculated as 4,000A, by the following formula:

$$\mathrm{Ir} = 3{,}000\mathrm{kW} \div 750\mathrm{V} = 4{,}000\mathrm{A}$$

Therefore, the 4,000 kW level of rectifier with rated current is more than 3,000 kW, and should be used as 2,000 kW x 2 banks.

The other merit of using 2 banks of rectifiers is to have the redundancy when one bank goes down. The TSS can be operated, although the train interval becomes twice. If TSS has only one bank, the train will be completely stopped when the rectifier has a problem. Therefore, it is strongly recommended that each substation should have two (2) banks of rectifiers.

2) Required Capacity for RSS

During the detailed study in Stage 2 of the F/S, it was found that RSS is only required at two (2) locations.

The required capacity of RSS is calculated by the required power supply by TSS for train driving and the required power supply by the SSS for the stations, depot and OCC. Required power supply by TSS is calculated by its capacity discussed above, and the other required power supply by RSS is calculated as availability rate of 70% of transformer capacity. The result of the required capacity of RSS is shown in Table 4.10.2.

The result shows that the required capacity of each RSS is approx. 16.8 MVA and 16.3 MVA, respectively. The required capacity of the rectifier is calculated as the R.M.S (Root Mean Square) value of the electric power for one hour in a peak hour (rush-time hour). In addition, required capacity for SSS and others is estimated by 70% of transformer capacity that is constantly consumed. Therefore, the power consumption at peak hour is determined to be about 16 MVA per second.

Adding about 20% margin, it is estimated that the RSS requires two (2) transformers of 20 MVA for each. The reason why 2 transformers should be installed is to securely transmit the capacity from the other RSS. Since the RSS is located at two places, the maximum capacity of each RSS is to be 40 MVA.

Table 4.10.2 Required Capacity for Substation

No.	RSS Name	TSS Name	Required Capacity						
			(1) TSS Rectifier (kW)	(2) Converting Rectifier Capacity to AC (kVA)	(3) SSS (kVA)	(4) (2)+(3) (kVA)	(5) RSS (kVA)	(6) Given RSS 20% margin (MVA)	(7) In case of one RSS outage (MVA)
1-0	Lotus Tower	(Kollupitiya)	3,634	3,840	1,050	4,890	16,830	20	40
1-1		Lotus Tower	3,516	3,710	770	4,480			
1-2		National Hospital	2,104	2,240	630	2,870			
1-3		Cotta Road	3,752	3,960	630	4,590			
2-1	Depot	Sethsiripaya	3,851	4,080	910	4,990	16,250	20	40
2-2		Plam Thuna	2,673	2,820	--	2,820			
2-3		Lumbini Temple	2,813	2,980	639	3,610			
2-4		Depot	2,982	2,980	980	4,130			
2-5		OCC	--	--	700	700			

Source: Survey Team

Note: In this table, the apparent power (kVA) uses a scalar sum as it is (In the event of the power factor exceeding 0.9, no large error occurs between the vector sum and scalar sum.). The rectifier adopts 12 pulse rectifier; since any standards in harmonic waves in Sri Lanka were not found, 12 pulse is selected according to Japanese standards that specify not to produce problems (Since the occurrence of harmonics is a physical phenomenon, there is no difference in occurrence by country.).

Countermeasures for Abnormal Events (e.g. in case of 1 RSS outage)

For example, when the Lotus Tower RSS experiences an "outage", electricity cannot be transmitted to the 3 connected TSS such as Lotus Tower, National Hospital and Cotta Road, and the train will be stopped. Even if a train stops between stations due to power failure, it is not recommended to let passengers walk on elevated track. Since JICA-LRT is fully elevated with installed third rail, when the third rail is pressurized during passengers walking on the deck, an electric shock could be generated and a serious injury could occur.

In order to prevent the above situation, at least, electricity should be sent from the Depot RSS to above three TSS to let trains move to the nearest station.

To meet this countermeasure, the Depot RSS needs both its own capacity (16,250 kVA) and the capacity of the Lotus Tower RSS (16,830 kVA). Therefore, the Depot RSS requires a capacity of 33,080 kVA, which means the numerical value is rounded-up to a standard number of 40,000 kVA or 40MVA.

Similarly to this 40MVA, the other RSS also requires 40MVA. This treatment, with each RSS having the capacity of 40MVA, secures unstopped operation in case of 1 RSS experiencing an outage.

If 40MVA is not possible due to the power supply by CEB, limited train operation (reduced number of services for train schedule) is required when one RSS is stopped.

Based on the above discussion, the recommendation of the required capacity for RSS is shown in Table 4.10.3.

Table 4.10.3 Proposed Required Capacity for RSS

No.	RSS Name	Normal Condition (KVA)	Required Capacity (MVA) Including backup system for next RSS for peak hour operation
1	Lotus Tower	16,830	40
2	Depot	16,250	40

Source: Survey Team

(3) Location of RSS and TSS

The candidate locations for the RSS are selected at two locations as shown in Table 4.10.4, where the 132 kV high voltage transmission line passes and its power can be received.

Table 4.10.4 Proposed Locations for RSS

No.	RSS Name	Reasons for selection of this location/ Notes
1	Lotus Tower	• CEB's Grid Substation (GSS) is nearby the RSS, and it is possible to bring 132 kV line from GSS easily. • It is planned to level land for constructing JICA-LRT's crossing bridge over SLR tracks.
2	Depot	• A 132kV transmission line tower is nearby the RSS, and it is possible to bring 132 kV line by envisioned CEB's Grid Substation which are implemented by another JICA loan project. • Since the place is marshy ground, it is necessary to surely protect moisture invasion with embankment etc. and cables from burial into water. It is necessary not to let the cable put in water.

Source: Survey Team

These candidate locations for the RSS were briefed to MMWD at the meeting with participation from the CEB. It was confirmed that there are enough capacity and lines provided by CEB.

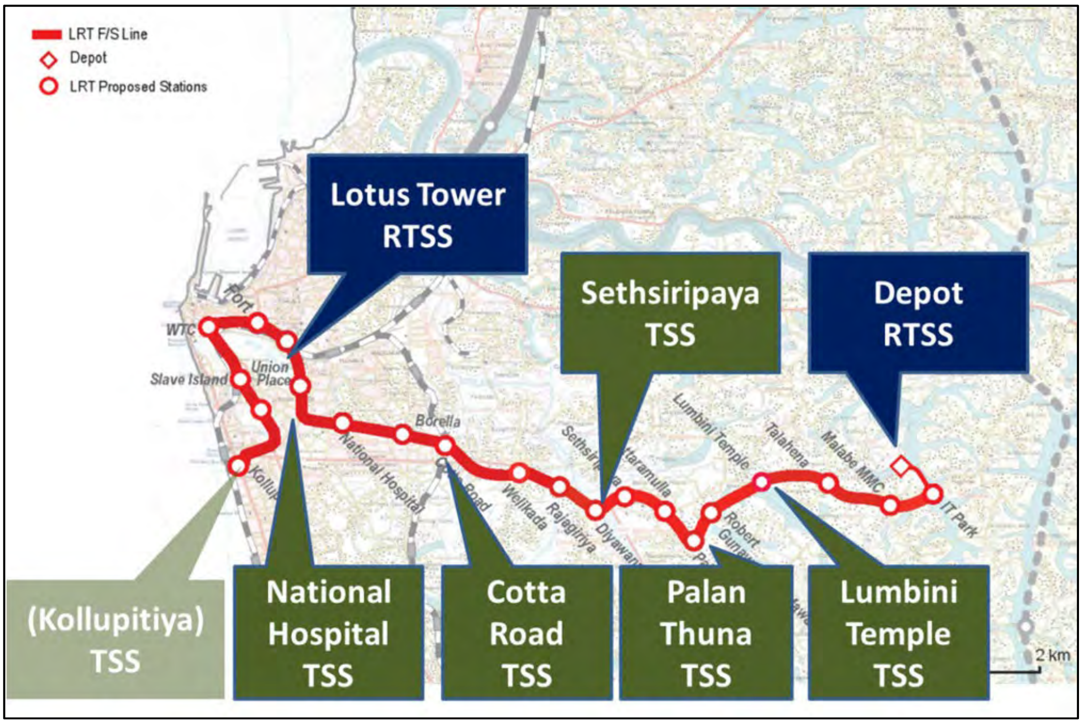
In general, a TSS should be installed at every 2 to 3km when the feeding voltage is DC 750V. Because of the 17km of JICA-LRT lines, seven TSS are planned to be installed. Table 4.10.5 shows the candidate locations for TSS with consideration of enough space of land and intervals.

Table 4.10.5 Proposed Locations for TSS

No.	TSS Name	Reasons for selection of this location/ Notes
1-0	(Kollupitiya)	• Originally, the Survey Team proposed the location at curvature area near Kollupitiya Station, which will be a space because of removed building due to affected by JICA-LRT viaduct. • It was discussed that it might not be at the above location, and that another location should be proposed nearby. • It is only for the future extension (It is not counted into the project).
1-1	Lotus Tower	• The Survey Team proposed to locate TSS at same location of Lotus Tower RSS. • The battery type regenerative power absorbing device is installed.
1-2	National Hospital	• Originally, the Survey Team proposed the location at the corner with combination of the building rebuilt due to affected by JICA-LRT viaduct. • It was the discussion that it might not be at the above location, and that another location should be proposed nearby. • There is potential location at the park nearby (Hyde Park) with the underground type of TSS.
1-3	Cotta road	• A vacant lot along the railway track of the Sri Lanka railway near Cotta Station, where the ballast for Sri Lanka Railways is currently located as the proposed site.
2-1	Sethsiripaya	• The site under elevated track section in the park. • The width of TSS should be considered not to exceed the width of JICA-LRT viaduct.
2-2	Palam Thuna	• Due to the increase of route/alignment avoiding EPA, it needs one more TSS between 2-1 and 2-3. • Since it is the high land value area, TSS is considered as underground type.
2-3	Lumbini Temple	• The site is current wetland near Lumbini Temple Station. Since it is marshy ground, it is necessary to surely prevent moisture invasion with embankment or elevated deck etc. • The battery type regenerative power absorbing device is installed.
2-4	Depot	• The site is marshy ground in planned Depot site near the IT Park Station. • It is necessary to surely prevent moisture invasion with embankment or elevated deck etc.

Source: Survey Team

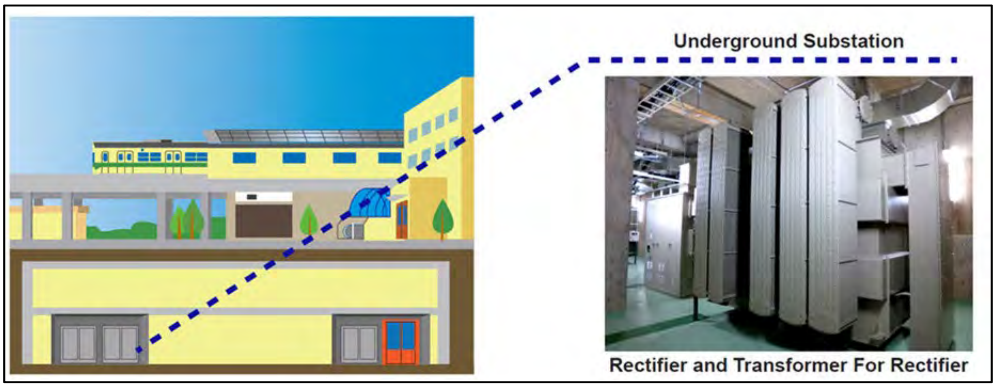
Figure 4.10.4 below depicts the location of the RSS and the TSS along the JICA-LRT route.



Source: Survey Team

Figure 4.10.4 Proposed Location of RSS and TSS

A conceptual image of the substation, especially underground of the building and land, is shown in Figure 4.10.5.



Source: Survey Team

Figure 4.10.5 Conceptual Section and Sample Photo of Underground Substation

The detailed location of each substation and the outline of installation are proposed as follows.

<u>Lotus Tower RSS + TSS (RSS (1), TSS (1-1))</u>

It is recommended to install RSS near the overpass of SLR near Lotus Tower. At Stage 1 of the F/S, the TSS was considered to be installed under the elevated area adjacent to Fort Station. The reason for the decision of the TSS to be adjacent to the Lotus Tower RSS is due to the difficulty to secure a space as the area around Fort Station is a high land value location. The

RSS part is an outdoor facility with a size of W 25 m × D 30 m, and the TSS part is an indoor facility with a building internal dimension of W 14 m × D 29 m × H 4.6 m. The TSS is equipped with a battery type regenerative power absorbing device. Because the RSS and TSS are co-located, it is called as "RTSS". Therefore, this facility is called as "Lotus Tower RTSS".

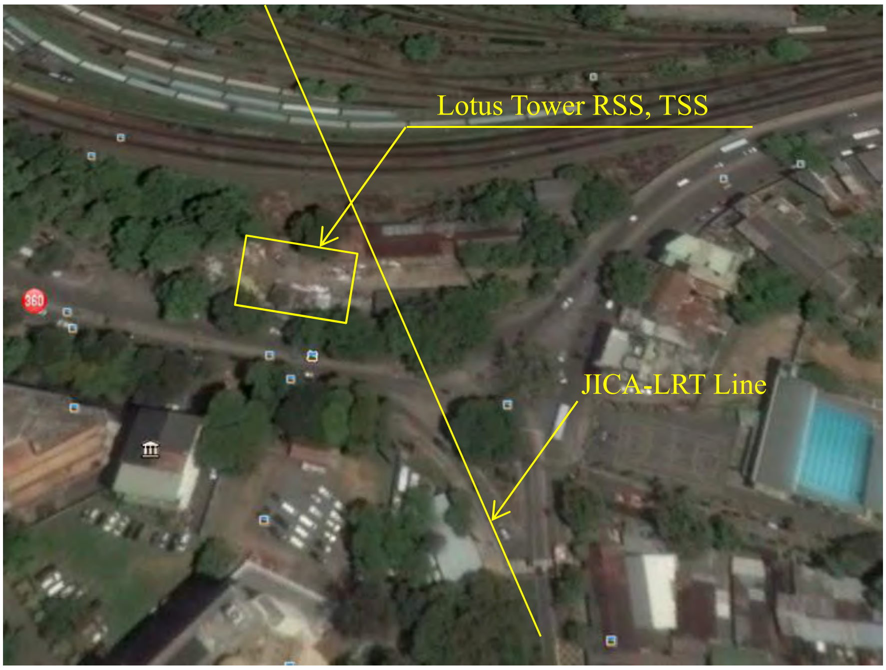


Figure 4.10.6 Location of Lotus Tower RTSS

National Hospital TSS (TSS (1-2))

Due to the difficulty of securing land in urban area, it is recommended to place TSS underground, below Hyde Park.

The volume of the underground substation is designed by minimizing the future required space for upgrade/replacement for substation. The internal size of the substation needs W 22 m × D 15 m × H 4.6 m, and the pit depth is about 1 m.

Regarding the height, it is required a sufficient height for the usage of gate-type crane to unload rectifiers (about 4 tons) into the underground.

There is a method which only stairs using by maintenance staff are installed as permanent equipment, and the entrance for large equipment which is not normally used is not considered as permanent one. Normally, the entrance of large equipment is used as a ventilation opening which can be removed for the purpose of moving large equipment. Because this place is a public park, installation of permanent facilities should be minimized.

If the mentioned method is applied, the height required above is unnecessary. Only requirements are the two openings connecting to the underground space with one is for stairs and the other is the entrance for large equipment (ventilation port). The size of the entrance for large equipment is about W 4 m × D 3 m. In addition, the height of the entrance and the stair needs to be raised by about 1 m from ground level to avoid flooding in heavy rainy season. It is noted that the above size of substation is indicated by internal size and volume.

Figure 4.10.7 National Hospital TSS Installation Location

<u>Cotta Road TSS (TSS (1-3))</u>

There is a ballast storage place on the south side of Cotta Road Station of Sri Lanka Railways, KV-line. It is proposed that this site would be used for the TSS and for the construction yard during civil construction works. The inside dimension of TSS is assumed as W 21m × D 14m × H 4.6m.

Figure 4.10.8 Cotta Road TSS Installation Location

Sethsiripaya TSS (TSS (2-1))

At the Stage-1 of the F/S, the RSS is considered to be placed at this location. Currently, the location is only enough for the TSS.

The location of Sethsiripaya TSS is under the elevation of the JICA-LRT running on the park. When the TSS is divided into two, the TSS can be installed under the viaduct of the JICA-LRT structure. This TSS's internal volume is W 23.2 m × D 7.4 m × H 4.6 m with 2 places that connect with each other by cables. Since Sethsiripaya could be flooded by heavy rain about 1 metre, it is necessary to make a waterproof-round dike with a height equal or higher than 1.5 m. For this reason, it is necessary to consider carefully on designing the shape of the entrance for large-sized vehicles.

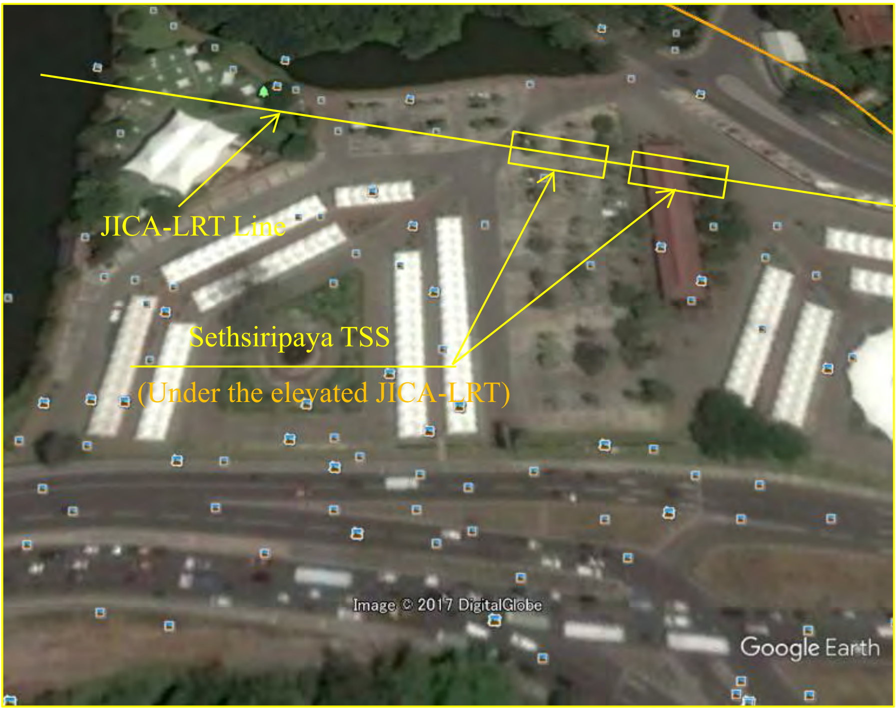


Figure 4.10.9 Sethsiripaya TSS Installation Site

Palan Thuna TSS (TSS (2-2))

As mentioned above, it is recommended to add one TSS to improve the TSS capacity balance.

Because it is assumed as a high price land area in front of Palan Thuna Station, the TSS should be located underground of the building if it is possible. In the case of an underground substation, the internal volume requires is W 18 m × D 15 m × H 4.6 m.

Regarding the entrance for large equipment, it is same as the National Hospital TSS. Even in the case of an on ground substation, it is necessary to secure the inside dimensions of building as W 14 m × D 29 m × H 4.6 m.

Figure 4.10.10 Palan Thuna TSS Installation Location

Lumbini Temple TSS (TSS (2-3))

As mentioned at the ITR, this TSS is to be located by the wetlands near Lumbini Temple Station, by artificial soil or embankment.

This TSS's size is W 14 m × D 29 m × H 4.6 m for the inside building dimensions. It is also equipped with a battery type regenerative power absorbing device, same as at the Lotus Tower RTSS.

As for the required space, approximately W 45 m × D 25 m is required at the site for handling heavy machinery such as crane car with maximum load of 4 tons.

Figure 4.10.11 Lumbini Temple TSS Installation Location

<u>Depot RTSS (RS (2), TSS (2-4))</u>

The Depot RSS will combine with the TSS as Depot RTSS (the more integrated facility is, the more cost will be saved). Although 400 metres is required from the main line, there are no issue if careful attention to current capacity and voltage drop are considered.

The RSS part is an outdoor facility measuring W 25 m × D 30 m, and the TSS and feeding room for the Depot is an indoor facility measuring W 14 m × D 29 m × H 4.6 m for the internal building dimensions.

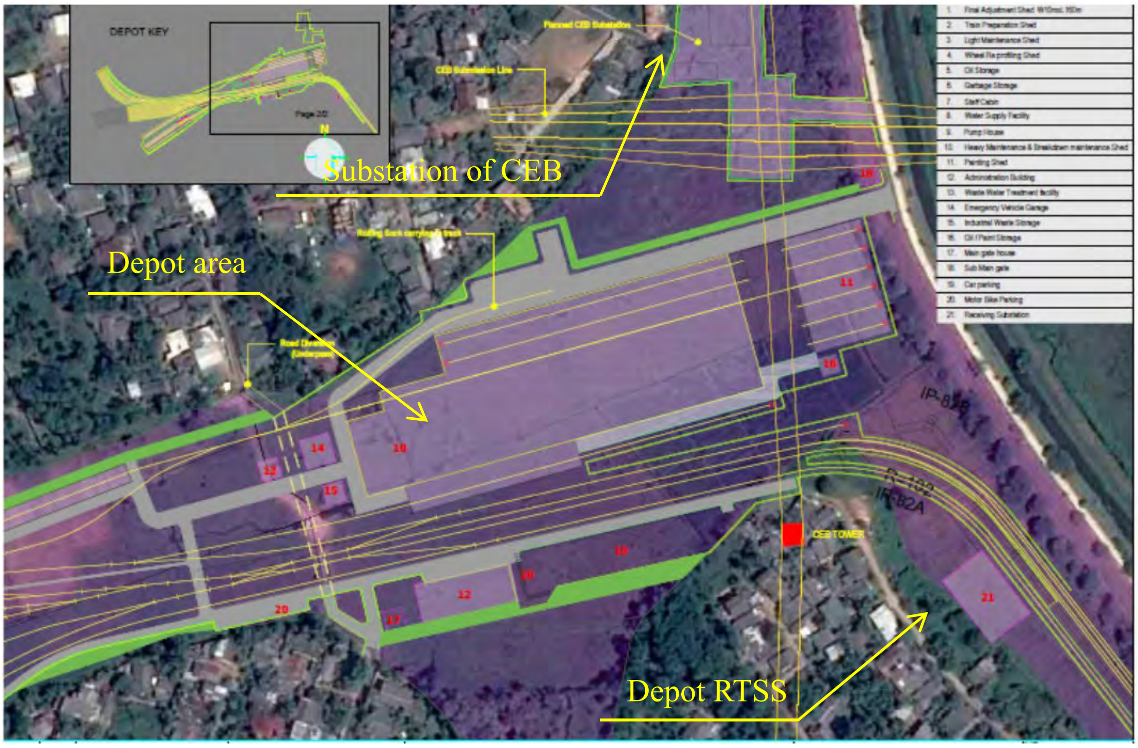


Figure 4.10.12 Location of Depot RTSS

(4) Impact to National Power Grid

1) General Observation

Since the electrical train system has been developed and improved in various countries including Japan, there is low possibility that the following items would not happen which has already been developed for absorbing the back effect to the national power grid:

- Maximum load fluctuation due to JICA-LRT
- Harmonic wave

The following section describes each theoretical background that does not affect any back effect to the grid.

2) Maximum Load Fluctuation due to JICA-LRT

In case of dividing the power consumption sources into the train operation consumption and the stations' electric power consumption, the capacity of each stations is 6,500 kVA in the transformer capacity; actual load is 4,550 kVA with the load factor of the transformer as 70%.

The current at AC 132 kV (Iacst) is calculated as follows:

$$\mathrm{Iacst} = 4{,}550/132\sqrt{3} = 19.9(\mathrm{A})$$

Even this load has a little change within a day with mild differences; it is almost stable in a short time.

Regarding the train operation power consumption, it is well-known that peak hour time needs the heaviest load; however, the electric current is slowly increased with almost constant level because of variable voltage and variable frequency (VVVF) application inverter motor in the rolling stock.

The severe condition of electric current is the time when the train reaches to 0 A with notch-off from the maximum current state of full notch. Therefore, the number of trains which turns off notch at the same time is estimated by a train operation simulation. The result of the simulation describes that there will be about eight (8) trains that turn off the notch at same time.

Therefore, it is considered that the maximum load fluctuation occurs as most severe situation when all of the eight trains run with the largest notch, and all of them turn off the notch.

Although there is a possibility that there are more than 8 trains in power operating, there are 8 trains that turn off the notch at the same time. Since the maximum power of a train is 2,400 kW (150 kW × 16 motors), the total power of the eight trains (Wdc) at this time is assumed as:

$$\mathrm{Wdc} = 2{,}400 \times 8 = 19{,}200(\mathrm{kW})$$

Since the energy is conserved, and the power factor of the 12-pulse rectifier is 0.96, the AC base (VA) is calculated as:

$$\mathrm{VA} = 19{,}200/0.96 = 20{,}000(\mathrm{kVA})$$

When the electric current is changed at 132 kV within 1 second, the change in the current on the 132 kV side, ΔIac, is expressed:

$$\Delta\mathrm{Iac} = 20{,}000/132\sqrt{3} = 87.5(\mathrm{A})$$

This change in the current is depicted in Figure 4.10.13 as follows:

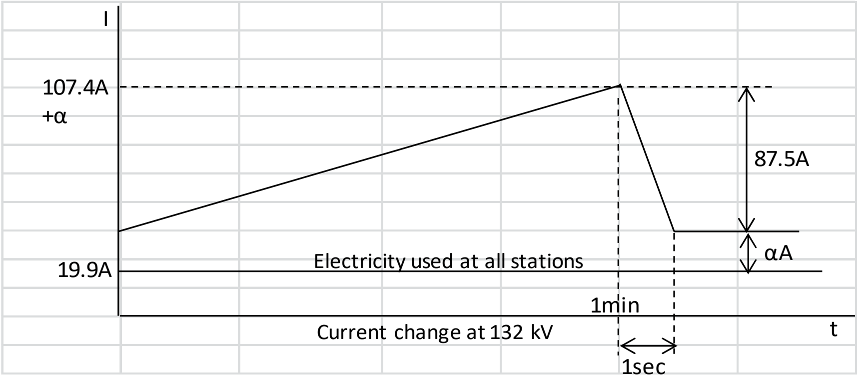


Figure 4.10.13 Diagram of Maximum Load Variation

In the above figure, αA represents the total current of the other trains which are performing power except the above 8 trains. This 87.5A is the maximum load fluctuation.

In order to absorb this voltage fluctuation, there are two alternatives as countermeasure.

- The first one is to suppress instantaneous current increase by inserting a series reactor into the negative retrace of DC 750V. Even the rectifier capacity is small at DC 750V, a large current will flow because a low voltage. The purpose of inserting is to suppress the rise of large current at the time of accident; the above mentioned benefit is also expected. The current rating of the reactor is 1.5 times of the rated current of the total rectifier capacity for each substation, and the reactance rating of the reactor is set to be 1.1mH or more. This is the rating value used by Japan railway companies.
- Another countermeasure is to install a battery type regenerative power absorbing device, which is planned to be located at two TSSs. The original purpose of this equipment is to absorb the regenerative electric power generating when the train brakes, to make effective use of the electric power during normal operation, and to ensure a stationary stop of a train by regenerative braking which is used of absorbed regenerative electric power. This battery also has an effect of suppressing sudden rise of voltage by regenerative braking and reduction of sudden drop voltage at overlapping start-up.

3) Measures against harmonic wave

There are three different levels of countermeasures against harmonic wave shown as follows:

- Rolling Stock: The electrical parts in rolling stock are designed to meet the international standard, such as IEC:IEC 61000-4-8, Electromagnetic Compatibility (EMC), which means that the rolling stock should confirm its standard before starting operation.
- TSS: The rectifier is the only device that emits harmonics. Applying 12-pulse rectifier, it can suppress the generation of harmonics.
- RSS: Applying the Δconnection of the tertiary winding of the RSS transformer, the third harmonic wave can be consumed within Δconnection area, and then the third harmonic is prevented from outflowing to the CEB. Figure 4.10.14 shown on the right is the symbol of the transformer using the Δ connection for the tertiary winding.

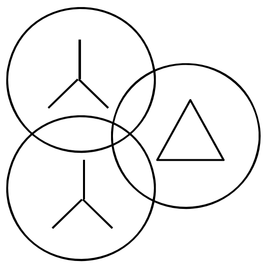


Figure 4.10.14 Three Winding Transformer Symbol

(5) Diversion of High Voltage Transmission Lines

As the JICA-LRT runs on an elevated viaduct, there are three crossing points that do not have safe clearance from the high voltage transmission line. Followings are descriptions of the locations and countermeasures.

Sethsiripaya

It is found that the clearance at the intersection of the 132 kV transmission line and the elevated JICA-LRT at Sethsiripaya does not satisfy the safety level of clearance. For this transmission line, construction work for improvement the transmission line is set to be done by a separate JICA loan project. After consultation with CEB, if the height limit on the JICA-LRT is changed from 20m to 15m from the ground, it is confirmed that the separation distance as 22m, which includes the safety separation distance of 5.18m and margin of 1.82m, is enough clearance for CEB regulations. Figure 4.10.15 shows the yellow line as the elevated line of the JICA-LRT and the orange line as the current 132 kV transmission line. Note that the location of each line in the figure is the image without the accuracy of detailed design.

Figure 4.10.15 Crossing Point with 132 kV Transmission Line at Sethsiripaya

Depot and Near IT Park station

Figure 4.10.16 shows the two crossing points by the 220 kV transmission line. Point A is the clearance between the Depot's building and the 220 kV transmission line which is insufficient, and Point B is the clearance between the elevated viaduct of JICA-LRT and the 220 kV transmission line near the IT Park station which is insufficient.

The Survey Team discussed with CEB the possible countermeasures such as a) diversion of 220 kV line for several towers, b) underground solution at only crossing sections and c) rising up solution at one tower. Since the pair of towers that cross the JICA-LRT facility are not angle-type towers (only suspension towers), option c) is not applicable. Comparing a) and b) with the experiences in Sri Lanka, currently option a) is preferable for diversion. The concept route of diversion of transmission line is indicated by the orange dashed line.

Figure 4.10.16 Crossing Points with the 220 kV Transmission Line and Diversion Plan (Depot and near IT Park Station)

(6) Regenerative Power Absorbing Device

Because PSD will be installed, trains should stop at a fixed point. Therefore, a regenerative power absorbing device for fixed stopping is required.

The reasons for the requirement of the regenerative power absorbing system are as follows: "When the regenerative brake jumps up voltage due to regenerative electric power by itself, regenerative error occurs and the function of the brake stops. At this time, when switching to the mechanical brake, the braking of the mechanical brake is delayed according to the changeover time, the train overruns, it deviates from the stop position requested by the train from the PSD side, and both door positions do not match."

Although this absorbing system has two types (e.g. inverter system or battery system), it is recommended to use a battery system.

The reason why the battery system is recommend is that, in the case of the inverter system, if the equipment that consumes on the AC side when regenerative power generation is not in operation, it will be released outside the power receiving point. However, in the case of the battery system, when the same situation occurs, it charges the battery and it is possible to consume electric power charged during train traveling.

Under the current JICA-LRT plan, it is recommended 2 devices installed at the Fort TSS and the Lumbini TSS. Note that detailed specifications should be conducted at the detailed design stage.

(7) Power SCADA

Power SCADA is responsible for monitoring and control of substations and electrical rooms, and placed in the OCC. A terminal of Power SCADA is installed in each substation and electric room, and it monitors and input and output (I/O) for controlling. This terminal device is named as Remote Terminal Unit (RTU). Power SCADA and RTU are connected by double looped optical cable. Power SCADA also captures the condition of each station's important electrical equipment for monitoring purpose.

(8) Third Rail

Third rail supplies power to trains along the track, as shown in Figure 4.10.17. It is supported by insulator and touch with train shoe. Construction of third rail includes not only placement of third rail, but also the placement of feeding cables to connect and supply the power to the third rail.

Note: It is not covered. Photo was taken in Depot
Source: Survey Team.

Figure 4.10.17 Photo of Third Rail

(9) Lightning Protection System

Some Japanese railway companies have introduced a lightning protection system due to thunder problem in Japan. Therefore, it might be considered necessary for Sri Lanka in the future.

4.10.2 Mechanical System

(1) List of Items for Mechanical System

The following items listed in Table 4.10.6 of mechanical equipment for JICA-LRT in Colombo, are registered to be installed at each station facility.

Table 4.10.6 Items for Mechanical System

Item.	Facilities	Item	Facilities
1) Air conditioning equipment	• Air conditioning equipment, (including attached piping construction) • Exhaust fans • Duct (including outlet, inlet, intake, exhaust)	5) Elevator Escalator	• Elevator • Escalator
2) Water supply and drainage facilities	• Water tank and accessories • Feed water pump • Sanitation equipment • Piping	6) Platform screen door (PSD)	• Half height PSD • Controllers • Power Supply System with UPS Please see at 4.11.7(8)
3) Fire protection equipment	• Fire alarm equipment • Fire water tank • Fire protection water pump • Fire hydrant related • Fire-fighting piping • Inert gas injection facility • Portable fire extinguisher	7) Auto Fare Collection (AFC)	• Ticket Vending Machine • Passenger Gate • Fare Adjustment Machine • Money Management Facilities • Station Server • Contactless integrated-circuit (IC) Card • Card Initializing System
4) Electrical equipment	• Power supply equipment (equivalent to electric SSS) • Power distribution equipment • Uninterruptible power system • Interior lamp and outlet • Ground fault facility • Building related automatic equipment		

Source: Survey Team

(2) AFC System

Since the Project provides a new system, the fare collection system should be carefully discussed in its system design stage to realize user-friendly service, as well as to secure its interoperability for future technology developments and innovations. It also carefully considered that this AFC system might not be a heavy system to operate and maintain with the JICA-LRT business company, which means the AFC system should be an affordable CAPEX and OPEX one.

In order to ensure smooth entering/exiting at the station for peak hour passenger volume, the AFC ticketing gate is crucial to be installed. For example, the Japanese AFC products are able to flow approx. 50 to 60 passengers per minute safely using contact-less IC/ near field communication (NFC) card/token.

The following are ideas of available cards/token types for the JICA-LRT.

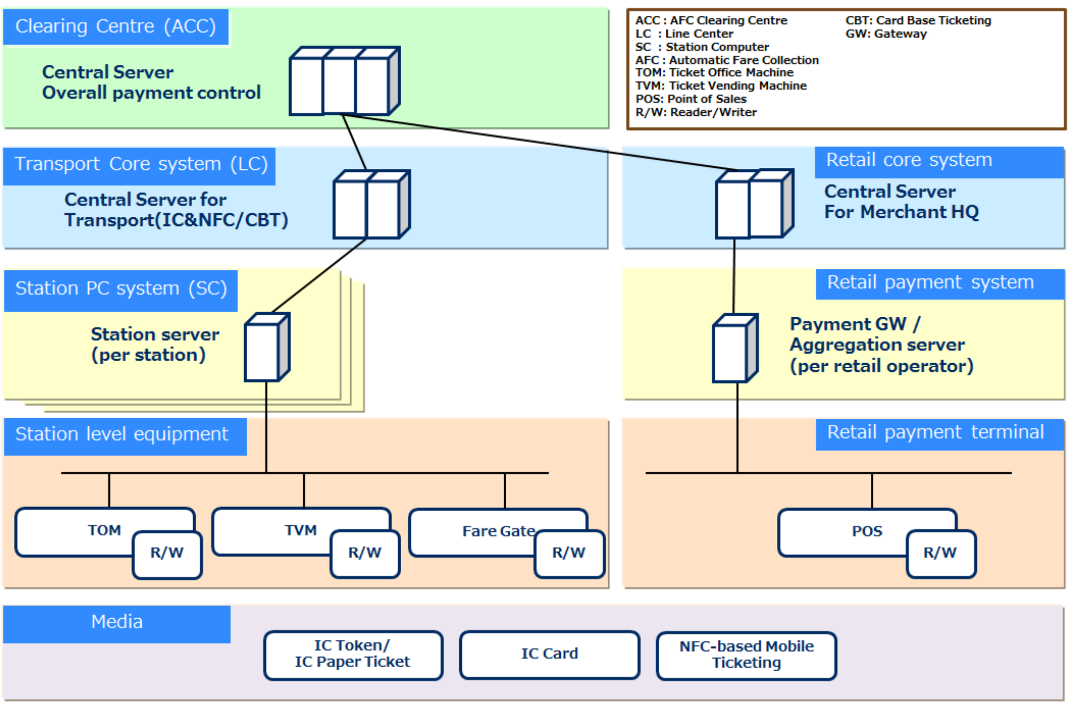
- IC token/paper: Single journey ticket for JICA-LRT;
- IC Card: Pre-paid card for multiple times for the payment of JICA-LRT and other related shops, stored value by top-up system (Monthly and seasons pass cards are also available);
- NFC: Same as IC card by smart phone devices.

Considering the IC card business in Sri Lanka, especially the current usage of IC cards for bus services, the following concept of AFC system at the Feasibility Study level is recommended. Further detailed system design will be discussed under basic design of the implementation stage.

- This AFC system accepts a contact-less IC/NFC card/token by multi-R/W with Security Application Module (SAM) with at least 3 slots. Magnetic paper-based ticket is not recommended due to the heavy mechanical equipment required. Quick Response (QR) code paper tickets might be possible if the above capacity of flow is realized after the technical renovation/upgrades.
- Card based ticketing (CBT) system with closed loop is recommended for reducing (Captial Expenditures (CAPEX) / Operational Expenditures (OPEX) at the initial stage. Although it is recognized that the account based ticketing (ABT) system with open loop has the potential of enhanced functions to connect with various smart cards and to use non-monetary transaction, it needs more CAPEX/OPEX than CBT. Therefore, the CBT system is the recommended level for JICA-LRT.
- This system allows IC/NFC card to use for the payment at the kiosk and other JICA-LRT related businesses. The top-up of value to IC/NFC is available at the both of ticket office machines, ticket vending machines and point of sales at retail shops regulated by the JICA-LRT business company.
- Number of transaction per day is estimated by 1.0 million users with 3.0 million transactions for JICA-LRT fare and retail payment. The system requirement for allowable number of processing at same time is assumed to be 10,000 users.

Once this system starts within the JICA-LRT, further integration with future extension lines can be possible if close coordination among other lines is discussed. Legal arrangement for issuing the ticket as well as collecting the fare under the JICA-LRT business company will be discussed in the implementation stage.

Figure 4.10.18 shows the concept image for AFC system under CBT system for JICA-LRT.



Source: Survey Team

Figure 4.10.18 Concept Image for AFC System (CBT system)

4.11 Station Development

4.11.1 Design Principle

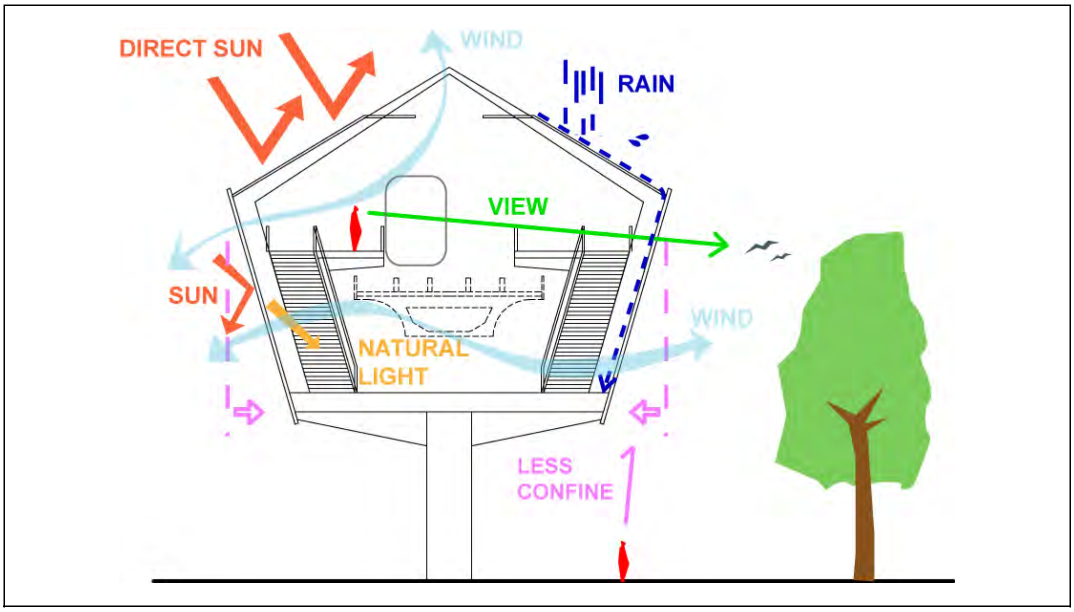
The station plan strongly affects the reliability of JICA-LRT service, efficiency of JICA-LRT operation, and comfortability of passengers, as well as the townscape of the area. Therefore, the structural design, construction method, and materials to be used should be carefully discussed in order to ensure not only functionality and cost-effectiveness, but also sustainability.

The planning principle for station design is set as the following 8 principles for this F/S:

- **Uniqueness of Colombo**: Combination of modernized image of and local building style in Sri Lanka is considered.
- **Green Stations**: Sustainability, natural ventilation, natural lighting, heat protection are considered into the station design.
- **Minimize oppression**: Reduction of the oppression feeling to the surrounding areas was considered in the leaning out shape of the station, which is also effective for reducing heat load.
- **Universal Design**[11]: Universal design will be considered for station design.
- **Sustainability and Easy Maintenance**: In order to prevent operation and maintenance costs being excessive burdensome, the concept of easy maintenance and sustainable design will be reflected to the building design and materials.
- **Community Development**: For improving the pedestrian connectivity, pedestrian decks/bridges will be developed.
- **Good Connectivity for Multi-modal Transfers**: The station plays an essential role for transferring the mode of transport, especially for public transport. Station design should strongly consider providing good transfer facilities.
- **Uniqueness of each Area**: As a gateway to the local community, the local uniqueness should be considered in addition to the standard design of the station.

Figure 4.11.1 shows the design concept of station facilities derived from the above mentioned design principles. Note that it will be examined at the actual site proposed to check its applicability.

[11] Universal Design is the design and composition of an environment so that it can be accessed, understood and used to the greatest extent possible by all people regardless of their age, size, ability or disability.



Source: Survey Team

Figure 4.11.1 Concept of Proposed Station

4.11.2 Summary of Station Design

All stations of the JICA-LRT route would have their own identity. Table 4.11.1 shows the design concepts of the all stations based on the preliminarily observations around the station area. Station type, Pedestrian Connectivity with, Transfer Points, and Feature to be planned are also shown in the table.

Regarding station type, each station is indicated as 1-ticketing exit, 2-ticketing exit, or others. Eleven stations are of the 1-ticketing exit type, two stations are 2-ticketing exit type, and three stations are of independent design. Each station's type is shown in Table 4.11.1. Plan, section and image of each station type are shown in Section 4.11.5.

Table 4.11.1 Design Summary of All JICA-LRT Stations

Station Name		Design Concept	Main Features	Station Type
05	Fort	Entrance of the City	Commerce Facilities	two platforms with 4 rails
06	Transport Centre	New Developing Town	Commerce Facilities, Lotus Tower	1-ticketing exit
07	St. Joseph's	College town	Commerce Facilities	1-ticketing exit
08	National Hospital	Centre of City	Hospital Complex, Town Hall, Commercial centre	2-ticketing exit
09	Borella	Crossing Artery	Commerce Facilities	2-ticketing exit
10	Cotta Rd.	Homelike Town	Residential Area	1-ticketing exit
11	Welikada	New urban connection	Commerce Facilities, Flyover	two platforms with 2 rails
12	Rajagiriya	IT Business Centre	Office Centre	1-ticketing exit
13	Sethsiripaya	Civic Centre	Government Offices	1-ticketing exit
14	Battaramulla	Shopping Square	Commerce Facilities, Government Offices	1-ticketing exit
15	Palan Thuna	Connection point from South	Parliament	1-ticketing exit
16	Robert Gunawardena	Administrative District	Government Offices	two platforms with 3 rails
17	Lumbini Temple	Peaceful Forest	Residential Area	1-ticketing exit
18	Talahena	Urban Nest	Residential Area	1-ticketing exit
19	Malabe	Sustainable Sub Centre	Fairground, Public Office	1-ticketing exit
20	IT Park	Gate to ICT	Entrance of IT Park Malabe, Residential Area	1-ticketing exit

Source: Survey Team

4.11.3 Accessibility from/to Station

Elevators will be provided on each side for all station types. Stations with a 2-ticketing exit also have an escalator on each side. Pedestrian decks will connect a station to important facilities such as a railway station, bus stop, junction of a road, a new-complex building, a school, and a hospital. A pedestrian deck will be provided under a JICA-LRT structure; a sample image of a walkway at the Bangkok MRT is shown in Figure 4.11.2. Pedestrian connections of each station are shown in Table 4.11.2. Location of the station can be changed and the connection point shall be developed in further study at the Detailed Design stage. Diagram maps of each station are shown in Appendix 8.

Source: mithunonthe.net

Figure 4.11.2 Photos of Walkway of Bangkok MRT

Table 4.11.2 Accessibility of All JICA-LRT Stations

Station Name		Pedestrian Deck Connectivity with	Transfer Point			Feature to be Planned		
			MmTH /MMC /P&R	Railway	Bus	Car Parking	Taxi Three-wheeler	RTS Connection
05	Fort	Railway station / bus terminal	MmTH	Fort	Terminal			
06	Transport Centre	Railway station (390m) / Beila lake side (234m)	MmTH	Maradana	Stop			(RTS-2)
07	St. Joseph's	National Hospital (780m)			Stop			
08	National Hospital	St. Joseph's/ National hospital (130m)			Stop			
09	Borella	Building, underground pass (221m)			Stand			RTS-3
10	Cotta Rd.			Cotta Rd.	Stop			
11	Welikada	Bus stop (turn around) / Nawala rd. / Cotta rd.	(MMC)		Stop		x	
12	Rajagiriya				Stop			
13	Sethsiripaya	Government office, Diyatha Uyama park (455m)			Stop			
14	Battaramulla		MMC		Stop	(x)	(x)	
15	Palan Thuna				Stop			
16	Robert Gunawardena		P&R		Stop	x	x	
17	Lumbini Temple				Stop			
18	Talahena				Stop			
19	Malabe	Bus stand (325m)	MMC		Stand		x	RTS-5, RTS-6
20	IT Park	Car parking	P&R		Stop	x	x	

Source: Survey Team

4.11.4 Components of Station Facility

The station plan, including the layout of platforms and station facilities, will be designed based on the available space and local requirements of each station. The following are the station facilities to be designed.

- Ticketing Office: working space for 4 people, with air conditioner
- Ticketing Gate: with AFC (Automated Fare Collection)
- Shop, Kiosk: with air conditioner
- Electric Room: with 4m x 3m floor opening for maintenance, with air conditioner
- Signal & Telecom Room: located on next to electrical room.
- Pump Room: provided between columns on ground floor.
- Toilet: with accessible toilet and ventilation.
- Platform (120m): located and identified by the alignment design because of the straight line requirement, with 3m width (minimum 2m width as a part), with natural ventilation, with roof for cover from rain and strong wind.
- Security Camera(s): with CCTV
- Fire Protection Facility

In addition to the above, there are necessary rooms for operations, such as storage, etc.

4.11.5 Station Type

The list of lift facilities (e.g. staircase, escalator, and elevator) is shown in Table 4.11.3. The width of staircase shown is the usable dimension.

Table 4.11.3 List of Lift Facilities of Major Types

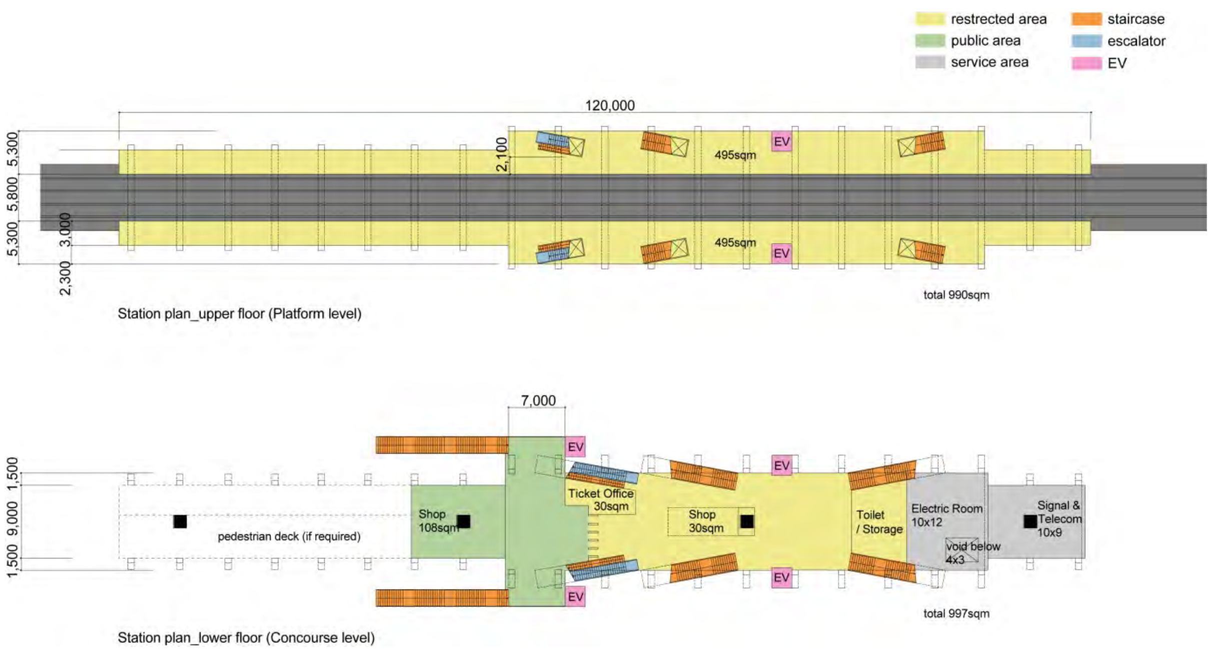
Level	Lift facilities	1 ticketing Exit type		2 ticketing Exit type	
		No.	Width(m)	No.	Width(m)
Ground level to Concourse level	Staircase	2	2	4	2
	Escalator	0	2	2	2
	Elevator (normal)	2		2	
Concourse level to Platform level	Staircase	6 (3)	2mx(2), 0.8mx(1)	4 (2)	2
	Escalator	2 (1)*	1.2	4 (2)	2
	Elevator (right angled)	2 (1)		2 (1)	

*( ) shows each platform

Source: Survey Team

(1) 1-Ticketing Exit type

Most of the stations belong to this type. The pedestrian deck can be connected on one side that is close to the ticketing gate. Service functions such as the electrical room and the signal and telecom room would be provided on the other side.

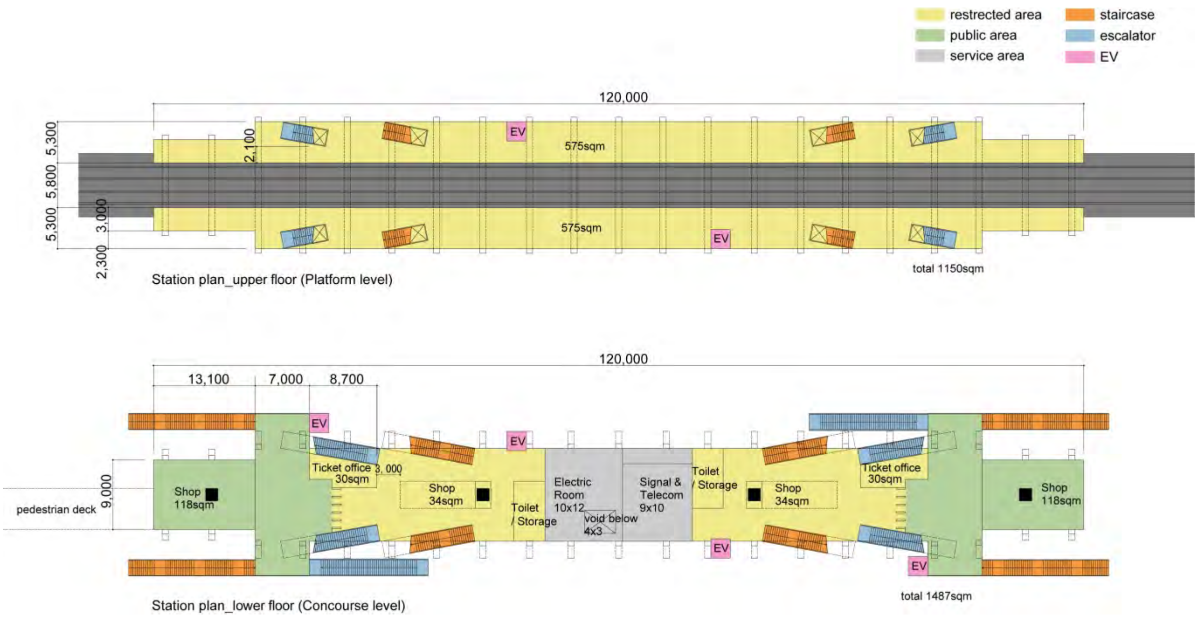


Source: Survey Team

Figure 4.11.3 Plan of 1-Ticketing Exit Type

(2) 2-Ticketing Exit type

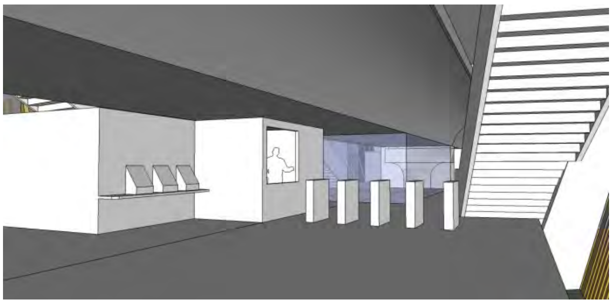
This type is adopted for only two stations: National Hospital Station and Borella Station. These stations are important connections to main features and other transport. Both sides have an exit and passengers can access from both sides. Service functions are located in the centre of the station on the concourse level.



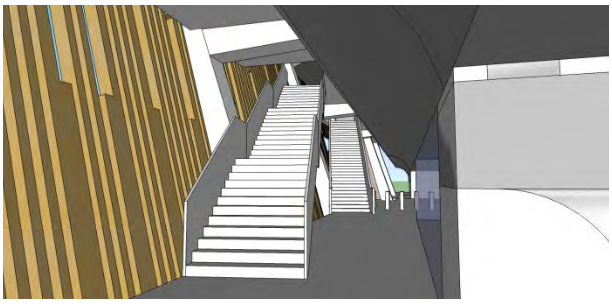
Source: Survey Team

Figure 4.11.4 Plan of 2-Ticketing Exit Type

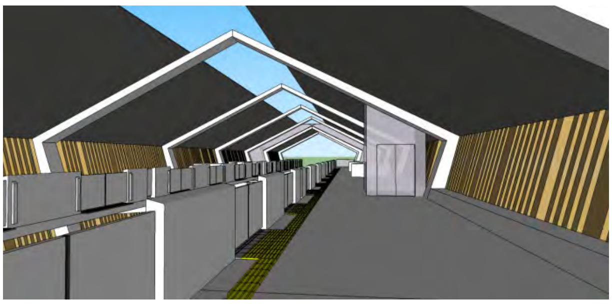
Façade of Station



Ticketing Machine and Gate



Concourse



Platform

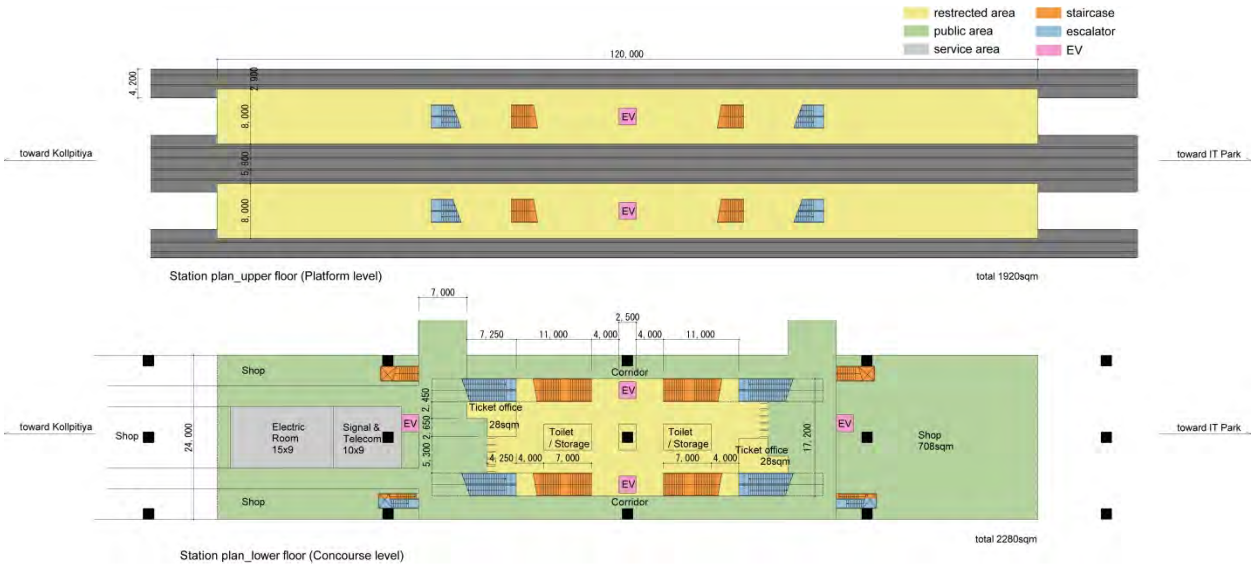
Source: Survey Team

Figure 4.11.5 Image of Two ticketing Exit type

(3) Others: Fort Station and Robert Gunawardena Station

Fort Station is the largest station on JICA-LRT, and has major transport connections of railway station and bus terminal. It has two platforms between four rails, thus lift functions are located in the middle of the platform. There are two ticketing exits and passengers can access on both sides.

Robert Gunawardena Station has two platforms between three rails, and has a similar plan to that of Fort Station. The width of the centre rail of Fort Station should be narrow.



Source: Survey Team

Figure 4.11.6 Plan of Fort Station

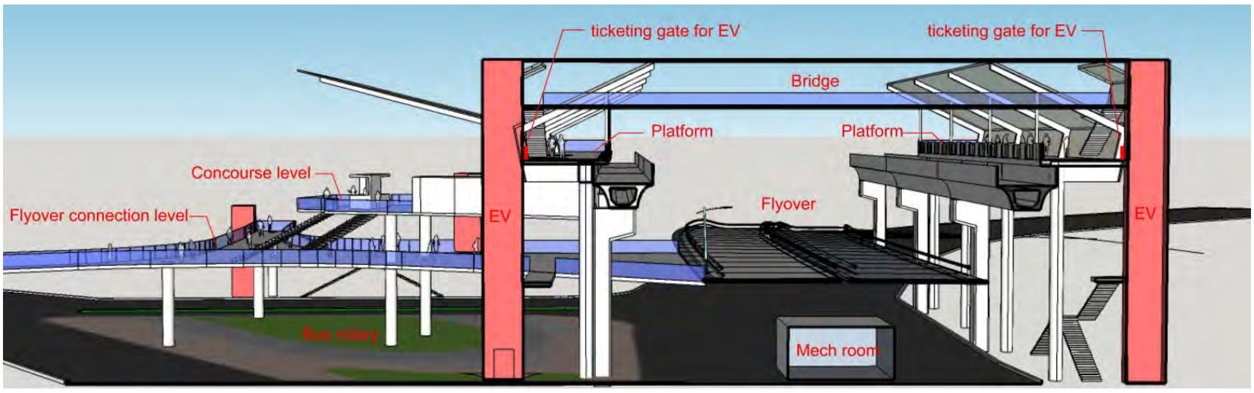
(4) Others: Welikada Station

Welikada Station is located above the Rajagiriya Flyover. The flyover connection floor should be provided between the ground level and concourse level. This station has two separate rails and each platform should be provided separately. Thus a bridge to connect the two platforms should be provided on the upper level of the platform.

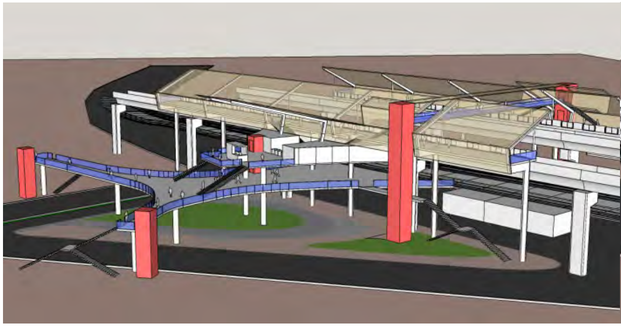
The south part of the station has a bus rotary with feeder bus service on the ground level. The area can be used as a construction site during the construction period. Passengers can get on and off bus on both ground levels and between ground and concourse by the flyover road.

For the north part, if a new shopping centre is built at same time as the construction of the station or later, it can be connected with the station at concourse level. The north part also has a flyover connection level between ground and concourse. Passengers can get on and off the bus on this level.

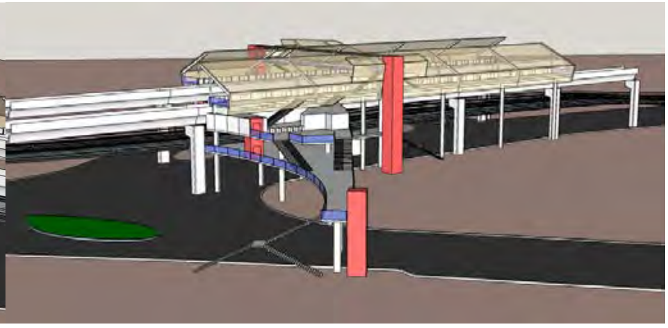
The cross section and the north/south parts of the station are shown in Figure 4.11.7. Photos of the physical model are shown in Figure 4.11.8.



Section image of Welikada Station



South part of Welikada Station



North part of Welikada Station

Source: Survey Team

Figure 4.11.7 Images of Welikada Station

Rajagiriya Flyover

Rajagiriya Flyover on ground level

Welikada Station looking from east

Welikada Station looking from south

Welikada Station looking from north

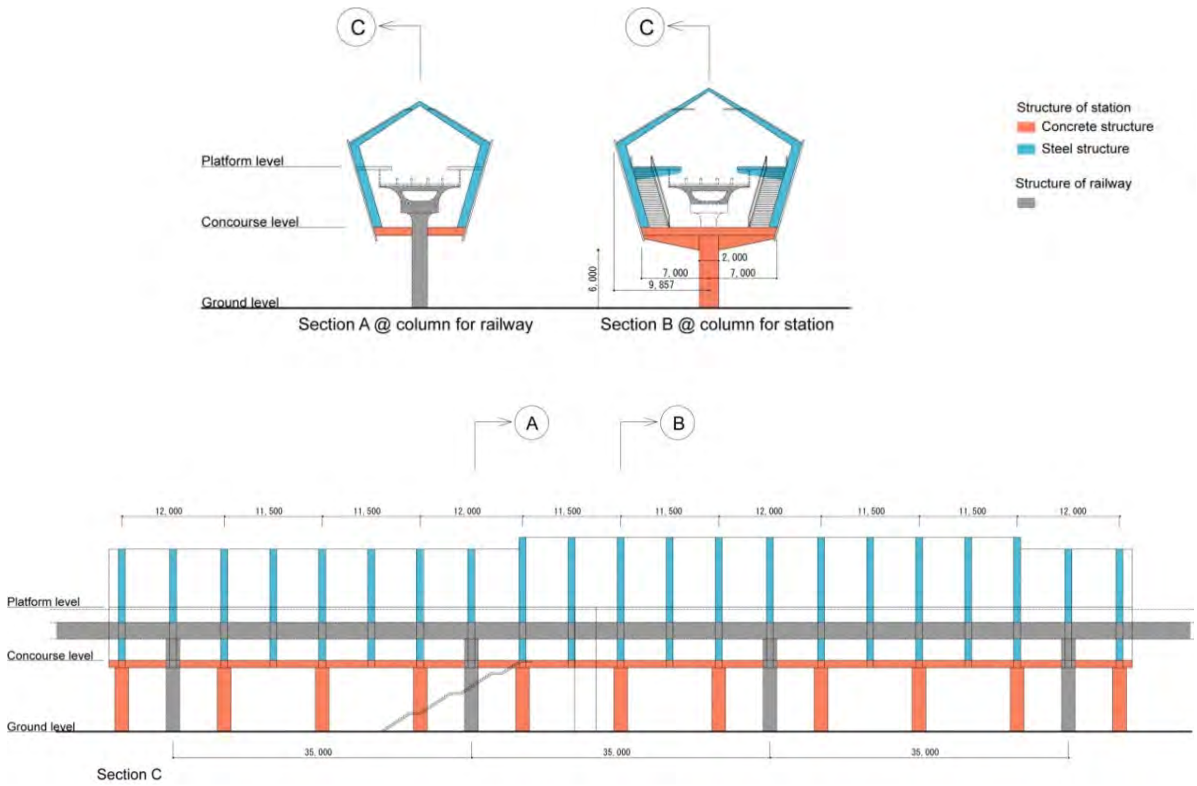
Welikada Station looking from above

Source: Survey Team

Figure 4.11.8 Photos of Welikada Station model

4.11.6 Structure of Station

The structure of the station should be separated from the structure of the railway. This structure method has many effects including to the planning, façade design, costs and construction period. The column of the railway should be provided every 35m, and the column of the station should be provided about every 11.5m. For the structure of the station, from ground level to concourse level, the RC structure should be adopted for stability when a busy road is on ground below. From concourse level to platform level, a steel structure should be adopted for its light weight. A pentagonal structure is a feasible design since a platform can be supported only by beams and the design freedom can be increased on the concourse level. Figure 4.11.9 shows a pentagonal structure diagram.



Source: Survey Team

Figure 4.11.9 Structure Diagram

Structure calculations of each type of station were performed; the result of the structural calculations is shown in Appendix 9.

(1) Summary of Structural Design

1) Loading Condition

- Superimposed Load: This should be derived from the architectural finishing information.
- Live Loads: This is shown in Table 4.11.4.

Table 4.11.4 Live loads

Building and rooms	Live load (N/mm²)		
	For slab and beam	For framing	For earthquake
Steel Roof	600	100	100
Pedestrian deck	3,500	3,200	2,100

Source: Survey Team

- Earthquake Load: Structures in Sri Lanka do not need to be designed for loads due to earthquakes, as Sri Lanka is not in a zone regularly affected by earthquakes. However, it should be in accordance with the structure parameters of Japan building codes to minimize such risk: Base shear coefficient = 0.10, Importance factor = 1.25.
- Wind Load: The basic design speed shall be 33m/sec. (Wind Loading Zone Factor Z=3)

2) Materials

The basic structure materials are shown in Table 4.11.5.

Table 4.11.5 Materials List

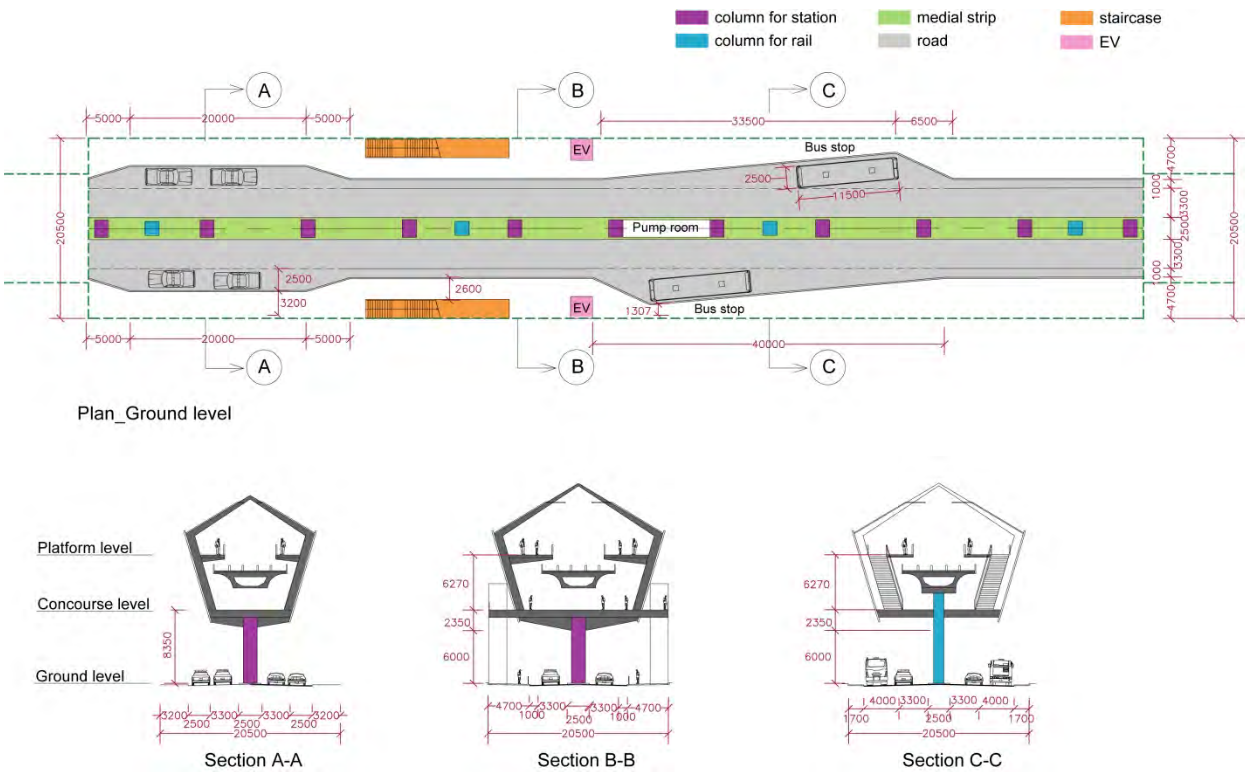
Material	Location, item	Detail
Concrete	Foundation to 1st floor slabs	Cylinder strength 24N/mm²
Reinforcement	Round steel bar	6~φ9
	Deformed bar	SD295A : D10~D16
		SD345 : D19～D25
		SD390 : D29～D38
Steel	Shape steel, Steel plate	SS400, SM490, SSC400, STKR400, STK400

Source: Survey Team

4.11.7 Design Study

(1) Road Layout Plan under a Station with 1-Ticketing Exit

The ROW width is 20.5m. For the width of road, the position of staircases should have the minimum width shown in section B of Figure 4.11.10. The ROW breakdown is 2.5m of centre is for the structure of the railway and station, 3.3m is for road main lane, and 1m is for the load shoulder on each direction. The other position can be used as drop-on/-off point of cars and three-wheelers, and a bus stop. A location of lift functions should be adjusted after further discussion with local residents at the Detailed Design stage.

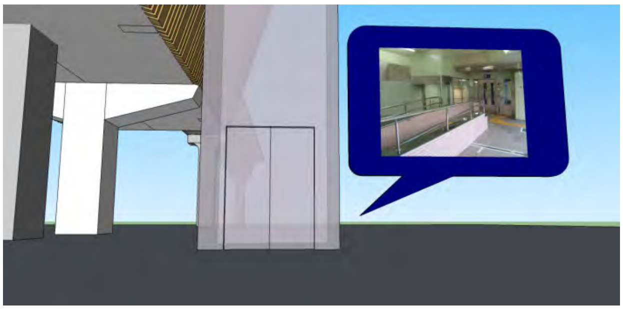


Source: Survey Team

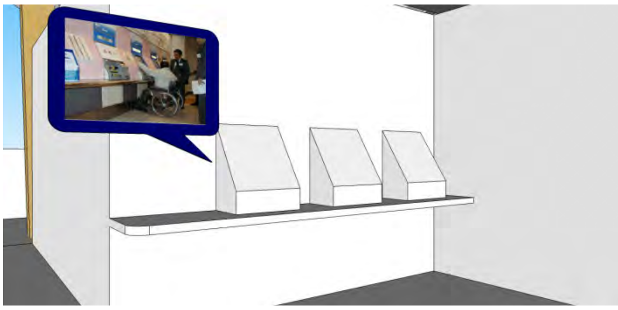
Figure 4.11.10 Road Layout Plan and Section of Station with 1-Ticketing Exit

(2) Design Study for Universal Design

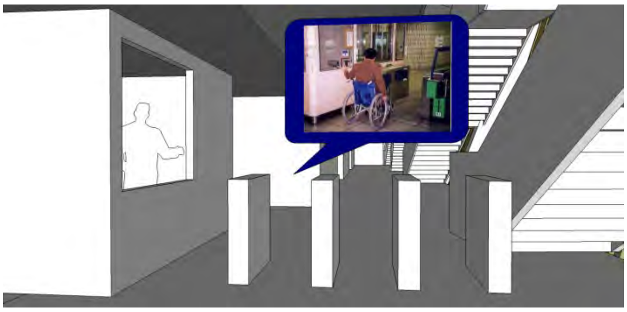
The design study for universal design considers the following points shown in Figure 4.11.11.



Access from/to Elevator on Ground Level

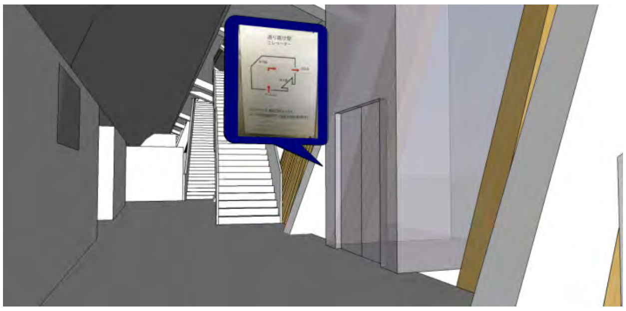


Height of Ticketing Machine

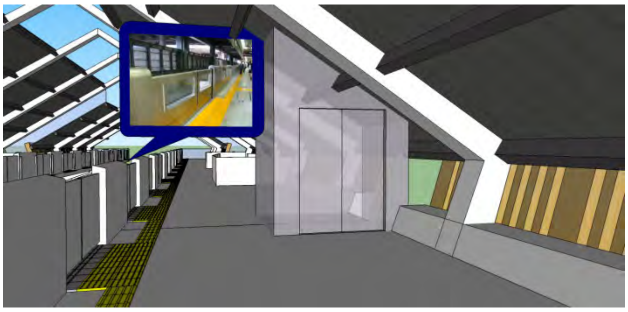


Width of Ticketing Gate

Location of Sign



Elevator Type



Platform Screen Door

Location and Quantity of Bench

Source: Survey Team

Figure 4.11.11 Study Items for Universal Design

(3) Number and Width of Ticketing Gate

As a result of the Workshop toward Accessible LRT System dated on Sep. 7th 2017, one of the gates on the operator side shall have 900mm width to accomplish universal design. The other gates shall be provided in 800mm width for security.

Source: Survey Team

Figure 4.11.12 Photo of the Workshop toward Accessible LRT System

The number of gates should be calculated by the number of people. One gate can be used by 60 people per minute; thus, 3,600 people can use one gate per hour.

1-ticketing exit has five (5) gates: 3,600 x 5 = 18,000 (people/ hour, station)

2-ticketing exit has ten (10) gates: 3,600 x 10 = 36,000 (people/ hour, station)

Table 4.11.6 shows the Volume of Peak Passenger Boarding Alighting in 2035. The above number covers the outbound/inbound total. The total amount of all stations with 1-tickeing exit is less than 18,000, except Cotta Road Station that may be able to adopt the 2-tickeing exit type.

Table 4.11.6 Peak Passenger Boarding Alighting Volume (2035)

Station	Station type	Boarding Round	Alighting Round	Boarding/ Alighting Total	Outbound/ Inbound Total
Fort	Other	5,200	-	5,200	10,400
Transport Centre	1-tiketing ex.	5,700	100	5,800	11,600
St. Joseph's	1-tiketing ex.	2,700	2,700	5,400	10,800
National Hospital	2-tiketing ex.	2,600	2,000	4,600	9,200
Borella	2-tiketing ex.	4,800	1,700	6,500	13,000
Cotta Rd	1-tiketing ex.	7,700	2,300	10,000	20,000
Walikada	Other	800	3,400	4,200	8,400
Rajagiriya	1-tiketing ex.	1,500	3,000	4,500	9,000
Sethsiripaya	1-tiketing ex.	700	1,500	2,200	4,400
Battaramulla	1-tiketing ex.	500	600	1,100	2,200
Palan Thuna	1-tiketing ex.	1,200	2,700	3,900	7,800
Robert G.	Other	200	800	1,000	2,000
Lumbini Temple	1-tiketing ex.	400	1,400	1,800	3,600
Talahena	1-tiketing ex.	400	1,300	1,700	3,400
Malabe	1-tiketing ex.	400	4,900	5,300	10,600
IT Park	1-tiketing ex.	100	6,600	6,700	13,400

(Unit: people/hour) (Unit: people/hour)

Source: Survey Team

(4) Number and Width of Staircase and Escalator from/to platform

The width and number of staircases and escalators should be considered for passenger flow. The conventional calculation method is shown below.

Staircase: W = N / 2,500

Escalator: n = N / 6,750 (1.2m width type)

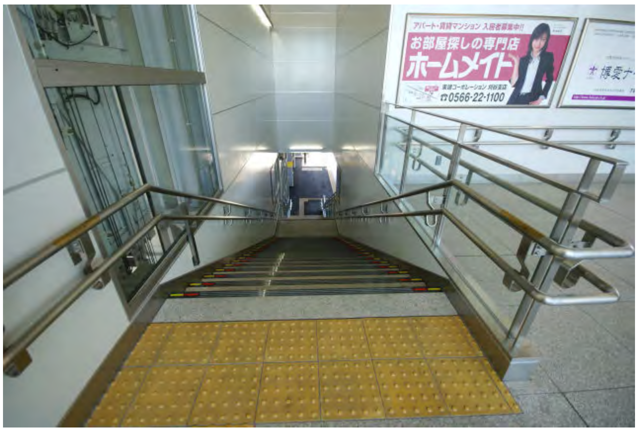
W: width of stair (m), N: passenger flow per hour in peak time (people), n: number of escalators.

Station with 1-ticketing exit has two sets of 2m width staircases, one set of 0.8m width staircase, and one set of 1.2m width escalator. Two sets of 2m width staircases has a sign for going up and down; 1.3m for going down +0.7m for going up. An example of this staircase width is shown in Figure 4.11.13; an image of the sign is shown in Figure 4.11.14. One escalator is to go up to the platform. The simulation of going up to and down from the platform is shown in Figure 4.11.15. A calculation study of alighting passenger flow in peak time is shown below.

Total staircase width: 1.3+1.3+0.8=3.4 (m)

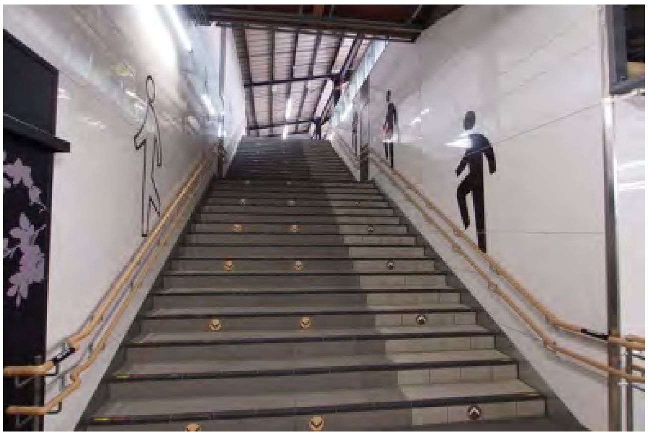
N=3.4 x 2,500= 8,500 (people/ hour) >*6,100 (people/hour)

* 6,100 (people/hour) is Peak hour passenger alighting volume (2035) at IT Park Station. IT Park Station has highest volume of alighting passenger in peak hour, shown in Table 4.11.6.



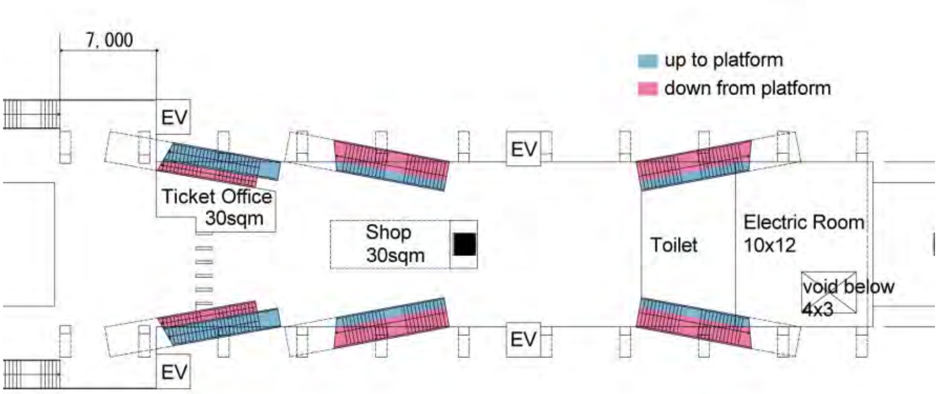
Source : Noda Shinmachi Station (http://www.isok.jp/rail/station/tokaido/nodashin/)

Figure 4.11.13 Example of 2m width Staircase



Source : (C)dk_kawachi

Figure 4.11.14 Sign of Stairs for Going Up and Down

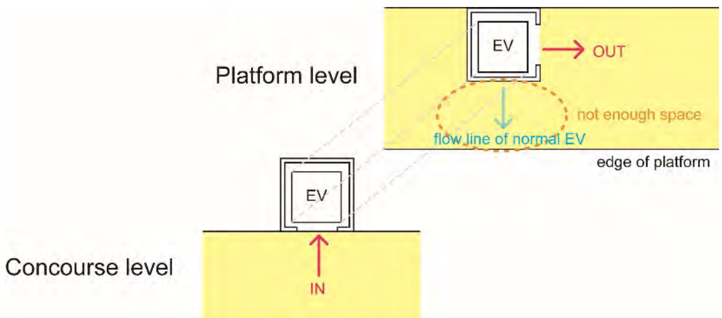


Source: Survey Team

Figure 4.11.15 Simulation of Use in Peak Time in Station of One Ticketing Exit

(5) Type of Elevator from/to Platform

An elevator with two direction exits in a right angle should be installed to connect from concourse level to platform level. This type of elevator is popular in Japan, and it will be functional. During the disabled people workshop, the attendees could easily understand even though this type of elevator is not currently present in Sri Lanka. A diagram of this elevator is shown in Figure 4.11.16. The usable dimension of the elevator car is 1.5m x 1.5m; people who use a wheelchair or baby stroller can fit easily.



Source: Survey Team

Figure 4.11.16 Diagram of Elevator with Two Direction Exit in Right Angle

(6) Platform Screen Door

PSD should be installed in all platforms for safety reasons. The length of the platform is 120m, and PSD will cover the full length. Most PSDs are 50-100kg/m in weight, thus the long term loading of the edge of platform can be covered by 100kg/m. Figure 4.11.17 shows a sample image of PSD.

Source: (c) takuya870625

Figure 4.11.17 Image of Platform Screen Door

(7) Guide Blocks

Guide blocks should be installed at locations that blind people use, such as in front of the EV, staircases, escalators, ticketing machines, ticketing gates, edges of platform and access points of trains.

(8) Signage

For signage, the following points are taken into consideration of the design.

- Clear Visibility: of size, font, colour, and location
- Universal Design: with numbering system and pictograms

(9) Air Conditioner

The office, shop, and electrical room will be provided with air conditioners, so that their room temperature would not exceed a suitable level due to the heat generated from the transformer.

The indoor design condition is shown in Table 4.11.7.

Table 4.11.7 Indoor condition

Room name	Temperature (degree)	Humidity (%)
Office, Shop	26.0	Not required
Electrical room	30.0	Not required

Source: Survey Team

(10) Electrical Room

The transformer for 1 (single) phase and 3 (three) phase from the feeding power supply will be installed in the Electrical Room. The power supply from the transformer will be distributed to lighting, receptacle, air conditioner and pump. The equipment of railway will be supplied by the feeding team for railway.

(11) Lighting

The platform will be furnished with indirect lighting fixtures. The corridor will be provided with down light type fixtures with LED lamp.

(12) Pump Room

The domestic water supply system will consist of reservoir tank and water pressurized pump unit, which distributes potable water to toilets/WC and the office with sufficient water pressure of 0.2 MPa. The tank and water pressure pump unit will be accommodated in the pump room.

(13) Security

CCTV will be installed at the ticket gate, ticket selling area, escalators and inside elevators. Rooms and corridor will be protected with a fire detection system that consists of fire control panel and smoke/heat detectors.

Shutters will be provided on the boundary between a restricted area and public area when a station is closed.

(14) Drainage System

Sewerage drainage from each station located in Colombo city will be discharged to the city sewer main of CMC. Since no city sewer main is available in other cities, sewage drainage should be treated by WTP.

Requirement for effluent from WTP shall comply with “The Gazette of the Democratic Socialist Republic of Sri Lanka” No. 1534/18, February 2008.

(15) Lightning Protection System

A station will be protected from lighting strikes by a conventional type of lighting protection system.

(16) Solar panel

Solar panel can be installed in a large station like Fort station. Initial costs and O&M of solar panel need to be considered in further study at the Detailed Design stage.

4.11.8 Development of Station and Surroundings

Stations will be nodes for connecting the JICA-LRT to the city, which is the place where many people come together. Stations will also be connecting points to other transportation modes, such as buses, taxis, three-wheelers, bicycles, private cars, and walking.

Stations have a potential to promote Transit Oriented Development (TOD), an urban development method to create a mixed-use development around the node of public transportation. TOD will provide easy access for people to public services, commercial activities, and public transportation.

Developing mixed-use facilities around the stations will encourage people to use JICA-LRT and allow the JICA-LRT operator to increase users of the JICA-LRT.

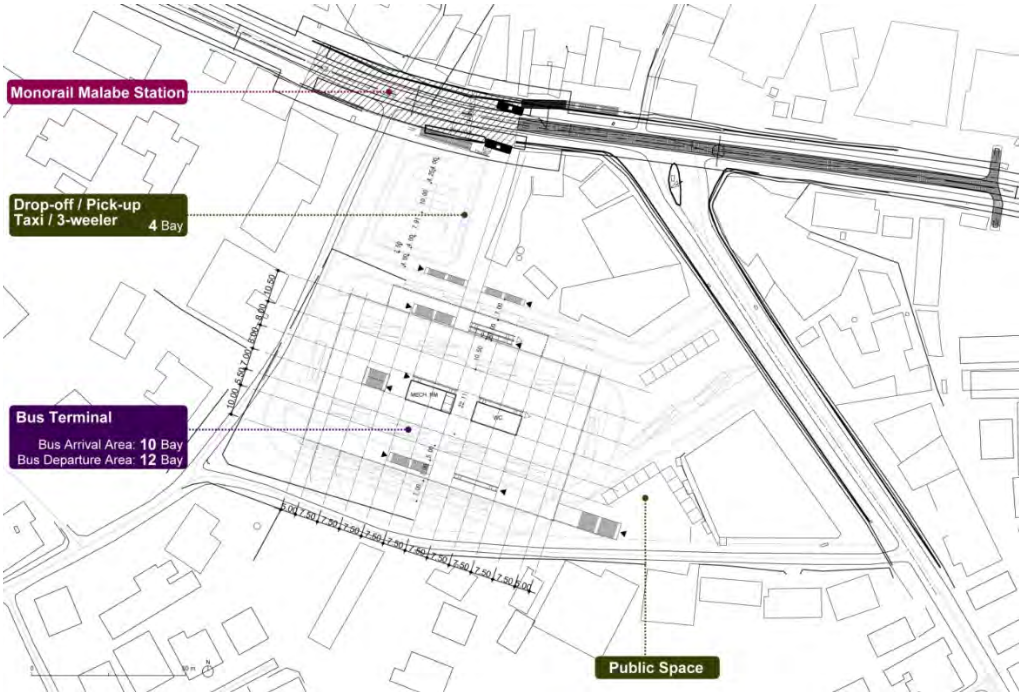
Layout of the station and the connecting plan to the surrounding area is one of the most important factors for the area development, by dictating movement of pedestrians and bicycles, and impacting the commercial activities around the station. Connection plans to the surrounding area for each station is shown in Appendix 9.

Development of the surrounding area should not only consider a minimum inside ROW allocation of 20.5m, but also integral development with facilities, transport and car parking. Table 4.11.2 shows accessibility features of all stations.

With consideration of the above impact, the layout plan of each station will be carefully prepared based on the study of the surrounding area. In this Survey, only the conceptual land development plan of the station and surroundings will be developed, as shown in the example of the Malabe Multi-modal Centre (MMC) below, which is recommended to be developed with the Bus Terminal and surrounding commercial facilities. If it is necessary to further study the development of the facility layout plan, this needs to be discussed and added to the tasks of the Basic and Detailed Design stage.

Source: Survey Team

Figure 4.11.18 Example of Location and Characteristics of Malabe Station and MMC (SKYTRAIN)



Source: Survey Team

Figure 4.11.19 Example of Layout Plan of Malabe Station and MMC (SKYTRAIN)

4.12 Construction Plan

4.12.1 General

The construction of this project will require a careful planning and organization, given the magnitude of the works, time constraints and the construction site on busy national and arterial roads.

The challenges faced during construction will include:

- To adopt rapid construction techniques while still ensuring quality,
- To plan and organize all construction activities to ensure smooth flow of construction and the avoidance of delays on critical path activities,
- To organize and supervise sufficient work teams and construction equipment and proper coordination with other contractors as necessary,
- To construct and organize a suitable temporary casting yard close to the site,
- To implement well planned traffic management plans to ensure minimal impact on traffic, with traffic re-routing plans as necessary,
- To incorporate utility relocations, or design changes imposed by utility locations, into the construction planning,
- To assure the safety of the construction operations at all times.

(1) Viaduct

1) Foundation (Piling)

The viaduct foundations are comprised of conventional bored piles (cast in-situ RC piles) and pile caps.

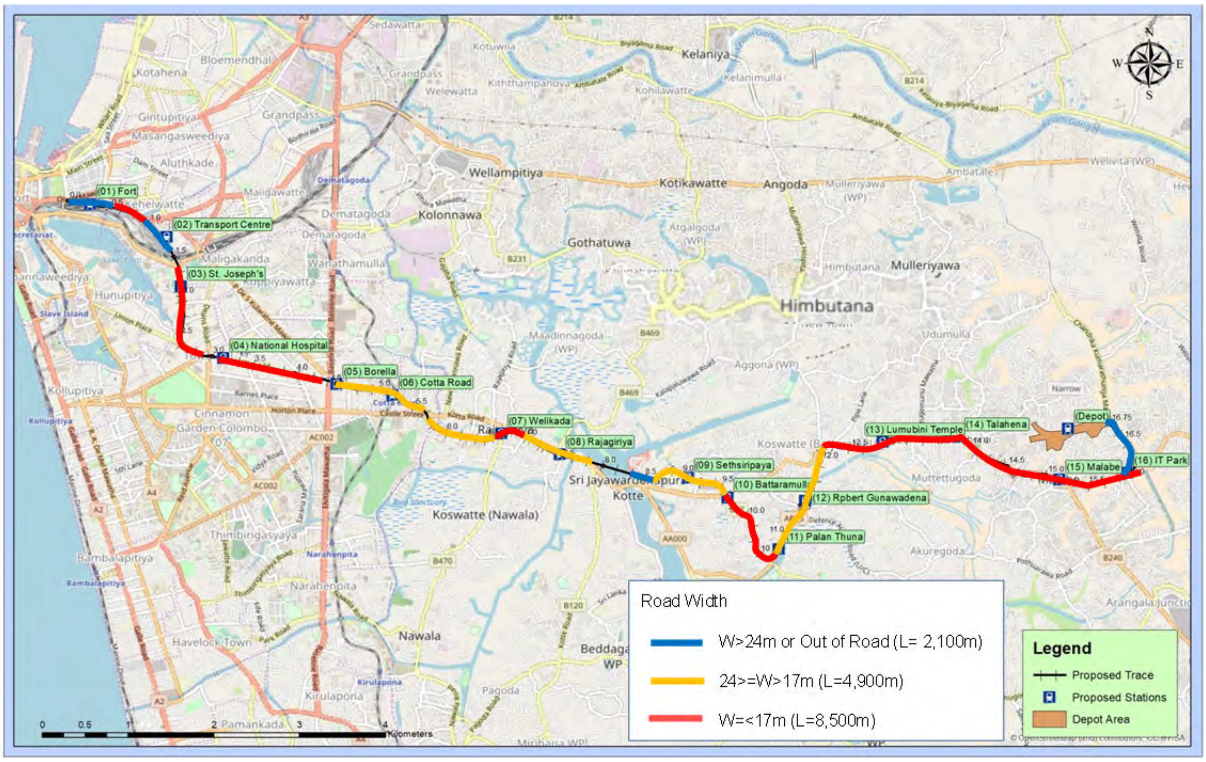
The bored piles will be constructed using high torque powered rotary drilling rigs mounted on crawler cranes and using various buckets, augers and chisels. Excavation will be carried out under a bentonite slurry or the use of temporary casings together. Following the completion of the boring and the placement of the steel re-bar cage in the pile excavation, concrete is placed using a tremie pipe while the bentonite slurry is pumped away, and the temporary casing is extracted just after completion of the concreting.

Critical issues during construction will include:

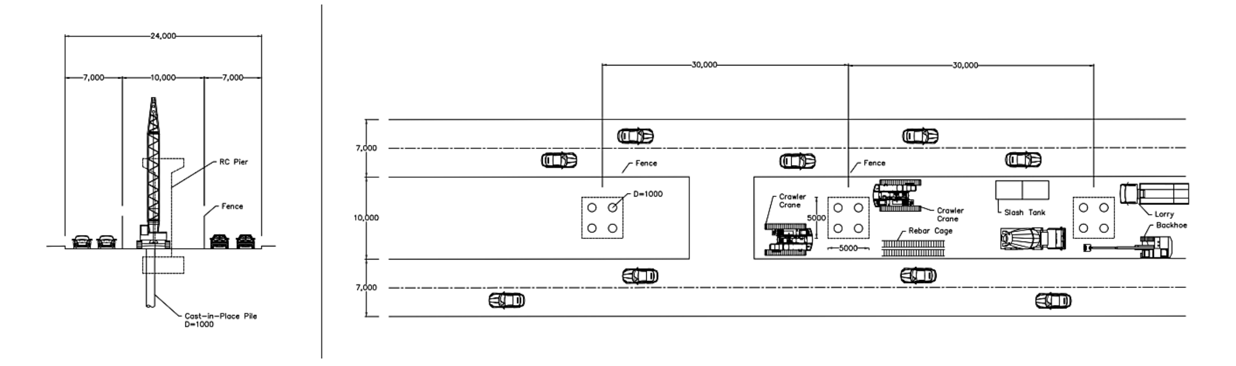
- Proper mixing and recycling of the bentonite slurry to ensure the formation of a waterproof lining ("cake") on the face of the excavation and allow clean placement of concrete,
- Ensuring that the end of the tremie pipe is always sufficiently embedded in the wet concrete as the bored pile concreting progresses,
- Avoidance of cold joints due to breakdown in supply of concrete,
- Overcasting of the pile and chipping back, or baling of the contaminated concrete while wet, to ensure good quality concrete at the pile head.

To allow sufficient space for the construction of the bored piles and pile caps, and to accommodate the construction equipment, a width of at least 10m will typically be required as a work space on the central occupation of the affected roads.

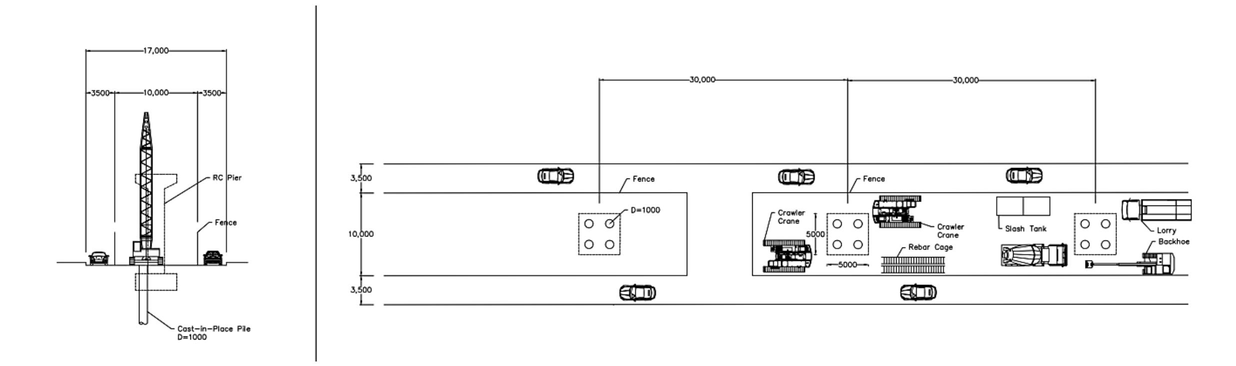
The road width along the JICA-LRT route, and the typical layouts of the construction work space arrangement on the affected roads by road width are shown in Figure 4.12.1.



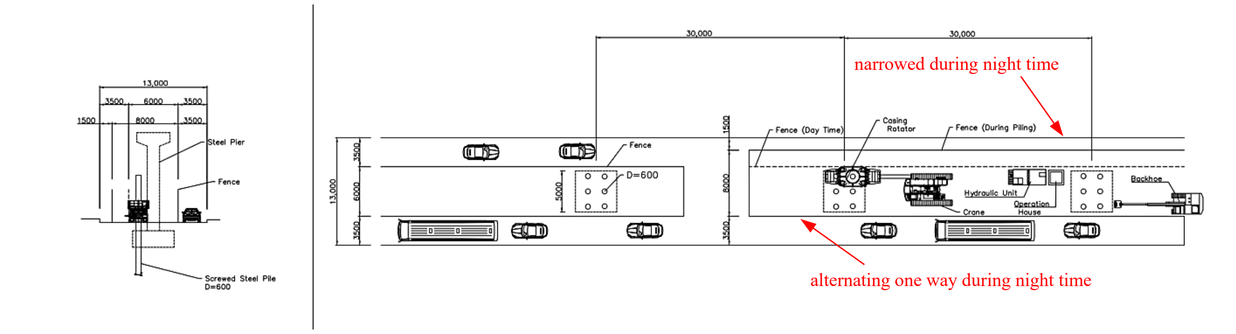
Road Widths along the JICA-LRT Route



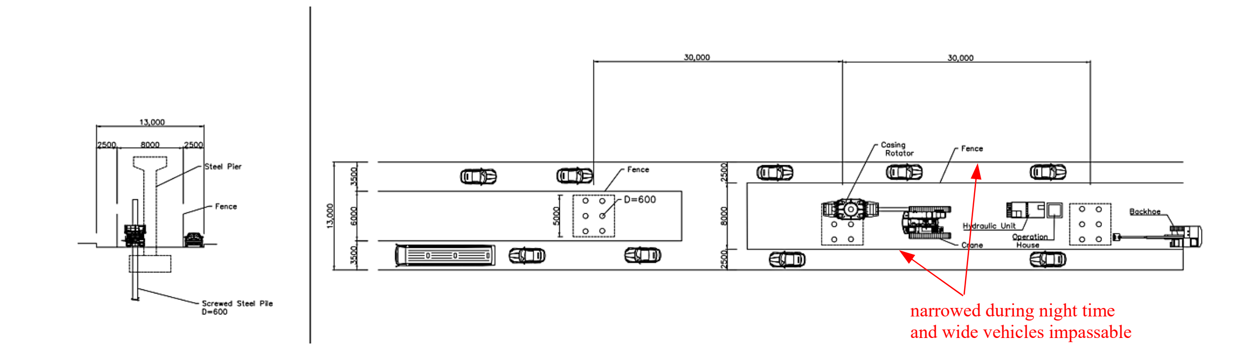
Wide Road (W>24m)



Typical Road (24m>=W>17m)



Narrow Road (Option1) (W=<17m)



Narrow Road (Option2) (W=<17m)

Source: Survey Team

Figure 4.12.1 Typical Layout of the Construction Work Space Arrangement

a) Wide Road and Typical Road (W > 24m, 24m ≥W > 17m)

Wide roads and typical roads can secure two and one traffic lanes for each direction respectively with keeping 10m-wide occupation for the construction works at the centre. The conventional bored piles and pile caps will be applied to the JICA-LRT sections along the wide or typical roads. The construction works can be carried out anytime without stopping traffic. The period of constructing the conventional bored piles and pile cap for one pier column will be approximately 3 to 4 weeks.

b) Narrow Road (W ≤ 17m)

Narrow roads with width is less than or equal 17m cannot accommodate the 10m-wide construction area at the centre of the roads if one traffic lane for each direction is required. Therefore, for the narrow roads, screwed steel piles are planned to be applied; construction work requires only an 8m-wide occupation at the centre of the roads since no excess earth is generated, and no bentonite slurry plant, no re-bar cage and no concrete are necessary. The period of constructing the screwed steel piles and pile cap will be approximately 2 weeks, which is faster than the conventional bored piles.

Source: Tekkou Shinbun website (https://this.kiji.is/282681929030009953) and
Ueda Kikou website (http://www.uedakikou.co.jp/industrial/industrial_eco.html)

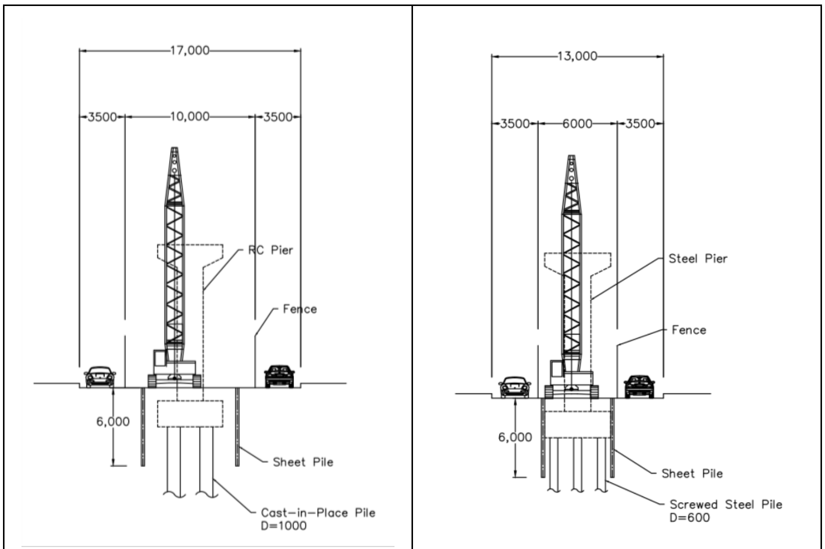
Figure 4.12.2 Screwed Steel Pile

Narrow road (Option 1) shown in Figure 4.12.1 is to expand the construction work space to 8m wide at night time in order to carry out piling work. Then one side of the traffic lane can keep 3.5m wide, however the traffic lane on the other side will be just 1.5m wide, which only motor bikes, three-wheelers and pedestrians can pass. Vehicles can go through only on the 3.5m wide traffic lane, which will be an alternating one way every 5 minutes or so.

Narrow road (Option 2) shown above is also to expand the construction work space to 8m wide at night time, but traffic lanes on both sides will be the same width (2.5m). Then, small vehicles can pass narrowed lane, however it is hard for wider vehicles such as buses and trucks to go through the affected roads, requiring detours for the wider vehicles.

For both options 1 and 2, 3 or 4 substructures in row will be in one construction space occupying the road centre. Substructures construction is generally implemented from one side to other, and the construction space will be slid forward for every completion of the substructure construction.

In the narrow roads, due to the insufficient construction work space, sheet piles may be used as moulds for pouring concrete of pile caps. Since these sheet piles cannot be extracted and reused, construction cost of the pile caps for this case will be higher than the normal case.



Typical Road	**Narrow Road**

Source: Survey Team

Figure 4.12.3 Sheet Pile for Pile Cap Construction

2) Substructure

Conventional RC pier columns will be used for the viaduct substructures of the JICA-LRT. It is strongly recommended that the columns should be constructed using standardized steel forms to promote a good quality of finishing and reduce construction cycle times. The period of the conventional RC pier column construction will be approximately 5 weeks.

Source: Survey Team

Figure 4.12.4 RC Pier Column Construction (Sample)

For narrow roads that interferes traffic, steel pier columns can be utilized, of which the construction period of approximately 2 weeks is much shorter than the conventional RC pier columns. Members of the steel pier columns are manufactured in the factory, transported to the construction sites, and easily erected using a crane in a short time.

Source:
Prof. Miki (Daido Institute of Technology) website (http://www.daido-it.ac.jp/~doboku/miki/pier1.html) and
Road Structure Journal website (https://www.kozobutsu-hozen-journal.net/walks/detail.php?id=114)

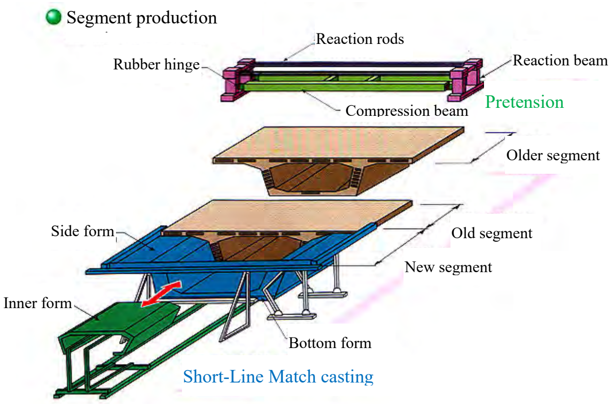
Figure 4.12.5 Steel Pier Column Construction (Sample)

3) Superstructure

As stated earlier, the PC box girder is recommended in the standard section including the station, except for several special sections.

<u>PC Box Girder Segment Manufacturing</u>

A pre-cast concrete method will be applied to the manufacturing of the PC box girder. One span of the PC box girder (standard 30m) is divided into several segments, and those segments are manufactured in the temporary yard along the planned JICA-LRT line. The temporary manufacturing yard is equipped a portal crane and shed. Figure 4.12.6 shows an example of the PC box girder segment manufacturing.



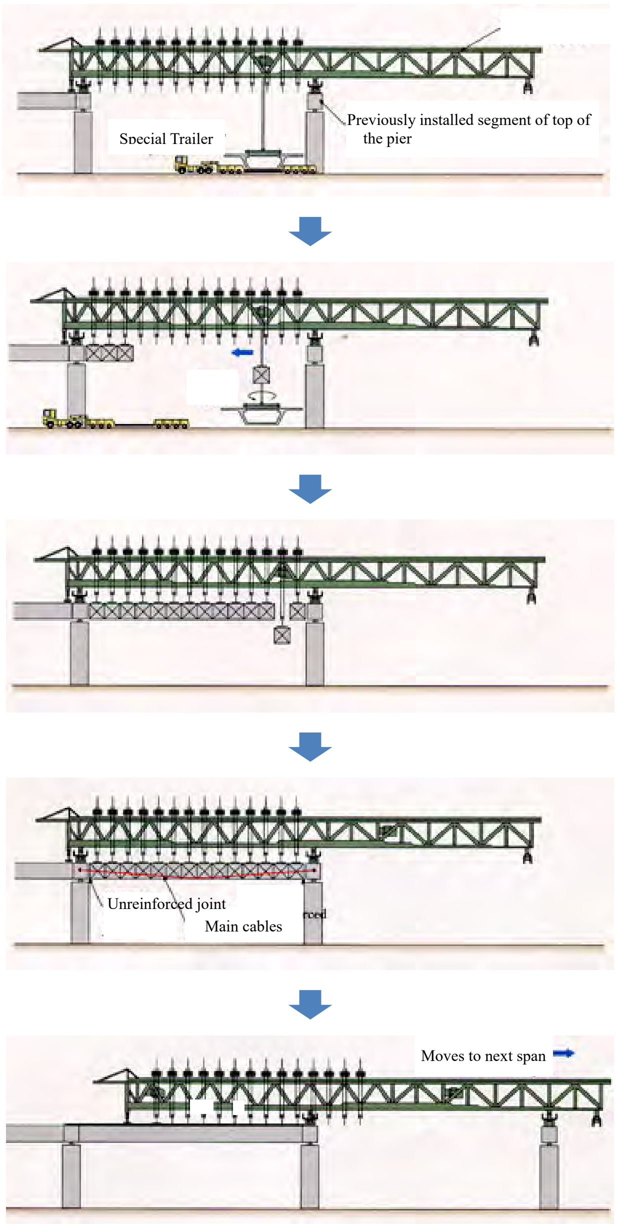
Source: Showa Concrete Industry website (http://www.showa-con.co.jp/cms/site/technology/c_number06.html) and
Road Structure Journal website (https://www.kozobutsu-hozen-journal.net/walks/detail.php?id=17&page=2)

Figure 4.12.6 PC Box Girder Segment Manufacturing (Sample)

After the completion of manufacturing, each segment is loaded on a special trailer by the portal crane and transported to the construction site one by one.

<u>Erection of the PC Box Girder</u>

Regarding the girder erection, a span-by-span method using a hanger type erection girder will be adopted. In places where an adequate construction yard is secured, the segments will be erected using the erection girder. Once all the segments are hung under the erection girder, main PC cables will be installed through all the segments and stressed. After completion, the erection girder moves to the next span. The period of the PC box girder erection for one span will be approximately 1 week. Figure 4.12.7 shows schematic drawings for a girder erection procedure.



Source: Showa Concrete Industry website (http://www.showa-con.co.jp/cms/site/technology/c_number06.html)

Figure 4.12.7 PC Box Girder Segment Manufacturing (Sample)

4) Construction of Viaducts (Bridge) on the Surface Water (Diyawanna Lake)

Structure types of the viaducts to be constructed on the surface water are basically the same as those to be constructed on the ground. However, construction methods are different. Installation of a temporary jetty (stage) parallel to the JICA-LRT alignment and an access to the jetty is required. Steel members and pre-cast concrete panels are to be used for the jetty and width of the stage will be 10 to 12m. In addition, cofferdams built using steel sheet piles are necessary for the piling work and substructure construction. The cofferdam is to make a dry area inside and enable construction works. Images of the temporary jetty and cofferdam are shown in Figure 4.12.8.

Source: Kyoto Prefecture website (http://www.pref.kyoto.jp/chutan/doboku/1228288326711.html) and Nippon P.S website (http://www.nipponps.co.jp/genbashoukai-banjougawa.htm)

Figure 4.12.8 Temporary Jetty and Cofferdam (Sample)

Superstructure works also utilize the temporary jetty. Girders and/or segments will be transported on to the stage and erected using cranes or an erection girder. After completion of the viaducts construction, the temporary jetty will be totally dismantled and removed.

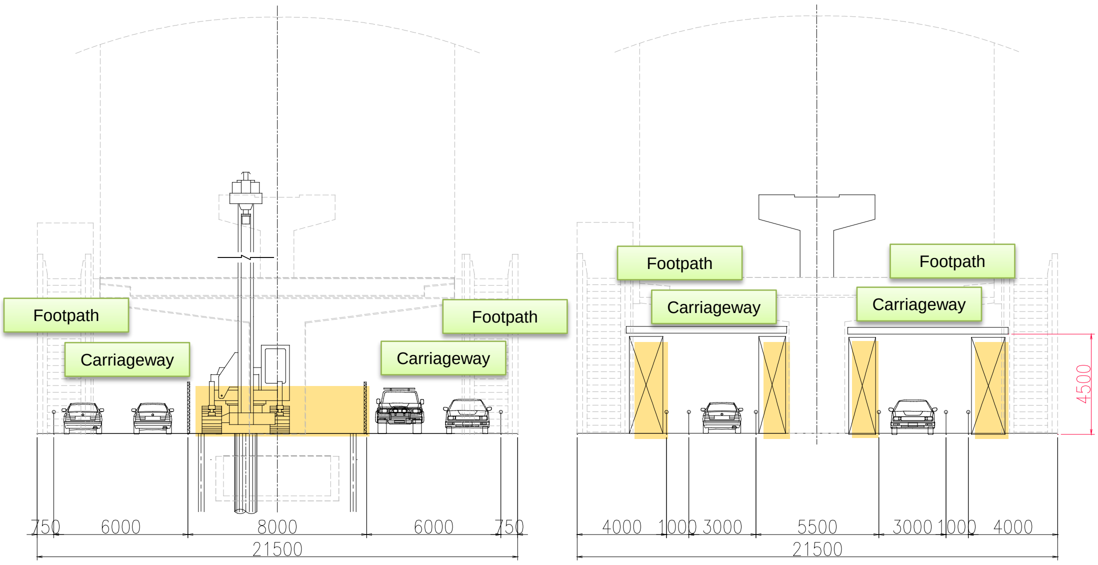
The period of the JICA-LRT viaducts construction works in the Diyawanna Lake will be approximately twelve (12) months.

5) Elevated Stations

Most sections of the proposed JICA-LRT line are planned to be constructed over existing roads, and so are most of the stations. Some of the existing roads where the new stations will be built are not wide enough for construction and allowing traffic flow at the same time. In such a case of station construction, temporary road block and detours during the construction period may be required.

For the elevated station design concept proposed in this Survey, the station structure is supported entirely by centrally located piers with cantilever pier heads. The critical phase in terms of impact on traffic is during the construction of the cantilever pier heads. At this stage, the central construction area will occupy a width of approximately 18m along the road to allow remaining work support to the cantilever ends of the pier head. The contractor will need to occupy two (2) lanes in each direction along the road during the construction of the cantilever piers. However, once the pier heads are constructed and the concourse level supporting beams and floor are in place, the traffic lanes can be re-opened and construction can proceed with minimal impact on traffic flow, at least during daylight hours. The occupation of traffic lanes at each station is projected for approximately six (6) months before station construction progresses sufficiently to allow full road access to the traffic.

For reducing the influence on traffic along the roads during the station construction, the contractor may be required to consider and select appropriate construction methods and procedures. For example, using pre-cast or pre-fabricated parts and sections for the structure such as cantilever pier heads, the concourse level supporting beams and floor slabs, etc., instead of the cast in place method, would shorten the construction period and minimize the impact on traffic flow. It would also be possible to install temporary protective structures over the existing road where the station is to be constructed. Although this structure may impose a height limitation for the traffic (slightly lower than the standard required height), it would keep a minimum of one lane open to allow traffic through without the road blocked or detours in place. Wider land acquisition along the existing roads would be necessary for constructing some of the stations as well. Typical work space layout during station pier and cantilever pier head construction and concourse level supporting beams and floor placing is shown in Figure 4.12.9.



Source: Survey Team

Figure 4.12.9 Typical Work Space Layout for Station Pier Construction

Typical progress photographs of the elevated station construction are shown in Figure 4.12.11 to Figure 4.12.13.

Source: Survey Team

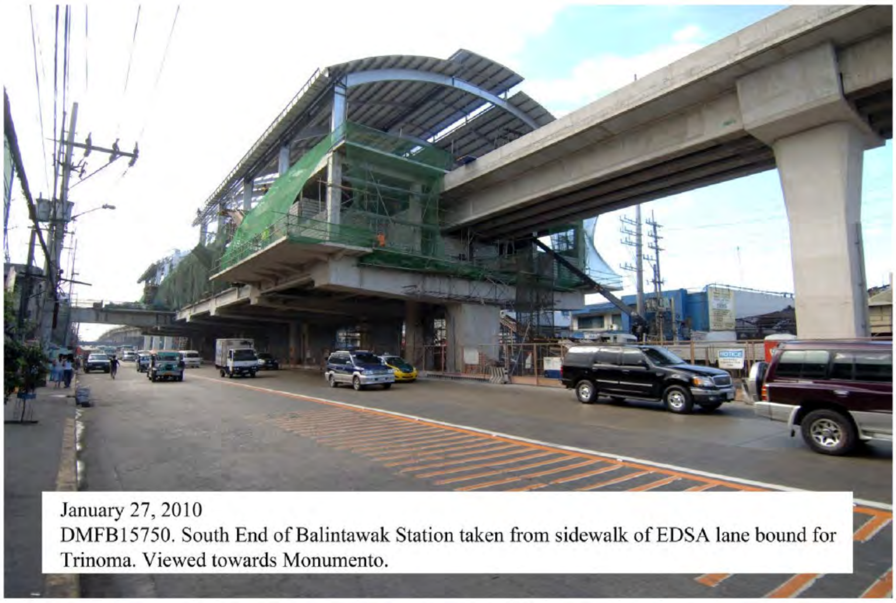
Figure 4.12.10 Station Cantilever Pier Construction (Sample)

Source: Survey Team

Figure 4.12.11 Station Concourse and Platform Construction (Sample)

Source: Survey Team

Figure 4.12.12 Station Platforms and Roof Frame under Construction (Sample)



Source: Survey Team

Figure 4.12.13 Station Roof Covering under Construction (Sample)

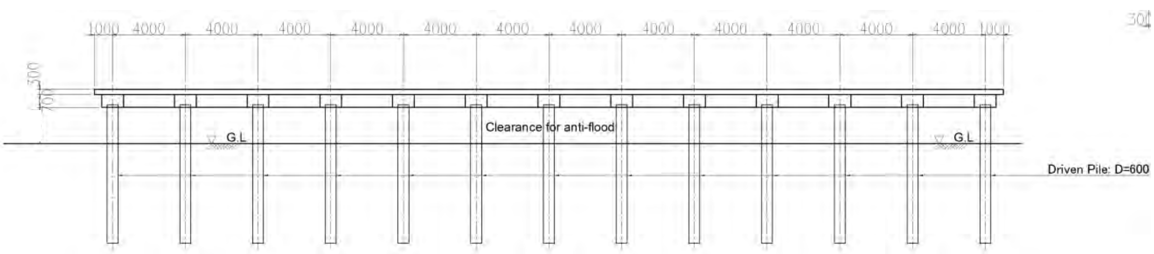
The projected construction period for the elevated station substructures and frames (civil and architectural), excluding pier construction and girder installation, is around eight (8) months and that for E&M installations is approximately another ten (10) months, which is eighteen (18) months in total for each station.

6) Depot Civil Structures

The depot, which is planned to be located north of Malabe Station, will be constructed on an elevated RC platform since the planned area experiences seasonal flooding. The elevated platform consists of pre-tensioned spun high strength concrete (PHC) pile foundations and RC slabs, to create space over the existing ground for the flooding. The outlines of the elevated platform are as follows:

- Pre-tensioned spun PHC piles of approximately 13.5m long and 600mm diameter to be driven down to the supporting layer;
- Distance between the piles is 4m and 4.5m centre to centre;
- Reinforced concrete slab of 300mm thick with beams on the piles; and
- One unit of the elevated platform is 50m by 20m.

The planned elevated depot platform is shown in Figure 4.12.14.



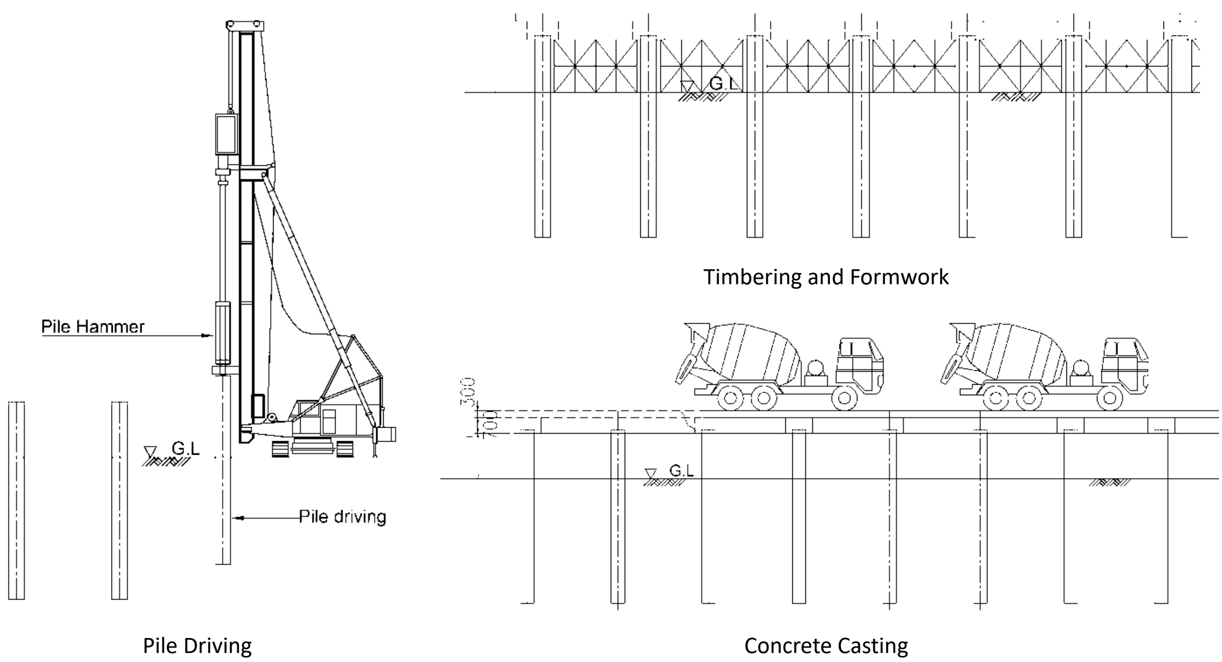
Source: Survey Team

Figure 4.12.14 Planned Elevated Depot Platform

The construction procedure for the elevated platform is as follows:

- Preparation works (clearing & grubbing, levelling, external and internal access roads construction, dewatering system installation, partial soft soil improvement work, etc.)
- Precast reinforced concrete pile driving using pile driver
- Manual pile head treatment
- Pile testing such as static load test, pile integrity sonic test and pile dynamic analysis (PDA) test when required
- Timbering for formwork for beam and slab construction
- Formwork for beam and slab construction
- Reinforcement bar installation for beam and slab
- Concrete placing and curing for beam and slab
- Dismantling formwork and timbering
- Moving to the next unit of the elevated platform
- Construction of the next elevated platform by repeating 2) to 10) above

Figure 4.12.15 shows typical construction methods of the elevated concrete slab (pile driving, timbering and formwork, and concrete casting). The projected construction schedule for one unit of the elevated depot platform will be one (1) month.



Source: Survey Team

Figure 4.12.15 Typical Construction Methods for the Elevated Depot Platform

As mentioned earlier, the proposed area for the depot construction has a flood retardation function and its ground condition is soft and swampy, which may greatly affect the construction activities. In addition, the area of the elevated depot platform is extensive, and construction scale and quantities are large, however the construction period will be relatively short. Therefore, the contractor may be required to consider appropriate countermeasures for those adverse construction conditions as follows:

- Installation of sufficient dewatering system for preventing or minimizing the occasional flooding;

- Utilization of special pile driving machine for soft soil condition; and
- Application of precast reinforced concrete slab method which would suffer less impact from the soft soil and flooding conditions would be able to shorten the construction period, and secure better quality of the structure.

For depot buildings and other structures (e.g. a heavy and breakdown maintenance shed; painting shop; inspection shed; light maintenance shed; wheel re-profiling lathe shop; train preparation shed; and administration building), other types of separate foundations would be required to be designed and constructed for bearing the load.

7) Utility Diversion

It is known in this study that the following utilities will be affecting construction of the JICA-LRT structures:

- Transmission Line (220kV, 132kV);
- Distribution Power Line (33kV, 11kV, 400V);
- Telecom underground (including Optical Fiber);
- Telecom overhead;
- Water supply; and
- Sewage.

Some of information on utilities layout and position has been obtained from CEB for power line, SLT and Dialog for telecom line, and CMC and NWS&DR for water and sewer. However, how each utility interfering with the JICA-LRT structures will be clear in Detailed Design stage with actual locations of piers and trial excavations. Therefore it is necessary to discuss and coordinate with the above utility owners and make diversion plans during the Detailed Design stage. Under the Survey, the identification of above mentioned utilities on the alignment of JICA-LRT has been commenced by MMS to save the time for Detailed Design stage. In addition, the diversion plan for high voltage transmission line of 220kV around depot and Malabe is under studied with the cooperation with CEB's officers.

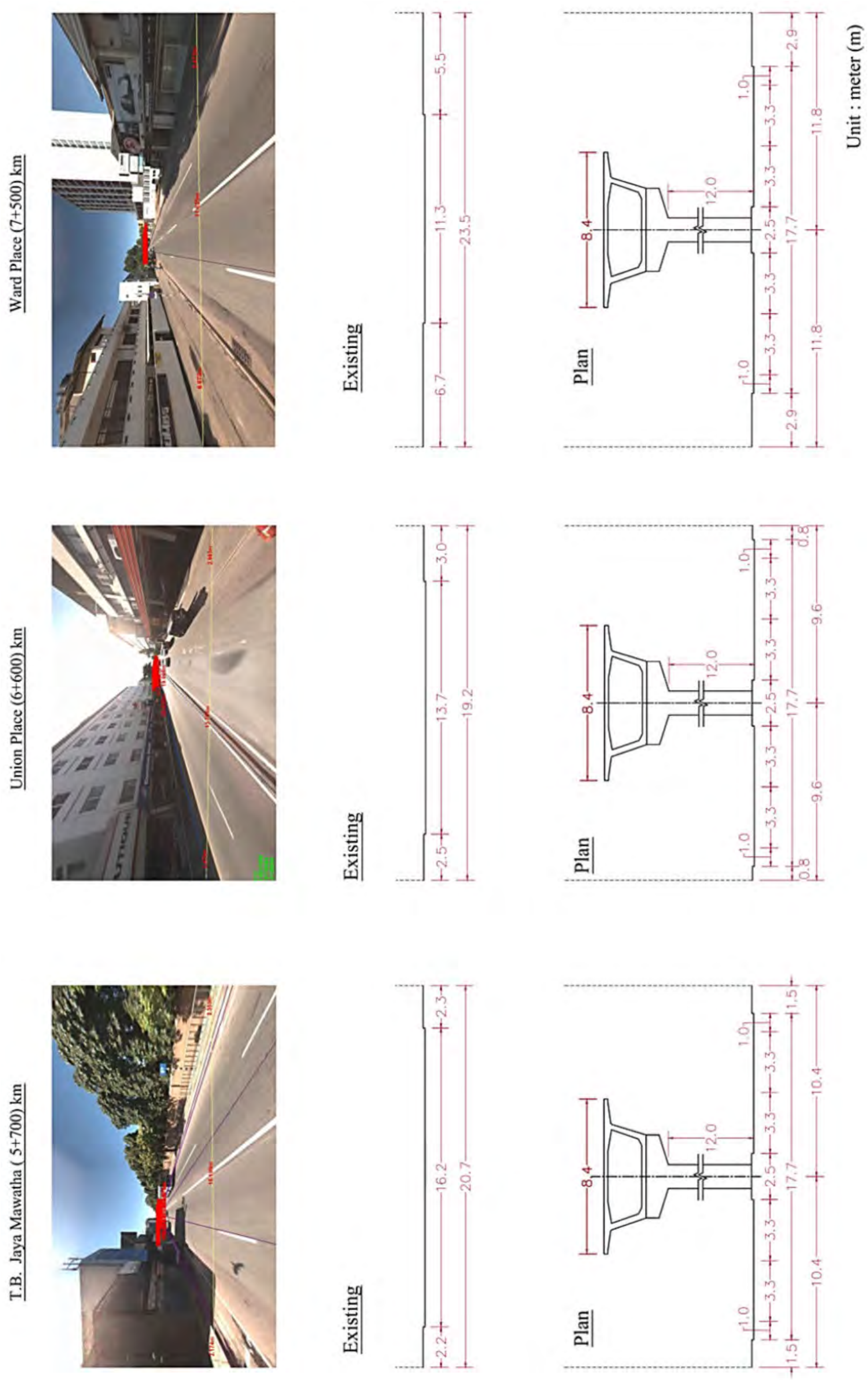
The utility diversion is planned to be implemented in the independent package. The contractor will be selected by the Local Competitive Bidding (LCB) and the actual diversion works will be carried out by the specialty sub-contractors. The utility diversion is basically required to be completed before the commencement of the construction of JICA-LRT for a smooth progress of the Project though some of the diversion works only can be done parallel with the construction works.

(2) Typical Cross-section on Major Roads

The road after the JICA-LRT viaduct construction will consist of 3.3m-wide traffic lanes, 1.0m-wide hard shoulders and 2.5m-wide median with the JICA-LRT viaduct.

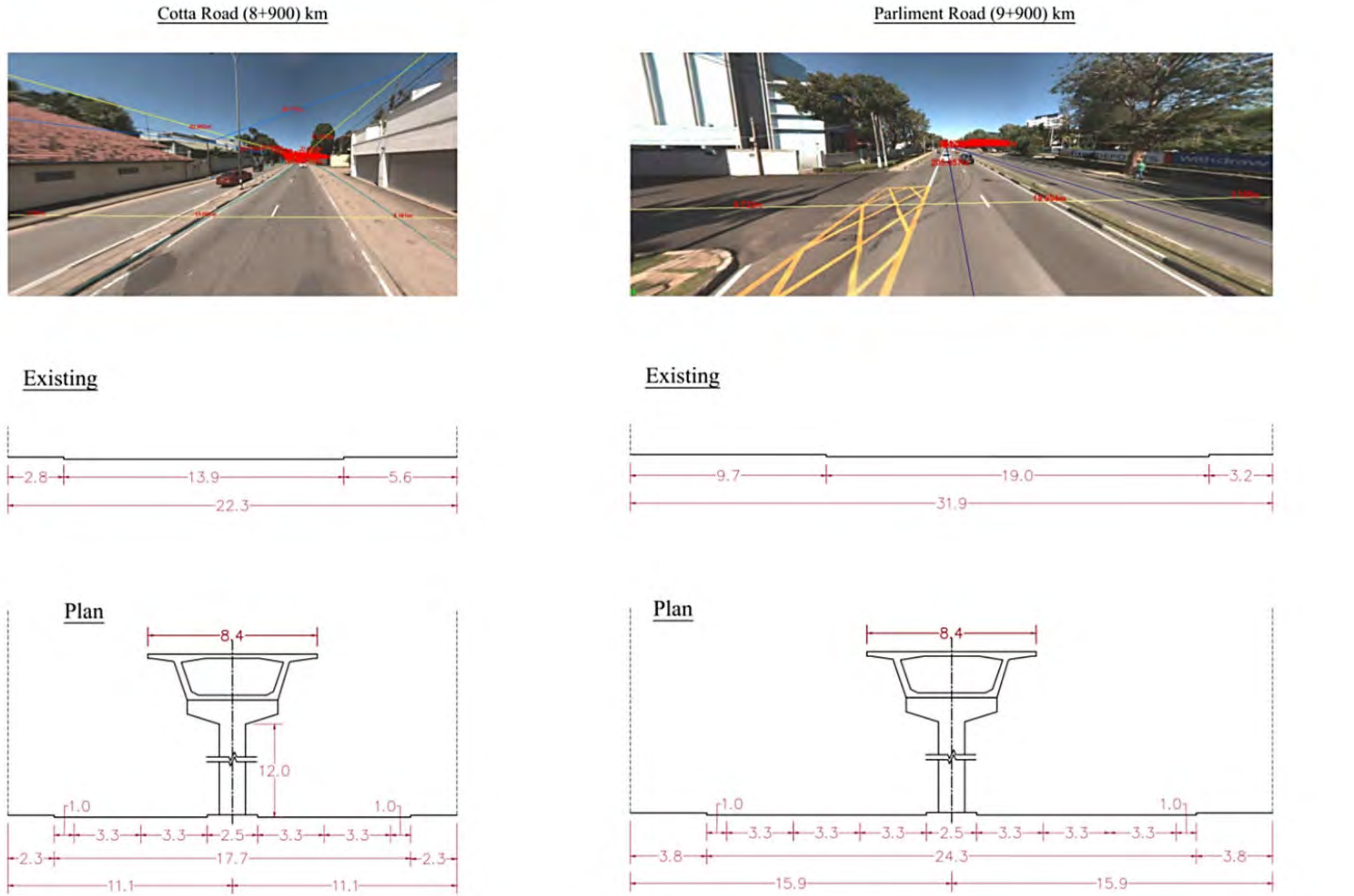
Typical cross sections of major roads are shown from Figure 4.12.16 to Figure 4.12.19.

In most of the roads, the original number of lanes can be kept after the JICA-LRT viaduct construction. However, the width of sidewalk will be less than 1.5m at several roads. Wider sidewalks can be constructed by reducing the hard shoulder width in such roads.



Source: Survey Team

Figure 4.12.16 Road Section in Major Road (1/4)



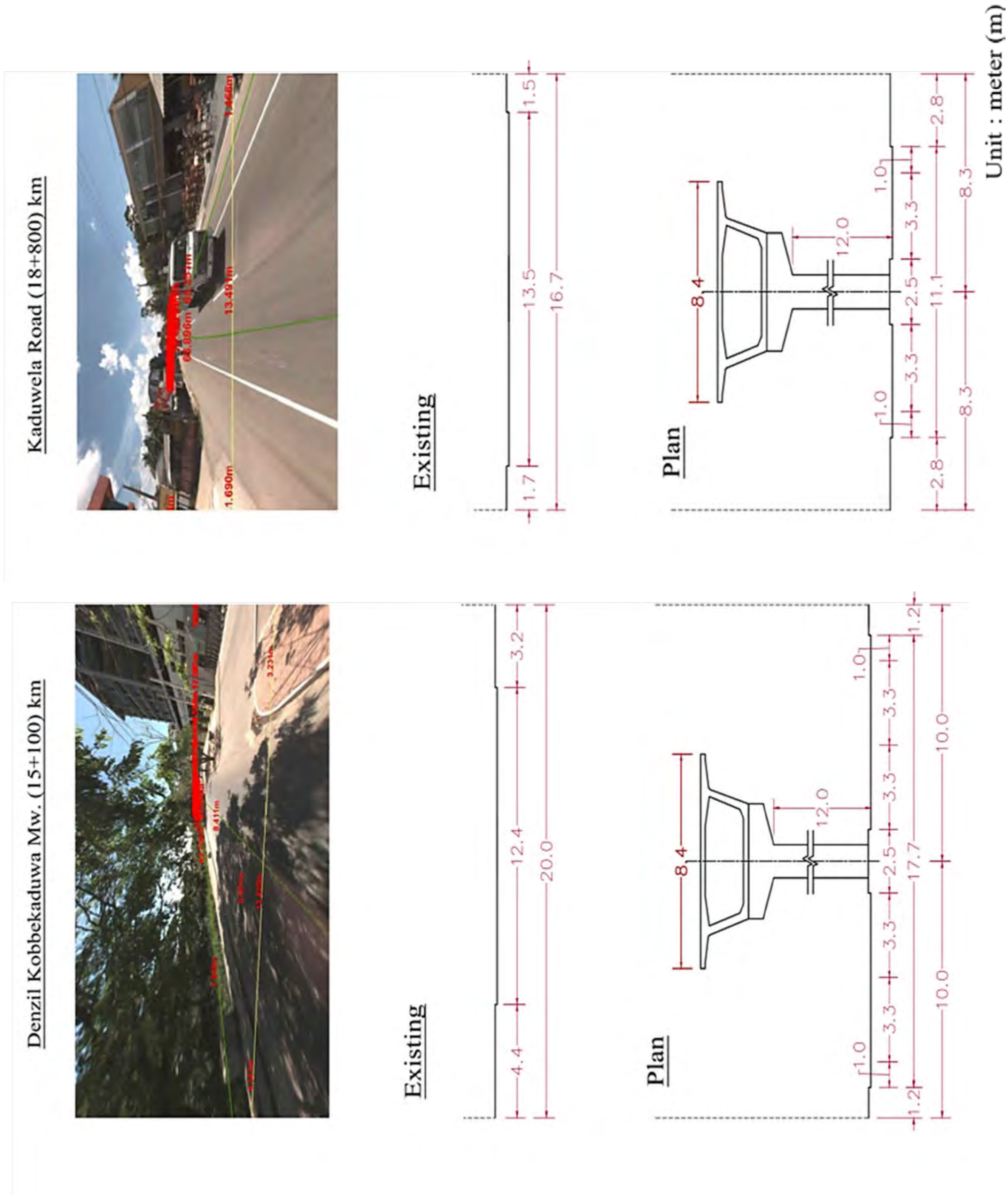
Source: Survey Team

Figure 4.12.17 Road Section in Major Road (2/4)

Unit : meter (m)

Source: Survey Team

Figure 4.12.18 Road Section in Major Road (3/4)



Source: Survey Team

Figure 4.12.19 Road Section in Major Road (4/4)

4.12.2 Construction Safety Management

(1) Legislation on Construction Safety

According to the report of "Construction Safety Survey for Japanese Yen Loan Project (STEP) in 2014 in Asia" (the original is in Japanese) implemented by JICA survey team, a law did not exist in Sri Lanka that corresponds to the Japanese Industrial Safety and Health Act. Meanwhile, Sri Lanka has the Factories Ordinance, which was enacted in 1942 and has repeatedly been revised so far, that is mainly for the safety and health on factory works but also applicable to construction sites and works. During this survey on the JICA-LRT the progress of an enactment of the Industrial Safety and Health Act is asked again and it is found that the enactment process by the Government of Sri Lanka is still on the way.

(2) Current Situation on Construction Safety

The following situation of the construction field in Sri Lanka was deduced from interviews and surveys:

- Insufficient skilled workers due to the construction boom in Colombo;
- Not enough experienced sub-contractors;
- No established construction safety management technologies, and lack of opportunity for workers to attend the safety education and training on construction works;
- No quality standard and inadequate maintenance for construction machineries; and
- Accidents frequently occur in construction sites due to the above.

(3) Characteristics of JICA-LRT Construction

The JICA-LRT main line is planned to be an elevated railway and constructed mostly on the existing roads. Some of the roads are wide and have heavy traffic, while some are narrow and curvy. The JICA-LRT main line crosses several road intersections and a lake. Construction works for the main line include pile foundation, pile cap, pier, girder, station, track, etc.. The depot is planned to be placed on a wetland and field, which have a function of flood control. For the depot area, construction works consist of pile foundation, elevated slab deck, track, buildings, etc. Main materials for the structures will be steel and concrete. Utilities including high-voltage cables either cross or are along the planned JICA-LRT main line and the depot.

Based on the above, the JICA-LRT construction works have the following characteristics:

- Construction works at elevated structures;
- Construction works in heavy traffic;
- Construction works using heavy machineries;
- Construction works using welding;
- Construction works on the water; and
- Construction works near high-voltage cables.

(4) The Guidance for the Management of Safety for Construction Works in Japanese ODA Project

For the construction characteristics of the JICA-LRT listed above, technical guidance for safe execution of the following type of works and accident prevention measures stated in "The Guidance for the Management of Safety for Construction Works in Japanese ODA Project" (https://www.jica.go.jp/english/our_work/types_of_assistance/c8h0vm00008zx0m8-att/guidance_en.pdf), prepared by JICA in September 2014, should be applicable:

- Excavation Work;
- Pile Foundation Work;
- Form and Form Shoring System Work;
- Reinforcing Bar Work;
- Concrete Work;
- Work over Water;
- Measures for Prevention of Fall Accidents;
- Measures for Prevention of Accidents Involving Flying or Falling Objects;
- Measures for Prevention of Accidents Involving Collapse of Structures;
- Measures for Prevention of Accidents Involving Construction Machinery;
- Measures for Prevention of Public Accidents;
- Measures for Prevention of Traffic Accidents; and
- Protective Gear.

(5) Safety Management for the JICA-LRT Construction

Contractors will be required to prepare the Safety Plan for the Project, inclusive of items stated in Chapter 3 of "The Guidance for the Management of Safety for Construction Works in Japanese ODA Project", including: basic policies; organization structure; plan–do–check–act (PDCA) cycle; monitoring; education and training; voluntary activities; sharing information; response to emergencies and unforeseen circumstances, etc.; as well as other items specifically arisen from the characteristics of the JICA-LRT construction. The Safety Plan is a part of the Contractor's proposal and is submitted in the bidding.

The Safety Plan of the successful bidder (the Contractor) will be reviewed by the Employer and the Engineer (Consultant). The Contractor also needs to provide the Method Statement for each work item, including the safety management, before the commencement of the each work. The construction works are implemented with the safety management regulated in the approved Safety Plan and Method Statements. The Safety Manager appointed by the Contractor and approved by the Employer is duly responsible for the safety on the construction works, and will complete his/her duties under the supervision of the Consultant's Safety, Health and Environment Expert and Resident Engineers.

4.13 Disability and Gender Mainstreaming

4.13.1 Disability Mainstreaming

(1) Legal, Planning and Institutional Framework on the Person with Disabilities

1) Legal Framework of the Persons with Disabilities

The government of Sri Lanka prescribes "Protection of the Rights of Persons with Disabilities Act, No. 28 of 1996" to ensure the equal rights of the Persons with Disabilities (PwD). In addition, Ministry of Social Services and Social Welfare prescribed "Disabled Persons (Accessibility) Regulations, No. 1 of 2006" to ensure the accessibilities of PwD in all public buildings and transportation. The regulation was developed through the consultations with party organizations and referred to the regulation of the United Nations.

Ministry of Health, Directorate for Youth, Elderly and Persons with Disabilities prescribes "Design Considerations on Accessibility for Persons with Disabilities" in 2013. However, this design consideration has not legally stipulated such as regulation and gazette. The sizes described in the design consideration are partly different from the "Disabled Persons

(Accessibility) Regulations", and it is not widely recognized as the accessibility regulation. According to the interview with a party organization official, the "Disabled Persons (Accessibility) Regulations" is in the process of revision to modify the mistakes of the figures and usability of PwD.

2) National Action Plan for the Protection and Promotion of Human Rights 2017-2021

National Action Plan for the Protection and Promotion of Human Rights 2017-2021 is the latest national plan regarding to PwD. Chapter 5 of the Plan covers "Rights of Persons with Disabilities" and sets the goals, objectives, activities, responsible agencies time frame and its performance indicator. As for public transport, a goal "Accessible built environment, transportation communication and assistive technologies" covers securing the accessible transport to PwD. Its objective and activities are shown in Table 4.13.1.

Table 4.13.1 Strategy and its Actions to Address Accessible Public Transport (Extracted)

Goal 8. **Accessible built environment, transportation communication and assistive technologies**
Objective **8.2. People with disabilities have access to affordable and accessible public transportation to enable them to travel and participate fully in all aspects of life**
Activity 8.2.1. Establish a mechanism to monitor the implementation of standards and guidelines as defined in Accessibility Regulations of 2006, to receive complaints, and to take legal action against owners of public transport that do not conform to those regulations 8.2.2. Educate the transport providers on needs of PwD (including policy makers in the transport sector) 8.2.3. Include modules on accessibility in relevant educational and training curricula of all occupations relevant to the transportation system (eg. Engineers) 8.2.4. 1/3 of the fleet of buses operated by the Sri Lanka Transport Board are accessible to wheelchair users and all bus stands are adapted to accommodate persons with all types of disabilities 8.2.5. Adaptations made to 1/3 of railway stations to accommodate people with all types of disabilities and at least one coach on all trains adapted to accommodate wheelchair users 8.2.6. Provide incentives, through tax related and other concessions, to private transport operators, including taxis, to provide accessible transport services at affordable prices 8.2.7. Issue Circular eliminating use of derogatory terms related to disability used by transport service providers to identify locations on routes

Source: National Action Plan for the Protection and Promotion of Human Rights 2017-2021

3) Statistics for Persons with Disabilities

Department of Census and Statistics conducted a survey to identify the functional difficulties as a part of the Census of Population and Housing 2012. The survey used six short questions recommended by the United Nations Economic and Social Council for Asia and the Pacific (UNESCAP). In this census, following definition and types were used to compile the summary of PwD.

Disability: "*Person with disability means any person who, as a result of any deficiency in his physical or mental capabilities, whether congenital or not, is unable by himself to ensure for himself, wholly or partly, the necessities of life*".

Type of functional difficulties:

- Vision (even with the use of glassed if used)
- Audibility (even with the use of hearing aids if used)
- Mobility (walking a short distance or up/ down 12 steps in stairway)

- Cognition (memory and perception)
- Day to day self-care such as getting dressed, washing etc.
- Communicability

The table shown in the next page is the summary of the PwD in Sri Lanka. The statistics also highlights the level of education and employment status of PwD. Specifically, 14 percent of them have never had schooling and 28 percent of them are economically active, which are considerably lower than average population[12]. According to the participants of the Workshop toward Accessible LRT System conducted in this Survey, a large number of people had seeing difficulties and walking difficulties due to the civil conflict, and many of those who had seeing difficulties in their adulthood did not have opportunities for education such as reading braille. These characteristics should be considered for the preliminary design of the station facilities by introducing audible guidance in the vehicle and the station facilities.

Table 4.13.2 Summary of the Number of Persons with Disabilities in Sri Lanka

Difficulties	Difficulty (Number)	Rate per 1000 persons		
		Total	Male	Female
Total with difficulties	1,617,924	87	77	96
Seeing	996,939	54	47	60
Walking	734,213	39	31	47
Hearing	389,077	21	19	23
Cognition	343,689	18	16	21
Self-care	197,575	11	10	11
Communication	180,833	10	10	10

Source: Census of Population and Housing-2012, Sri Lanka

4) Government Stakeholder of Disability Sector

As for government sector, Ministry of Social Empowerment, Welfare and Kandyan Heritage is the leading agency regarding to securing accessibility of PwD by prescribing the law and the regulation and implements social welfare activities. National Secretariat for Persons with Disabilities (NSPD) and Department of Social Services implement programs such as providing monthly allowance for PwD, operating a vocational training center, facilitation for recreational activities for children with disabilities and so on. Ministry of Health, Nutrition & Indigenous Medicine also covers mainly health issues of PwD and has a department called Department of Youth Elderly Disabled & Displaced.

(2) Challenges of the Disabled Persons Using Public Transportation

In response to the Disabled Persons (Accessibility) Regulations, No. 1 of 2006, a certain number of facilities are equipped with slopes, handrails and elevators. However, the contractors often do not understand the meanings of the regulation and install the barrier-free equipment improperly, for example, too steep ramps with slippery material and randomly equipped guiding blocks. Regarding to railway facilities, most of the train stations were constructed before the regulation and its designs are far from barrier-free. Poorly equipped facilities and the design of the station currently prevent PwD from going out and using the public transportation comfortably by themselves. According to the interview with the participants of the workshop toward Accessible LRT system, certain numbers of PwD manage to commute by themselves using public transportation, but they sometimes get lost due to insufficient information for PwD.

[12] According to Census 2012, Primary school enrollment rate is 96.8% in male, 96.9% in female. Also Census 2012 indicated 459,462 persons are economically inactive due to disabled/infirm.

(3) Activities of Development Partners

JICA has been implementing various kinds of technical assistance and projects in Sri Lanka, and has strong working relationship with the government stakeholders and the stakeholder organizations[13]. For example, JICA Distance Learning and Multimedia Education Project provided trainings to transfer the technology of Digital Accessible Information System (DAISY) conversion in 2003. Japan Overseas Cooperation Volunteer (JOCV) has been contributing to the disability sector such as occupational therapist, physiotherapist, and social welfare sector in Sri Lanka and as of September 2017, 10 volunteers have been dispatched in entire Sri Lanka. In addition, R/D of "The Project for Strengthening Education for Children with Special Needs through Inclusive Education Approach in Sri Lanka" was signed in November 2017 and the Project is expected to start in April 2018.

4.13.2 Gender Mainstreaming

(1) Legal, Planning and Institutional Framework on the Gender Equality

1) Legal Basis on the Gender Equality

Regarding the gender equality, the Constitution of Sri Lanka specifically prohibits sex based discrimination in the article 12 (2) and 12 (3)[14]. The Women's Charter adopted by the Government in 1993 guarantees equality and equal protection of the law, and has specified prohibition of gender based discrimination. The Charter also imposes obligations on the state to address violence against women, procedurally and substantively in preventing and in responding to violence. In addition to above-mentioned legal basis, the following policies, plans include the items, charters related with gender equality.

- Population and Reproductive Health Policy
- The National Health Policy
- National Policy on Youth
- National Family Policy
- Prevention of Domestic Violence Act 2005
- Plan of Action supporting the Prevention of Domestic Violence Act
- Local Authorities Elections (Amendment) Act No.1 of 2016 (a mandatory quota of 25 percent for women at local level)
- National Mental Health Policy
- Policy on Anti-trafficking
- National Action Plan for the Protection and Promotion of Human Rights
- Guidelines for a Code on Sexual Harassment

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[13] Stakeholder organization is the term to describe the organization composed by PwD such as hearing difficulties person, blind person.

[14] Article 12 of the Constitution prescribe Right to equality below.
(https://www.parliament.lk/files/pdf/constitution.pdf)
12.2(2) No citizen shall be discriminated against on the grounds of race, religion, language, caste, sex, political opinion, place of birth or any one of such grounds (-)
12(3) No person shall, on the grounds of race, religion, language, caste, sex or any one of such grounds, be subject to any disability, liability, restriction or condition with regard to access to shops, public restaurants, hotels, places of public entertainment and places of public worship of his own religion.

2) National Action Plan for the Protection and Promotion of Human Rights 2017-2021

National Action Plan for the Protection and Promotion of Human Rights 2017-2021 is the latest national plan regarding to gender equality. Chapter 3 of the Plan covers "Rights for Women" and sets the goals, objectives, activities, responsible agencies time frame and its performance indicator. As for public transportation, an activity "Invest in public transport to ensure safe and regular services for working women" is stipulated to achieve one of the goals "Promotion of women's economic rights and independence, including access to employment".

3) Policy Framework and National Plan of Action to address Sexual and Gender-based Violence (SGBV) 2016-2020

Policy Framework and National Plan of Action to address Sexual and Gender-based Violence (SGBV) 2016-2020 compiled by the Ministry of Women and Child Affairs with the technical assistance of United Nations Development Program (UNDP) was approved by the Cabinet on 7th June 2016. The Policy Framework includes sector plan for child affairs, disaster management, economic development and employment, education, empowerment and prevention, foreign employment, health, justice and law reform, and media. Even though public transportation is not an independent sector covered in the Policy Framework, securing the safe and affordable public transportation prevails as a cross-cutting issue. For example, issues in the economic development and employment sector mention sexual harassment occurs in workplaces, public transport and other public space, and it is not properly reported due to social stigma and being afraid of revenge. Specifically, in the sector of empowerment and prevention, there is a specific strategy and actions regarding to public transport.

Table 4.13.3 Strategy and its Actions to Address Sexual Harassment in the Public Transport (extracted)

Strategy **5.3. Promote a policy response and implement mechanisms to address sexual harassment in public transport and ensure quality transport services**
5.3.1. Initiate a policy dialogue with the Ministry of Transport to address sexual harassment in all modes of transport (bus, train, three wheeler, staff vehicles etc.) and develop guidelines 5.3.2 Collaborate with relevant stakeholders for effective implementation of the policy guideline 5.3.3 Create awareness among the vehicle owners and operators (drivers, conductors, school transport) of public and private transport services on the guidelines 5.3.4 Create public awareness on the key aspects of the guideline to encourage public engagement 5.3.5 Promote a public transport hotline to receive complaints on SGBV and to make the required referrals

Source: Policy Framework and National Plan of Action to address Sexual and Gender-based Violence (SGBV) 2016-2020

4) Statistics for Gender Mainstreaming

According to the UNDP's Human Development Index (HDI) in 2016, Sri Lanka was rated 0.766 and ranked as 73rd of 188 countries while Inequality-adjusted HDI (IHDI) was rated 0.678 and 65th of 188 countries. The difference between HDI and IHDI is lower than other South Asian countries such as India, Bangladesh, Nepal, and Pakistan[15]. That indicates gender inequality is smaller than other neighboring countries, yet economic status and political participation remains to be coped.

[15] While the difference in Sri Lanka is 11.6, that of India is 27.2, Bhutan is 29.4, Nepal is 27.0, and Pakistan is 30.9. (http://hdr.undp.org/en/composite/IHDI : accessed on Dec.4th December, 2017)

Department of Census and Statistics compiled gender dis-aggregated census called "The Sri Lankan Women Partner in Progress" in 2014. The census covers population, education, health and nutrition, contribution to economy, public life, special concerns. As mentioned above, major challenges to achieve gender equalities in Sri Lanka are labor force participation (male 74.9%, female 35.6%) and political participation. As for political participation, women are represented at the helm of the administrative hierarchy within the country as Ministry Secretaries in 2014 (20%). Women's participation in legislature has remained very low and women representation in parliament has always been and still is below 10 percent.

(2) Current conditions and issues on gender in public transportation

Even though there is no detailed statistics available in this specific sector, the major issues regarding to women in public transportation in Sri Lanka are sexual harassment in the crowed vehicles and minor offenses such as pick pockets since women are more likely to be the target of such offences. A survey introduced in a report of the World Bank[16] indicated that more than 80 per cent of the women and girls in Sri Lanka experience sexual harassment while using public transportation. The report also points out that unsafe transportation is deterrence for female population to enter labor force whose rate is approximately half compared to that of male. Extremely crowded vehicle, unavailability of escalator and elevator, high and wide gap between platform and vehicle can be a major deterrence of using public transportation especially for women in later stage of pregnancy.

(3) Gender mainstreaming projects by other donors

Among infrastructure projects implemented by donors, ADB implemented several projects whose components include gender mainstreaming. For example, the Improving Connectivity to Support Livelihoods and Gender Equality Project supports the rehabilitation and maintenance of the rural access roads by utilizing the female labor force to generate the income and focuses on the transport that improves the daily communication of women. The project recognized the difference mode and purpose of transportation by male and female, and considered target route to equally benefit both male and female.

ADB also compiled a report to introduce the methodology of gender assessment, implementation of the loan projects with gender consideration in Sri Lanka. The report introduces the following projects.

- North East Coastal Community Development Project
- Secondary Towns and Rural Community-Based Water Supply and Sanitation Project
- North East Community Restoration and Development Project-II)
- Tsunami- Affected Areas Rebuilding Project

(4) Suggested gender consideration for the Project of JICA-LRT

The Survey Team recognizes the necessity to consider the situation that women are in disadvantaged circumstance in terms of safety and mobility especially for pregnant women. Due to the limitation of the number of train cars of the JICA-LRT, it is not technically feasible to introduce women-only train car in the Project. As for the safety inside the train car, there is suggestion to introduce the priority seats and spaces inside the train car for needy passengers. In consideration to the mobility of pregnant women, pregnant women were invited to the Workshop toward Accessible JICA-LRT system to check the usability of the station facilities.

[16] Getting to Work "Unlocking Women's Potential in Sri Lanka's Labor Force", World Bank (2017)

Considering the above-mentioned situation, safe working environment for women should be secured during the construction period. For example, securing the separate rest rooms, awareness raising activities for the sexual harassment for the construction workers and creation of proper employment opportunities for women are desirable to tackle current gender issues in Sri Lanka.

It is also indispensable to secure safe environment for women after the operation of the JICA-LRT. The safety measures can be training for employees of the stations, installation of a hotline for the gender-based violence, utilization of mass media for the awareness raising, create posters in the station and vehicles.

4.13.3 The Workshop toward Accessible LRT System

The accessibility of the JICA-LRT is emphasized to all beneficiaries such as pregnant women, women with small children, elderly persons, and PwD. The design accessible to such population is beneficial for all passengers such as passengers with large luggage. By introducing the example of Japan and other countries, the workshop pursues the station design accessible to all users.

JICA promotes the idea of "Mainstreaming disability" which aims to include PwD in the development process of infrastructure as well as gender mainstreaming. Under the ideas, the Survey involves PwD and women in the design stage to directly reflect their opinions.

(1) Overview of the Workshop

The workshop was a consulting process with preferable parameters of design standard for barrier-free facilities such as platform, ticketing gate and steps for PwD, pregnant women and elders in the workshop. The workshop with the model of the station facilities was held with the participants of PwD, women, pregnant women, elderly persons to understand their needs and preferable size for the JICA-LRT facilities. The contents of the workshop were described as follows:

1) Objective of the Workshop

The objective of the workshop is to understand the needs of expected users who needs special cares to be barrier-free station areas in the new LRT system and to raise the awareness of counterpart agencies regarding to the barrier free design. Throughout the communication with the party organizations, it is designed to mutually understand the difficulties relating to the mobility of PwD by experiencing the limitation of movement. It was expected to formulate the action plan by the group discussion with various stakeholders.

Also trial of the actual size of the station facilities can verify the usability of major facilities such as the JICA-LRT station buildings to be constructed in the future (ticket gates, elevators, ticket vending machines, platform, and handrail) and usability of the dimensions.

2) Participants of the Workshop

The participant of the workshop is shown in Table 4.13.4.

Table 4.13.4 Participants of the Workshop

<table>
<tr><th rowspan="1">Stakeholders</th><th>Government officials</th></tr>
<tr><td rowspan="3">・Development with Disabled Network
・Sri Lanka Federation of the Visually Handicapped
・Mobility Handicapped Technician Association Sri Lanka
・Sri Lanka Council for Blind
・Sri Lanka Foundation for Disabled (SLFD)
・DAISY Lanka Foundation
・Sri Lanka Spiral Cord Network
・Janathakshan
・Disability Organization Joint Front</td><td>・MMWD
・Ministry of Social Empowerment and Welfare
・Ministry of Women and Child Affairs
・UDA
・Sri Lanka Police</td></tr>
<tr><td>Expected passengers</td></tr>
<tr><td>・Pregnant women
・Elderly persons
・PwD and those who are supporting the going out (Visually impaired, physically impaired using wheelchair and staff, hearing impaired)</td></tr>
</table>

Source: Survey Team

3) Program of the Workshop

The workshop was conducted as a two-day program. The objective of the first day was to understand the barrier-free transportation in Japan and current challenges of the public transportation in Sri Lanka.

Foundation for Promoting Personal Mobility and Ecological Transportation (ECOMO Foundation) made two presentations about explanation of barrier-free concepts, its history of development, and practices of barrier-free transportation in Japan as well as examples of human resource development activities. These presentations enabled participants to have general understanding of disability and barrier-free and more concrete examples of what to be achieved in Sri Lanka. Group discussion followed after these presentations with different topics toward accessible LRT system in Sri Lanka. Each group presented the result of the group discussion.

After having understanding of barrier-free/accessible transportation from the first day's program, the second day, all participants had opportunities to learn the actual challenges for PwD to use public transportation. In order to verify the usability of barrier-free facilities (ticket vending machine, ticket gate, handrail, elevator, platform) at JICA-LRT station, disabled participants and participants without disability using supporting tools (wheel chair, crutches, eyes mask, elderly experience kits) tried the models of actual size of the station facilities and gave their specific comments and suggestions on each item.

1st day, September 6, 2017 (Wednesday)

Theme: Introduction of the Japanese Barrier-free activities

Time	Item	Lecturers
8:30-9:00	Registration	
9:00-9:20	Opening Remarks Ice Breaking	Mr. H.M.J.J Herath MMWD
9:20-9:30	Introduction of the JICA-LRT Project	Mr. H.M.J.J Herath MMWD
9:30-10:00	Understanding disability	Mr. Atsushi Matsubara ECOMO-foundation
10:00-10:30	Effort for barrier-free transportation in Japan	Ms. Keiko Takeshima ECOMO-foundation
10:30-10:40	Coffee Break	
10:40-10:55	Introduction of the concept of station design	Mr. Yoshihisa Asada JICA Survey Team

Time	Item	Lecturers
10:55-11:25	Group Discussion (Topic: Issues on barrier-free in Sri Lanka and Action Plan to solve the issues)	All Participants
11:25-11:50	Presentation on the result of the Group Discussion	All Participants
11:50-12:00	Closing Remarks	Mr. H.M.J.J Herath MMWD

Source: Survey Team

2nd day, September 7, 2017 (Thursday)

Theme: Needs for accessible JICA-LRT Station

Time	Item	Lecturers
8:30-9:00	Registration	
9:00-9:20	Opening remarks	Mr. Chaminda Ariyasada MMWD
9:20-9:40	Challenges to use public transportation	Mr. Nishantha Kumara Mr. C. Siriwardena
9:40-10:00	Preparation and explanation of the assessment of the accessible route for disabled persons	Facilitators: Ecomo-foundation, JICA Survey Team
10:00-11:00	Needs/evaluation on sizes of facilities for JICA-LRT station for all (Target: ticket wicket /ticketing machine / handrail/ elevator/ slope/platform)	
11:00-11:10	Coffee Break	
11:10-10:50	Wrap up of the assessment on route (Mutual understanding of barriers)	All Participants
11:50-12:00	Wrap up and closing remarks	Mr. Chaminda Ariyasada MMWD

Source: Survey Team

The Survey Team arranged necessary reasonable accommodations since the participants of the workshop included visually impaired persons, hearing impaired persons and wheelchair users. In order to assure the physical and information accessibility for the participants, following reasonable accommodations were prepared during and after the workshop.

- The venue of the workshop was accessible by elevator. Eventually, the venue was the same building as Ministry of Social Welfare, so a lot of participants especially visually impaired persons could arrive at the venue by themselves because they occasionally visit the building.
- The workshop was held with sign language translation. In Sri Lanka, Ministry of Social Welfare employs three sign language translators who can provide translation services.
- The project compiled a DVD of the workshop which includes the proceeding of the workshop, movie of the lecture with sign language translation and DAISY version of the proceeding so that every participant could access the proceeding and lecture of the workshop.

(2) Result of the Workshop

The result of the workshop was compiled as the proceeding of the workshop. For the detailed contents, please refer to Appendix 10 Proceeding of the workshop.

Throughout the implementation of the workshop, the Sri Lankan side understood the importance of actual trial of the facilities and the difficulties of PwD. Height and width of the facilities will be considered based on the result of the workshop. The Project also consider the station facilities raised by the participants such as proper arrangement of the guiding blocs, audio announcement of the destination, understandable signature, help desk and button and so on. Participants commented that a certain number of visually impaired persons cannot read braille especially for those who lost the sight in the middle of their lives. Audio information is essential as well as braille when providing necessary information in the station and vehicle.

Participants also commented that it is the first opportunity for Sri Lanka to conduct such a workshop, and this should be a standard for other infrastructure development projects as a good example. Throughout the implementation of the workshop, working relationship with the government officials and party organizations has been established. This relationship is invaluable to promote accessible transportation during the detailed design and construction phase.

The summary and finding of each facility examined in the workshop is shown below.

a. Ticket vending machine

Trial of the ticket vending machine was conducted to check the reach of the participants using the same-size model of "Disabled Persons (Accessibility) Regulations No1, 2006". Although the coin slot of the vending machine is set as 1,300mm, some participants could not reach the height. A participant also pointed out to consider the persons with visually impaired by introducing tactile marking or audio output.

b. Ticket gate

The trial examined the usability of the height of the gate between 850mm and 950mm and width of the ticket gate between 900mm and 1,000mm. For the height of the ticket gate, majority of the participants answered that 850mm is more comfortable. For the width between the gates, participants with disability commented 900mm is enough, but for those who tried supporting equipment for the first time commented 1000mm is comfortable and 900mm is narrow for those who are not used to using the supporting equipment.

c. Handrail

The model handrail was designed based on the Japanese barrier-free guideline which stipulates that handrails to be two levels and their heights are 850mm and 650mm. Both heights have preference for certain participants and no one answered both heights were not comfortable. That means necessity of two levels is verified and the Japanese standard is also applicable to Sri Lankan participants including PwD.

d. Elevator

For the trial of the elevator, the Survey Team formed the actual size of the elevator based on the Japanese standard. One of the significant characteristics is that the elevator has two vertically located doors. Most participants commented the size is agreeable yet there is a comment that the size should be large enough to accommodate more than four persons. This type of elevator was not introduced in Sri Lanka, so this would be unfamiliar with the participant.

e. Platform

The width of the trial of the platform was designed as 3,000mm and installed model elevator and chairs to check the movability of the participants by crossing each other with different supporting equipment. In result, no specific trouble and inconvenience was observed during the trial.

4.14 Assessment of GHG Emissions

4.14.1 Background

In the Paris Agreement, the Government of Sri Lanka submitted the First Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat in November 2016.

Sri Lanka's NDCs had set the year of 2010 as a base year, and from 2021 to 2030 as a target period. For the Business-As-Usual (BAU) scenario by 2030, NDCs for mitigation intends to implement a minimum greenhouse gas (GHG) emissions reduction target of 20% in the energy sector (4% unconditionally and 16% conditionally), and of 10% in other sectors such as transport, industry, forests and waste) (3% unconditionally and 7% conditionally).

The NDCs for mitigation related to transportation sector are shown in

Table 4.14.1 below.

Table 4.14.1 Mitigation Actions List for Transport Sector

Sector	Mitigation Action
Transport	Establishment of energy efficient and environmentally sustainable transport systems by 2030
	Upgrade of Fuel Quality Standards (FQS) to reduce harmful emissions
	Reduce unproductive transport systems from current usage
	Shift passengers from private to public transport modes
	Enhance the efficiency and quality of public transport modes
	Reduction of GHG emissions in the maritime sector
	Gazette new emission standards to reduce GHG emissions
	Encourage and introduce low emission vehicles such as electric and hybrid
	Reduce traffic congestion in order to reduce GHG emission
	Reduction of GHG emissions in the aviation sector
	Establishment of a database management system for monitoring NDCs of transport sector

Source: INDC by Sri Lanka

The JICA-LRT directly contributes to the mitigation action of "Establishment of energy efficient and environmentally sustainable transport systems by 2030", and indirectly contributes to others.

In order to implement the JICA-LRT as a NDC, identification of an internationally acceptable and nationally executable Monitoring, Reporting, and Verification (MRV) system is needed to track the GHG emission reduction targets of the JICA-LRT. Then, the progress of GHG emission reduction is monitored and reported at the national as well as international level.

In this Survey, the GHG emission reduction of the JICA-LRT is estimated using the JICA Climate-FIT (2011, JICA) method, which is referred to the internationally accepted CDM methodology of Mass Rapid Transit Project: ACM0016.

4.14.2 Approach and Methodology

(1) Approach

In the implementation of JICA-LRT, GHG emissions are increased/decreased by the following activities in comparing with the case when JICA-LRT is not implemented:

- Construction Phase:
  - Carbon loss from disturbance on grassland by Depo construction
- Operation Phase:
  - Decrease of fossil fuel consumption by modal shift of passenger from existing transportation modes (e.g. buses, private car, taxi, motorbike) to JICA-LRT
  - Increase of electricity consumption in the operation of JICA-LRT

In this assessment, GHG reduction is finally calculated using GHG emissions estimated for each activity.

(2) Target Year

For the operation phase, the target year for this assessment is 2035.

(3) Methodology of GHG Emissions Estimation

The methodology to estimate GHG emissions is mainly based on JICA Climate-FIT (2011, JICA).

1) Construction Phase:

Carbon loss from disturbance on grassland by Depot construction is estimated by multiplying the total biomass, including above and below ground biomass in Depot construction area, and the carbon fraction value to convert dry matter to carbon.

$C_{LB} = B_{Total} \times A \times CF \times 44/12$

$B_{Total} = B_{AG} + B_{BG}$

$B_{BG} = B_{AG} \times R$

C_{LB} = Carbon stocks in living biomass in grassland (t-CO_2e/y)

A = land area of organic soils (ha)

CF = carbon fraction of dry matter (t-C/t-dm) (default = 0.5, IPCC GPG-LULUCF)

B_{Total} = total biomass, including above- and belowground (t-dm/ha)

B_{AG} = aboveground biomass (t-dm/ha)

B_{BG} = belowground biomass (t-dm/ha)

R = root-to-shoot ratio

2) Operation Phase:

The emissions reduction from the implementation of the JICA-LRT is determined as the difference between the GHG emission of baseline activity (existing mode of transportation, e.g. buses, private car, taxi, motorbike) and of project activity (e.g. LRT.).

$ER_y = BE_y - PE_y$

ER_y : GHG emission reduction through the project in year y (t-CO_2e/y)

BE_y : GHG emission from the baseline activity in year y (t-CO_2e/y)

PE_y : GHG emission from the project activity in year y (t-CO_2e/y)

a) Calculation of Baseline Emissions

Baseline GHG emissions are calculated by multiplying the number of passengers transported by JICA-LRT, the average trip distance of passenger by JICA-LRT, and the share of passengers by transport mode in case of the absence of JICA-LRT and CO_2 emission factor by transport mode.

$$BE_y = \sum_i \left(BPKM_y \times MS_{i,y} \times EF_{PKM,i} \right) = \sum_i \left(P_y \times BTDP_y \times MS_{i,y} \times EF_{PKM,i} \right)$$

$BPKM_y$: Passenger transportation volume/activity by the project in year y (passenger-km/y)

P_y : Number of passengers transported by the project in year y (passenger/y)

$BTDP_y$: Average trip distance of the passenger of the project activity in year y (km)

$MS_{i,y}$: Share of passengers by transport mode i in the baseline activity in year y (%)

$EF_{PKM,i}$: CO_2 emission factor per passenger kilometre for transport mode i (t-CO_2e /passenger-km)

b) Calculation of Project Emissions

This is estimated by multiplying annual electricity consumption associated with the operation of the JICA-LRT and the CO_2 emission factor of the electricity grid.

$$PE_y = EC_{PJ,y} \times EF_{elec}$$

$ECP_{J,y}$: Electricity consumption associated with the operation of the JICA-LRT in year y (MWh/y)

EF_{elec}: CO_2 emission factor of the electricity grid (t-CO_2e /MWh)

(4) Input data

1) Construction Phase:

Parameter	Description		Value	Unit	Source
A	Land area of organic soils		14.8	ha	JICA team
B_{AG}	Above ground biomass	Tropical moist & wet	6.2	t-dm/ha	Table 3.4.2, IPCC GPG-LULUCF
R	Root-to-shoot ratio	Tropical moist & wet	1.6		Table 3.4.3, IPCC GPG-LULUCF
CF	Carbon fraction of dry matter	Default value	0.5	t-C/t-dm	IPCC GPG-LULUCF

2) Operation Phase for 2035:

Parameter	Description		Value	Unit	Source
P_y	Number of passengers of the project activity in year y		181,676,560	passenger/year	=497,744 passenger/day(in yeas 2035) * 365 JICA team estimated
$BPKM_y$	Passenger transportation volume/activity by the project in year y		1,013,755,205	passenger-km/y	JICA team estimated
		Car	587,978,019	passenger-km/y	JICA team estimated using share of passengers by transport mode
		Motorcycle	152,063,281	passenger-km/y	
		3 Wheeler	101,375,520	passenger-km/y	
		Bus	172,338,385	passenger-km/y	
$EF_{PKM,i}$	CO_2 emission factor per passenger kilometre for transport mode i	Car	0.0000871	tCO_2/ passenger-km	JICA team estimated based on data of vehicle fuel economy shown in Note 1 and Note 2. EF of Car is estimated using the share of new registered vehicle number which is petro car(49.8%), hybrid car(46.1%) and diesel car(4.1%) based on 3 year data of 2014 – 2016.
		Motorcycle	0.0001004	tCO_2/ passenger-km	
		3 Wheeler	0.0001067	tCO_2 /passenger-km	
		Bus	0.0000257	tCO_2/ passenger-km	
$BTDP_y$	Average trip distance of passenger of the project in year y		5.58	km	JICA team estimated
$MS_{i,y}$	Share of passengers by transport mode i in the baseline scenario in year y	Car	58	%	JICA team estimated
		Motorcycle	15	%	
		3 Wheeler	10	%	
		Bus	17	%	
$EC_{PJ,y}$	Annual electricity consumption associated with the operation of the project in year y		35,852	MWh/year	In 2035 JICA team estimated
EF_{elec}	CO_2 emission factor of the electricity grid		0.7758	tCO_2/MWh	Averaged value for 5 years (from year 2011 to 2015) of Combined Margin for 2nd and 3rd period , from SLSEA in Sri Lanka, Note 3

Note 1: Slide 13 of "Future Emissions Standards and Fuel Quality Roadmap for Sri Lanka"(Thusitha Sugathapala, Director General, Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 28th April 2011)

Note 2: Slide 8 of "Role of Energy Efficiency in the Transport Sector NDCs of Sri Lanka"(Thusitha Sugathapala, Department of Mechanical Engineering, University of Moratuwa, 06th June 2017)

Note 3: Values of combined margin of 5 years (year 2011, 2012, 2013, 2014, 2015) are respectively 0.7514, 0.7508, 0.7142, 0.7352, 0.9274 tCO_2/MWh. As value of year 2015 is especially higher than values of other years and it might be unique data, JICA team adopted 5 year averaged data.

4.14.3 Estimated Results

In the construction phase, carbon loss from disturbance on grassland by Depot construction is estimated to be 436.8 t-CO_2e. In the operation phase, CO_2 reduction in year 2035 is estimated to be 53,929 t-CO_2e/y.

The detailed calculation process is shown below.

1) Construction Phase

Carbon loss from disturbance on grassland by Depot construction:

436.8 t-CO_2e = 16.1t-dm/ha×14.8ha×0.5 t-C/t-dm×44/12

Note: B_{Total} = 16.1 t-dm/ha = 6.2 + 6.2×1.6

2) Operation Phase for 2035

a) Baseline Emission

Car:	51,233 t-CO_2e/y = 587,978,019 pax.-km/y×0.0000871 t-CO_2e /pax.-km
Motorcycle:	15,266t-CO_2e/y=152,063,281pax.-km/y×0.0001004 t-CO_2e /pax.-km
3 Wheeler:	10,815t-CO_2e/y=101,375,520pax.-km/y×0.0001067 t-CO_2e /pax.-km
Bus:	4,428t-CO_2e/y = 172,338,385 pax.-km/y×0.0000257 t-CO_2e /pax.-km
Total:	81,743 t-CO_2e/y

b) Project Emissions

27,814 t-CO_2e/y = 35,852 MWh/y × 0.7758 t-CO_2e /MWh

c) Emission Reduction:

53,929 t-CO_2e/y = 81,743 t-CO_2e/y – 27,814 t-CO_2e/y

4.14.4 Recommendation

As mentioned above, since the transportation sector contributes the largest share of GHG of 27% in total emissions (SNC 2011), JICA-LRT is considered as the one of the contributors to reduce GHG. In addition, because the Government of Sri Lanka submitted NDC submitted to the UNFCCC Secretariat in 2016, the MRV system of GHG mitigation is expected to be developed for the JICA-LRT and its related projects.

Therefore, under the Project, the following activities are recommended to develop a MRV system in the Ministry of Megapolis and Western Development:

- Establishment of Coordination Team for MRV system development in JICA-LRT and its related projects. Coordination Team consists of department of environmental of MMWD, PMU and other related project such as feeder bus services.
- Collection and reviewing of relevant documents and information
- Estimation of GHG emission reduction in implementation of JICA-LRT and its related project with the development of GHG calculation methodology
- Study of MRV system with data collection system
- Establishment of MRV implementing structure
- Report preparation of MRV system in JICA-LRT and its related projects
- Organization of workshop to share experiences related to MRV system and latest information related to climate change
- Monitor the situation of construction work related to carbon loss in Depot site in construction stage
- Conduct the MRV in JICA-LRT and its related projects twice in operation stage
- Provide the MRV report with GHG reduction calculation

Chapter 5 Cost Estimation

5.1 Preliminary Cost Estimation

[Classified]

5.1.1 Project Summary for Cost Estimation

The project summary for the cost estimation is shown in Table 5.1.1 below. The opening year of operation is set in 2025.

Table 5.1.1 Project Summary

Line	Contents
Main Line	Fort Station – IT Park Station (connecting to Depot) Total length 17.0 km, 16 stations
Depot and Workshop	Total area: 16.0 ha (Reinforced concrete elevated deck area: 11.5 ha)

Source: Survey Team

5.1.2 Conditions for Project Cost Estimation

[Classified]

5.1.3 Construction Base Cost

[Classified]

5.1.4 Consulting Services Cost

[Classified]

5.1.5 Land Acquisition Cost

[Classified]

5.1.6 Total Project Cost

[Classified]

5.2 Adequacy of the Estimated Construction Cost

[Classified]

5.3 Procurement Policies and Plan for Materials and Equipment

[Classified]

5.4 STEP Applicability

[Classified]

5.5 Cost Reduction Measures

[Classified]