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Urban Railway Network Planning in the Greater Yangon, Myanmar

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Abstract: This paper aims at providing an overview on current situation and proposing a development plan of railway network by 2035 in the Greater Yangon, Republic of the Union of Myanmar. First, it briefly reviews actual conditions and performance of existing railway network in the area. Then, it applies a network analysis to confirm necessity on installation of new Mass Rapid Transit lines in order to support the development with multi-core structure of the area. Finally, a multi-aspect evaluation is implemented including spatial structure balance of urban area, accessibility to urban functions, connectivity in railway network, project cost and environmental and social impact. It concludes that introducing two new MRT lines along on North to South axis and East to West corridors are recommended.

Keywords: Yangon, Mass Rapid Transit, long-term planning

1. INTRODUCTION

Yangon City, with a population of about 5.1 million as of 2011 (JICA, 2013), the largest economic center of Myanmar, has been experiencing rapid urbanization and motorization along with the nation's economic growth. They put more pressure day by day on the existing transport infrastructure in Yangon City and its surrounding areas. Although the deteriorating urban traffic condition, represented by worsening traffic congestion, has become serious concerns socially, politically and environmentally, it has been rarely analyzed. Zhang *et al.* (2008) analyzed the potential demand of new public transit with stated preference data. Kato (2009) and Kato *et al.* (2011) examined the feasibility of introducing bus rapid transit system into Yangon with revealed preference data. However the data used in those studies were quite limited both in sample scale and in geographical coverage.

Under such circumstances, from May 2012 to March 2014, the Yangon Regional Government and the Japan International Cooperation Agency (JICA) implemented a project named "The project for Strategic Urban Development Plan of the Greater Yangon[1] (SUDP)" which produced a strategic urban development plan in March 2013. SUDP forecasted a rapid

[1] Greater Yangon: including Yangon City (784 km^2) and parts of the six neighboring townships of Kyauktan, Thanlyin, Hlegu, Hmawbi, Htantabin, and Twantay, which has a total area of approximately 1,500 km^2, and a population of 5.7 mil. as of 2013.

population growth in the area as shown in Table 1. By the year 2035, population of the Greater Yangon is expected to reach nearly 10 million, the population volume of a megacity in the world (JICA, 2014).

Table 1. Population forecast in the Greater Yangon in 2013, 2018, 2025 and 2035

			2013	2018	2025	2035
Night-time Population ('000)	Workers	Primary	58	58	58	58
		Secondary	219	263	350	562
		Tertiary	2,263	2,601	3,214	4,470
		Total Workers	2,540	2,921	3,622	5,089
	Student at Residence		1,164	1,303	1,532	1,938
	Others		2,013	2,212	2,462	2,685
	Total Night-time Population		5,716	6,437	7,615	9,712
Day-time Population ('000)	Employment	Primary	58	58	58	58
		Secondary	244	289	378	595
		Tertiary	2,263	2,610	3,242	4,547
		Total Employment	2,565	2,956	3,678	5,200
	Student at School places		1,164	1,303	1,532	1,938
	Others		2,013	2,212	2,462	2,685
	Total Day-time Population		5,741	6,472	7,672	9,823
Household Income ('000 Kyat/month)			240.6	340.5	522.2	954.7
Household Car Ownership Ratio (%)			11.6	16.8	23.2	32.3

Source: JICA (2014)

Following SUDP, from December 2012 to October 2014, the Yangon Regional Government and JICA carried out a project: "The Project for Comprehensive Urban Transport Plan of the Greater Yangon (YUTRA)" to prepare a comprehensive urban transport master plan in line with the above mentioned strategic urban development plan. It aims to provide efficient, safe, comfortable and environmentally friendly transport services to the people in the Greater Yangon in order to contribute to its balanced, inclusive and sustainable growth. The current issues of urban transport in Yangon, which are found from the YUTRA study, are summarized in Kojima *et al.* (2015).

This paper introduces a review of current transport conditions highlighting the railway and shows an analysis process of the railway network plan in the Greater Yangon. The paper is structured as follows. Section 2 presents current situation of railway network in the Greater Yangon. Then, Section 3 explains network plan options for railway network in the area. Section 4 discusses evaluation process and results on those network plan options. Finally, the achievements are summarized and outstanding issues are presented.

2. ISSUES IN THE CURRENT RAILWAY NETWORK IN THE GREATER YANGON

2.1 History of Railway Network Development in the Greater Yangon

Railway network in Yangon Region had been developed in three stages: the first stage was from late 19th century to 1910s, the second stage was from 1910s to 1988, and the third stage was from 1988 up to present, as showed in Figure 1 (JICA, 2013).

2.1.1 First stage: from the late 19th century to 1910s

In the late 19th century, two trunk lines, namely a part of Yangon-Pyay line and a part of Yangon-Toungoo line, were constructed in Yangon Region (see the left map of Figure 1). Yangon-Pyay line was constructed in 1877 as the first railway line in the country. The line was constructed for the purpose of transporting rice from Irrawaddy valley to the main port in Yangon. The alignment in Yangon Region passes along the left bank of Yangon River and Hlaing River. This was done to avoid topographical difficulties such as hilly areas, lakes, river crossings, etc. On the other hand, Yangon-Toungoo line, which is currently a part of Yangon-Mandalay line, was constructed in 1885 from the viewpoint of the strategic importance of accessibility to Upper Myanmar. The alignment in Yangon Region passes along the right bank of Puzundaung creek and Bago River for the same reason as the alignment of the Yangon-Pyay line. Initially, both lines were constructed as long distance railway lines. However, these railway lines now plays an important role not only as intercity transport, but also as urban transport modes for the city dwellers in Yangon, especially for low income people.

2.1.2 Second Stage: from 1910s to 1988

In 1911, a new single track railway line linking Malwagone with Mingalardon was constructed in order to ensure the logistics to/from the Mingalardon area which was the center for the army where many army personnel lived with their family and initially had poor access to the Central Business District (CBD) and Yangon port. It seems that the alignment was decided in terms of the ease of land acquisition due to the area being undeveloped at the time.

In 1959, the line linking Malwagone with Mingalardon was extended to Danyingone in order to complete the line as a circular railway, and Yangon Circular Railway was opened. In 1960, the track was doubled, and Yangon Circular Railway was completed (see the middle map of Figure 1). The alignment was decided for topographical reasons, easy land acquisition, and avoiding Yangon airport land.

2.1.3 Third Stage: from 1988 up to now

After 1988, Myanmar government has promoted the construction of new railway lines in the whole country in order to connect developed areas with undeveloped areas. 46% of total 5,844 km was constructed after 1988. Regarding the Yangon Region, a part of Thilawa Branch line from Toe Kyaung Galay Station to Ohk Pho Su Station was connected in 1993 in order to develop Thanlyin area which was separated from the center of Yangon city by Bago River and had many undeveloped areas. After that, the line was extended to Thilawa port in 2003 in order to transport cargo between Thilawa and areas further inland.

In the 21st century, Myanmar government expected that the number of university students will increase for future growth by establishing several universities at the outskirts of Yangon. As a travel mode for the students, Dagon University Branch Line and Eastern University Branch Line were constructed in 2006, and Computer University Branch Line was opened in 2007 (see the right map of Figure 1).

Consequently, railway network in the Greater Yangon is currently composed of eight lines, which include Yangon Circular Railway Line, Yangon-Mandalay Main Line and Yangon-Pyay Main Line as three main lines, and five branch lines, namely Thilawa Branch Line, Eastern University Branch Line, Dagon University Branch Line, Computer University Branch Line, and Yangon Port Freight Exclusive Branch Line, as shown in Figure 2 with a total length at 148.3km.

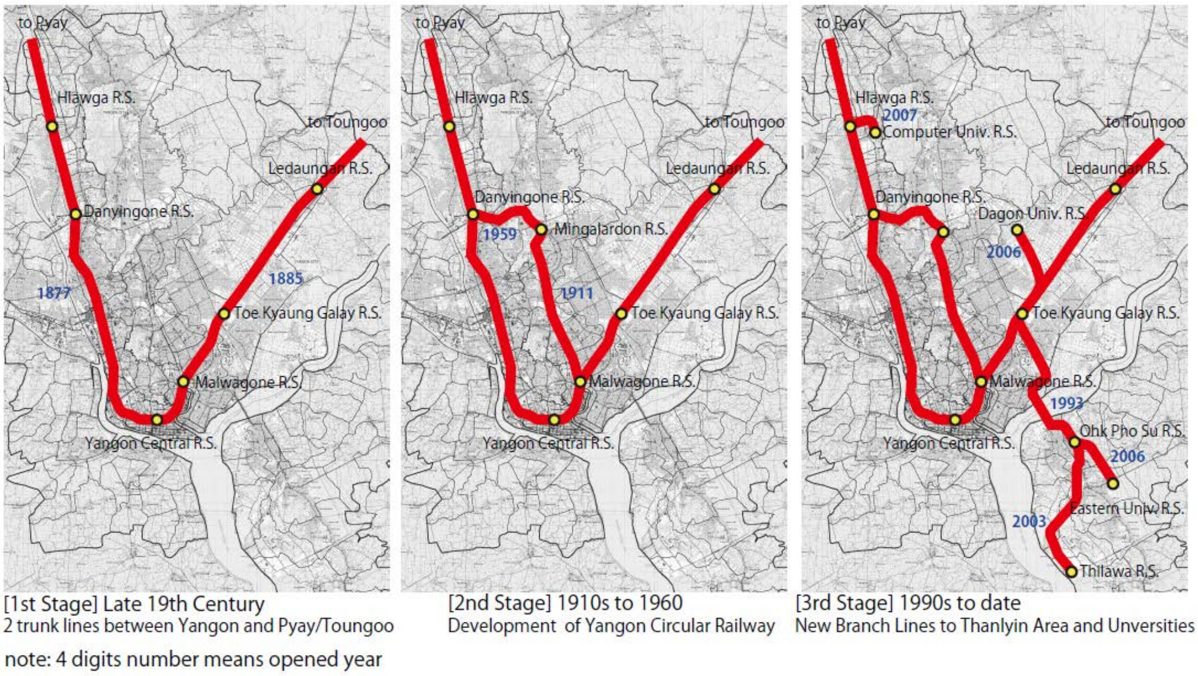


Figure 1. Chronological chart of railway network development in the Greater Yangon

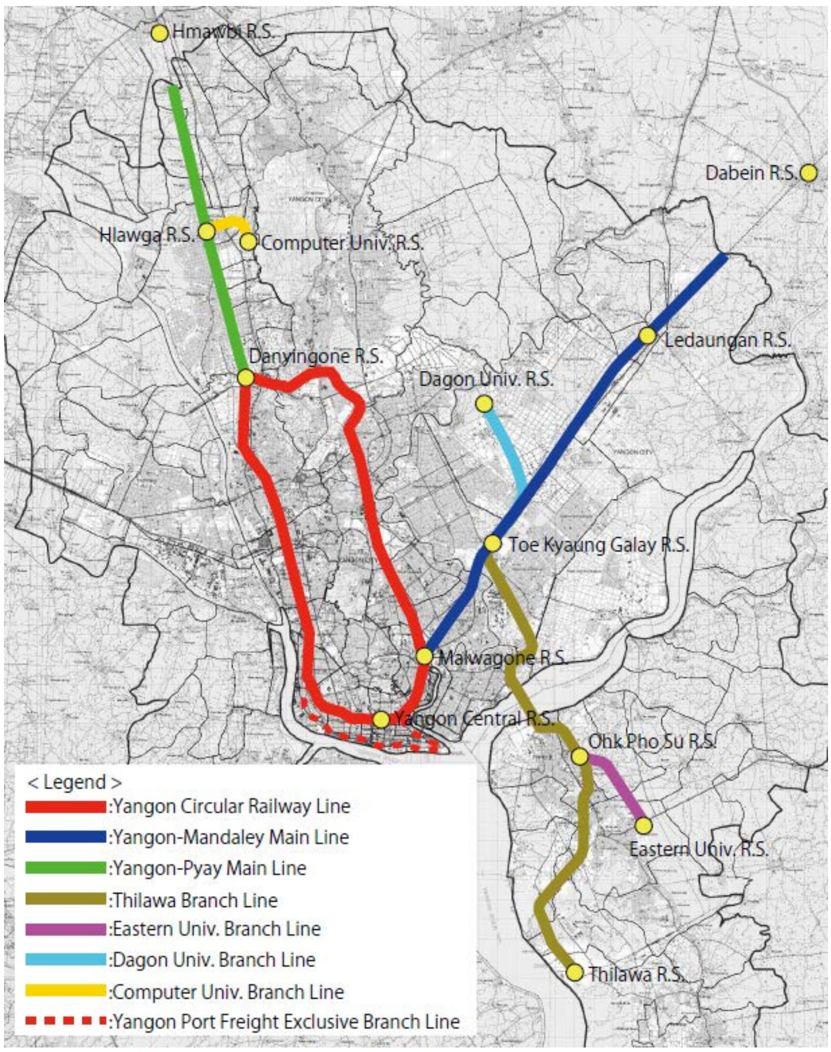


Figure 2. Current railway network in the Greater Yangon

2.2 Current railway lines in Yangon

Features of each line are summarized in Table 2. The Yangon Circular Railway Line is a closed circular line covers the central area of the city, has dimensions about 5 km in East-West direction and about 20 km in North-South direction. It is a 47.5 km length of full double-track, with a 3.6 km length section of double-double-track between Yangon station and Malwagone station. The line has 38 stations, mainly provides service to relatively low income earners and poor farmers who bring their cultivated products from the northern part of the city to sell in CBD. Daily train number on this line depends on section, varies from 14 trains to 102 trains per day.

Table 2. Features of current railway lines in the Greater Yangon

Route Name	Section	Length (km)	No. of Railway Station (R.S.)	Single track/ Double track	No. of Daily Operated Train	Remarks
Main Line						
Yangon Circular Railway Line	Whole Yangon Circular Railway	47.5 km	38	Double-double Track: (Yangon–Malwagone:3.6km) Double Track: (Remaining Section)	Yangon – Malwagone: 102 Malwagone – Paywatseikkone: 38 Paywatseikkone – Mingaladon: 34 Mingaladon – Danyingone:14 Danyingone – Insein: 54 Insein – Yangon: 79	
Yangon – Mandalay Main Line	Malwagone R.S. – a point between Ledaungan R.S. and Dabein R.S.	28.3 km	6	Double Track	Malwagone – Toe Kyaung Galay: 64 Toegyaunggalay – Ywarthagyi: 16	
Yangon – Pyay Main Line	Danyingone R.S.- Hlawga R.S.- a point between Hlawga R.S. and Hmawbi R.S.	20.1 km (10.5 km +9.6 km)	4	Double Track: (Yangon–Hlawga) Single Track: (Hlawga –Hmawbi)	Danyingone – Hlawkar: 40	
Branch Line						
Thilawa Branch Line	Toe Kyaung Galay R.S. – Ohk Pho Su R.S. – Thilawa R.S.	26.2 km	5	Single Track	Toe Kyaung Galay – Ohk Pho Su: 18 Ohk Pho Su – Thilawa: 4	
Eastern Univ. Branch Line	Ohk Pho Su R.S. – Eastern Univ. R.S.	5.4 km	1	Single Track	12	
Dagon Univ. Branch Line	Toe Kyaung Galay R.S. – Dagon Univ. R.S.	8.0 km	1	Single Track	18	
Computer Univ. Branch Line	Hlawga R.S. – Computer Univ. R.S.	2.9 km	1	Single Track	4	
Yangon Port Freight Exclusive Branch Line	Pazundaung R.S. – Botahtung Freight R.S. – Wadan Freight R.S. - Kyee Myin Daing R.S	9.9 km	2	Single Track	2 to 3 (irregular trains, Botahtaung Sta. / Dahnitaw Oil Sta. – Malwagone Sta.) 0 (No operation between Kyeemyindaing Sta. and Botahtaung Sta.)	No Passenger service. Freight train only.
Total		148.3 km (138.4 km for passenger line)	58 (56 for passenger station)		200	No. of R.S. is except Halts. R.S. + Halts =80 (78 for Pax.)

Source: “Traffic Data Yangon Circular Railway 2012 by MR”, interview to MR, and Google Earth

The Yangon-Mandalay Main Line is a part of an inter-city railway line linking Yangon city with Mandalay city, the second-largest city in Myanmar locates at 716 km north of Yangon. In the Greater Yangon, the section of Yangon-Mandalay Main Line only have 28.3 km length with 6 stations, start from Malwagone station to the cross point between the border line of Yangon Region with the railway line, i.e. a point between Ledaungan and Dabein Stations as shown in Figure 2. The section is double track, serving the operation of 16 or 64 trains a day, depend on section.

The Yangon-Pyay Main Line is also a part of an inter-city railway line, linking Yangon city with Pyay city, the principal town of Pyay Township in the Bago Region, located 260 km northwest of Yangon. In the Greater Yangon, the section of Yangon – Mandalay Main Line is 20.1 km length, consists of two parts. The first one is a double track line between Yangon and Hlawga Stations, and the second one is a single track line between Hlawga Station and the cross point between the border line of Yangon Region with the railway line, means a point between Hlawga and Hmawbi Stations. As of 2012, this section is operating 40 trains per day.

Among five branch line, the Thilawa Branch Line is the longest, with 26.2 km length and 5 stations. The line is single track, operates 4 trains or 18 trains a day depend on section.

Other three branch lines are lines connecting main lines with universities, having only one station which is the destination university. Thus, they are relatively short, with 2.9 km length in the Computer Univ. Branch Line, 5.4 km length in the Eastern Univ. Branch Line and 8.0km length in the Dagon Univ. Branch Line. All of the three lines are single track, serving 4 trains, 12 trains and 18 trains per day, respectively.

The only one freight railway line is 9.9 km length single track, with two end located at stations on the main lines, namely Pazundaung Station, which is close to Yangon Central Station, and Kyee Myin Daing Station, which locates at the west side of Yangon Central Station, and two mid-line stations. This line only serves two to three irregular trains per day.

2.3 Current Performance of Railway Network in the Greater Yangon

2.3.1 Railway system and service supply

Current railway system is generally in a substandard condition in the Greater Yangon. First, track condition is quite poor because: (1) relatively light, 37 kg/m rail, is used for even the trunk lines without sufficient maintenance thus the railhead is thoroughly worn out due to long duration of service but no replacement of rail; (2) insufficient ballast thickness under the sleeper causes accelerated roadbed deterioration; and (3) water stays on the tracks during rain due to the poor drainage condition, which leads to damage on roadbed and contaminates the ballast. Second, frequent troubles and malfunctions happen in the signal system due to its old system where shortcut circuit is easily caused by the water staying on the tracks. Telecommunications system is also old-fashioned such as walkie-talkie, telephone, etc. Third, all diesel locomotives and coaches are aging and deteriorated due to the insufficient maintenance. Particularly acceleration/deceleration performance of rolling stocks is quite poor due to locomotive traction type and it has a detrimental effect to the train operation frequency. Fourth, rail stations are not functional as key traffic connecting areas, due to unsatisfactory conditions of station plaza and poor ticketing system without connection with a local bus service, which is a major public transport mode in the area. It takes long time for boarding and alighting to/from trains because of low height platform. Additionally poor accessibility to station and no feeder service discourage commuters to use railway service. Additionally, the Yangon Circular Railway has 25 level crossings which are operated manually, taking long time and impairs the shortening of train operation interval.

Travel speed of railway service is quite low. The maximum speed is approximately

25-30km/h in the Yangon Circular Railway, Yangon-Mandalay Main Line and Yangon-Pyay Main Line in Yangon Region, which are the best maintained lines. Three hours are required to make a round trip of Yangon Circular Railway (47.5 km), which indicates that average speed is approximately 15km/h. The average speed in other suburban lines is 5-10km/h due to very substandard track conditions

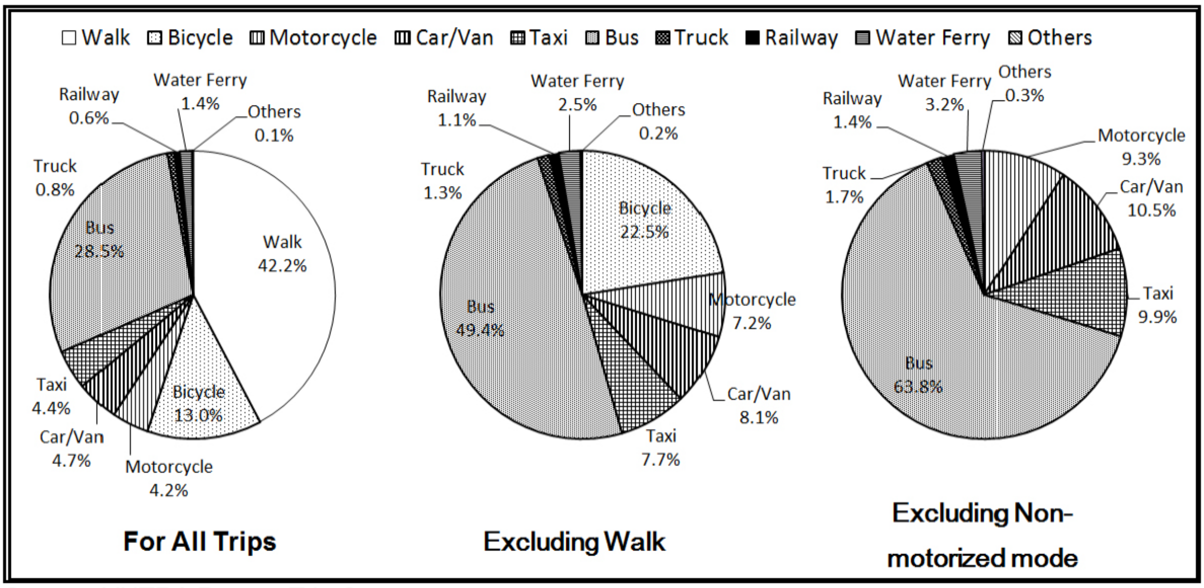
Many accidents also occurred on the Yangon Circular Railway. According to the accident record from January 2011 to November 2011 (Source: Myanmar Railways), 34 accidents were reported, which means one or two accidents per month occurred in average. The main reasons for high frequency of railway accidents are derailment due to poor maintenance of track, failure of rolling stock, signal, turnout, and carelessness of train drivers.

2.3.2 Railway demand

The person trip survey implemented in YUTRA (JICA, 2014) covering over 11,000 households, which accounts for 1.0% of total households, shows that about 11 million trips are made in a weekday in 2013. Excluding walk, about 6.5 million trips are made in a weekday. Modal share is summarized in Figure 3. It shows that the share of walk is remarkably high, 42.2% of the total trips. Excluding walk, bus has the largest share at 49.4 %, followed by bicycle (22.5 %), car/van (8.1%), taxi (7.7 %), motorcycle (7.2 %), and water ferry 2.5 %. The combined share of public transport (bus, taxi, railway and water ferry) is 60.7%, excluding walk, as high as in some developed countries. The so-called truck bus is one of the most popular public transport options for commuters in Yangon (Kato *et al.*, 2010). Since the motorcycle use is prohibited in CBD of Yangon City (Kojima et al., 2015), its modal share is low.

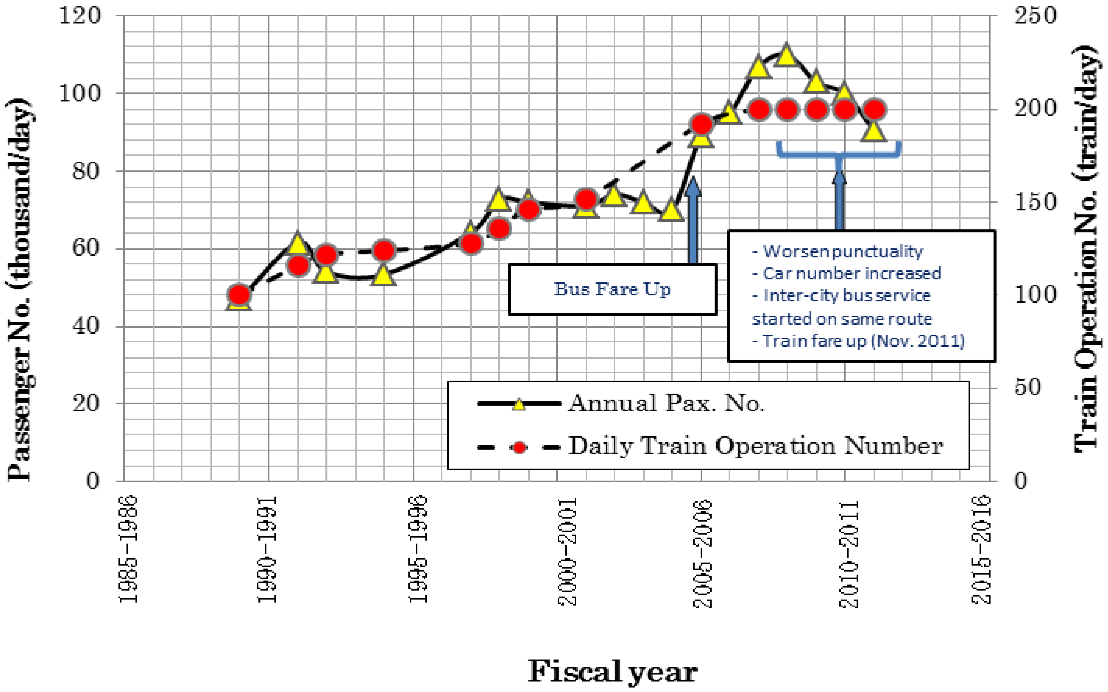
Railway has a share of only 1.1 % despite its relatively wide coverage network. Extreme low share of railway use could be attributed to poor passenger service, low accessibility to station, uncoordinated feeders service at station, many accidents, and dirtiness at stations and in trains.

Figure 4 shows the average daily ridership of Yangon Circular Railway and the Suburban Lines in 2011. They have 90,620 passengers per day while they operate 200 trains per day in average. It also indicates that the railway users had increased in general until late 2000s although there were some periods when the railway ridership shortly fell down. It should be noted that the railway ridership dropped drastically in the period of fiscal year 2009-2011, due to a series of factors as the worsening of punctuality due to poor maintenance, the increase of car supported by relaxation of import tax, the start of inter-city bus on competing road, and the increase of train fare in 2011.



Source: YUTRA Person Trip Survey

Figure 3. Modal share in the Greater Yangon, 2013



Source: Upgrading of Yangon Circular Railway Project: Facts About Yangon Circular Railways, 2011, Presentation Material by MR, and Traffic Data Yangon Circular Railway, 2012.

Figure 4. Changes in number of passengers and train operations of Yangon Circular railway and suburban lines

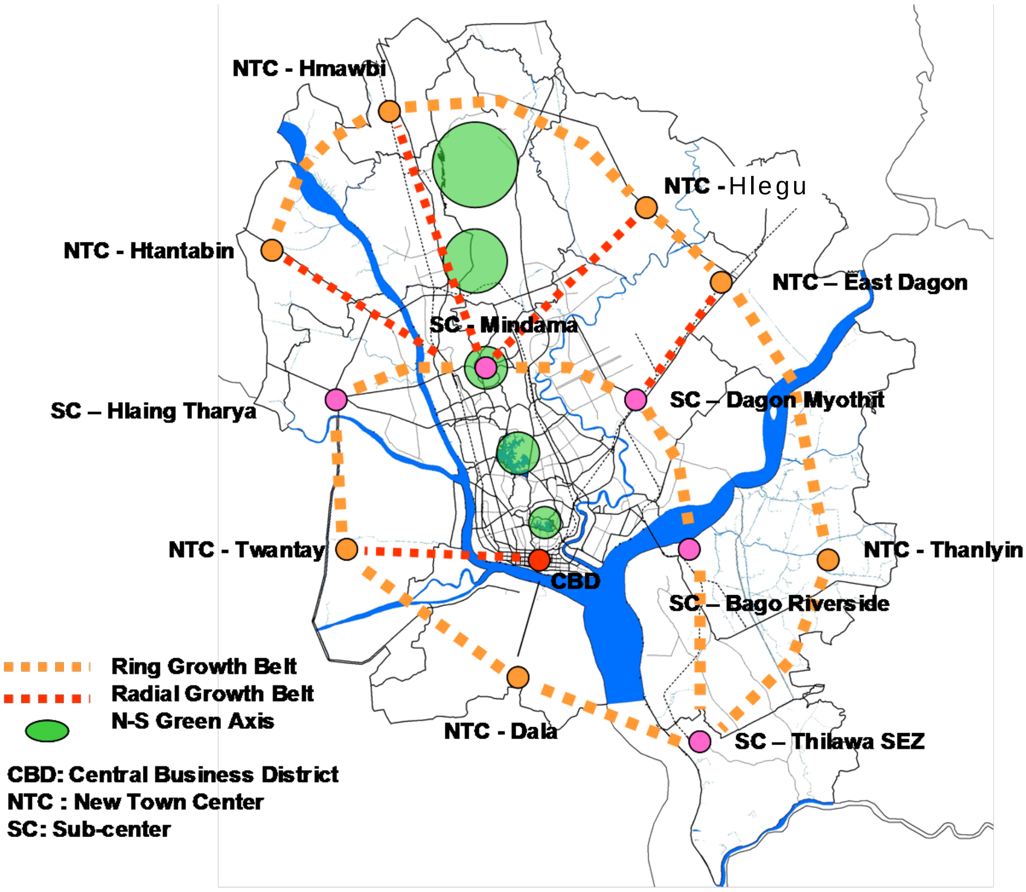
3. RAILWAY NETWORK PLAN IN YANGON

3.1 Urban Development Structure in the Future

The SUDP (JICA, 2013) proposed a multi centric and balanced development pattern as shown in Figure 5, namely “sub-centres with green isle system” as the spatial structure of the Greater

Yangon. It expects to contribute to reducing excessive traffic concentration to/from the existing CBD area. This pattern was officially approved by the Yangon Regional Government in May, 2013.

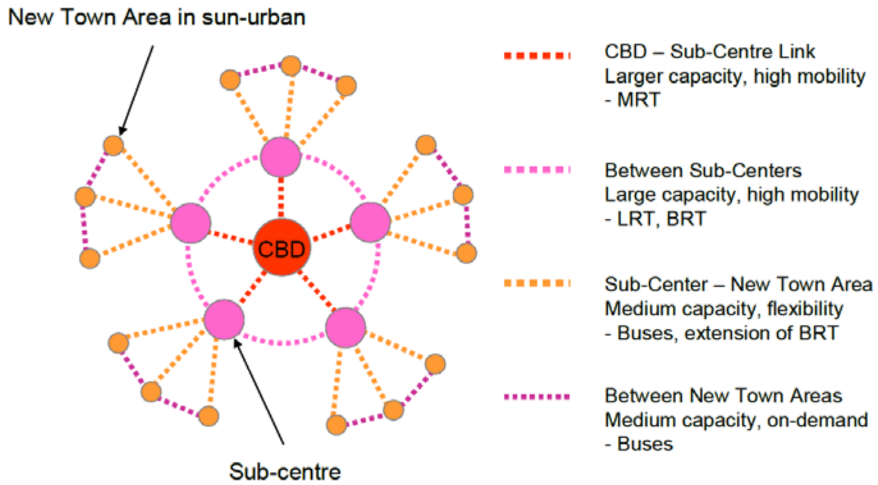
The SUDP recommended a hierarchical structure of centers including the primary center at the existing CBD; the secondary centers are Secondary CBDs or sub-centers (SC), namely, Mindama, Thilawa, Bago Riverside, Dagon Myothit, and Hlaing Tharya; and the tertiary centers are new town centers (NTC) located in suburban area, namely, Hlegu, Hmawbi, East Dagon, Thanlyin, Dala, Twantay, a006Ed Htantabin. Development scale of SCs is about 120ha for each except Thilawa sub-center, whose development area is 50 ha whereas that of NTCs is about 200 ha for each.



Source: SUDP (JICA, 2013)

Figure 5. Sub-centers with Green Isle System by SUDP

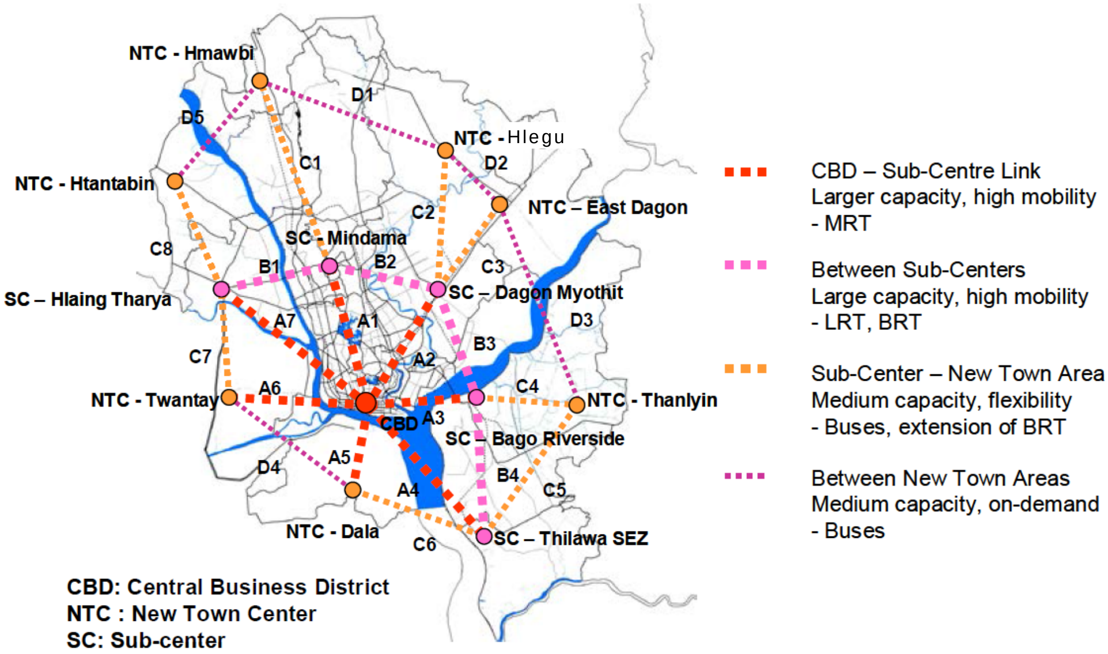
This suggests a hierarchical transport network to serve along each link in terms of capacity, speed, and modes. It should contain (1) links connecting CBD with SCs, which in general require large capacity, high speed, punctuality, etc. such as Mass Rapid Transit (MRT) as a preferred mode of transport; (2) links connecting SCs with SCs, which require medium capacity, high mobility and accessibility for circumference direction, etc. such as Light Rail Transit (LRT) and Bus Rapid Transit (BRT) on a ring road; and (3) links connecting SCs with NTCs and links connecting NTCs with NTCs, which require medium capacity, on-demand service, etc., such services can be provided by extension of BRT branch line, regular buses, and taxis. Figure 6 illustrates a concept of transport network under the given hierarchical urban structure.



Source: YUTRA Project Team

Figure 6. Theoretical framework of hierarchical center system and links

Figure 7 shows the hierarchical center system with corresponding links in the Greater Yangon proposed by SUDP (JICA, 2013). This proposed major network links connecting proposed centers including the existing road network and transit network. It includes also the transit lines in every link connecting centers in a hierarchical manner, which is supported by a hierarchical road network. It proposes that BRT should be served along an arterial road at higher level with six-lane or more with median, whereas it does not recommend BRT along a road at lower level such as with four-lane single carriageway. It also recommends that the Urban MRT (UMRT) should connect CBD with surrounding SCs, but it recommends further examination on the feasibility of its extension to NTCs and to strategic destinations such as an airport and a port area.



Source: YUTRA Project Team

Figure 7. Hierarchical center system with corresponding links proposed by SUDP

Current situation of each link is summarized in Table 3. Links between the CBD and its surrounding SCs or NTCs (A1, A2, A3, A4, A5, A6 and A7) are mainly supported by road transport, except the links with NTC-Twantay and NTC-Dala, where no road transport exists because there is no bridge to cross the Yangon River. The link with SC-Mindama has the largest capacity, with 12 lanes or road transport, equally allocated six lanes each on Pyay Road and Kaba Aye Pagoda Road. Road connection with SC-Thilawa SEZ has limited capacity with only two lanes through the Kyaik Khouk Pagoda Road. Two links to SC-Dagon Myothit and SC-Thilawa SEZ are additionally served by conventional railway lines.

Links between SCs (B1, B2, B3 and B4) are supported by four to six lanes of road. In addition, the link B4 between SC-Bago riverside and SC-Thilawa SEZ has conventional railway service. Also, many links between SCs and NTCs (C1, C2, C3, C4, C5, C6, C7 and C8) are supported by four to six lanes of road. Rarely, two of them are additionally supported by conventional railway (C1 and C3). However, the links C1, C6 and C7 have limited road capacity with only two lanes of road, or even no road connection because there is no bridge to cross the Yangon River. Note that the corridor between C1 and C2 is supported by Pyay road, a six-lane trunk road.

To compare with the above mentioned links, the links between NTCs (D1, D2, D3, D4 and D5) have relatively poorer condition with two or four lanes of road or no road connecting them (link D3 and D4). For the links D3 and D4, main transport linkage is through water transport.

Table 3. Current situation of links between centers, 2013

Link		Link between		Available Direct Network, 2013				
				Road	No of Lanes per direction	Myanma Railway	Water Transport	Major Road Links
CBD - Sub center Link	A1	CBD	SC-Mindama	○	12	×	×	Pyay Rd Kaba Aye Pagoda Rd.
	A2		SC-Dagon Myothit	○	4	○	×	No.2 Main Rd
	A3		SC-Bago Riverside	○	4	×	×	Yadanar Rd
	A4		SC-Thilawa SEZ	○	2	△	×	Kyaik Khouk Pagoda Rd
	A5		NTC-Dala	×	0	×	○	NA
	A6		NTC-Twantay	△	4	×	×	No.5 Main Rd Twantay Main Rd
	A7		SC-Hlaingtharyar	○	4	×	×	No.5 Main Rd
Link Between Sub-cebters	B1	SC-Hlaingtharyar	SC-Mindama	○	6	×	×	Lanthit Rd
	B2	SC-Mindama	SC-Dagon Myothit	○	4	×	×	Pin Lon Rd Thanthumar Rd
	B3	SC-Dagon Myothit	SC-Bago Riverside	○	4	×	×	Ayer Wun Rd
	B4	SC-Bago Riverside	SC-Thilawa SEZ	○	6	△	×	Dagon bridge Thanlyin bridge

Note: ○: available, △: availabale,but limited, ×: not available

Source: YUTRA Project Team

Table 3.(con’t) Current situation of links between centers, 2013

Sub-center and New Town Link	C1	NTC-Hmawbi	SC-Mindama	○	2	○	×	No.4 Main Rd
		Corridor inbetween C1 and C2		○	6	×	×	Pyay Rd
	C2	NTC-Hlegu	SC-Dagon Myothit	△	4	×	×	Min Yae Kyaw Swar Rd
	C3	NTC-East Dagon	SC-Dagon Myothit	○	4	○	×	No.2. Main Rd
	C4	NTC-Thanlyin	SC-Bago Riverside	○	4	×	×	Yangon Thilawar Rd
	C5	NTC-Thanlyin	SC-Thilawa SEZ	○	4	×	×	No.6 Main Rd
	C6	NTC-Dala	SC-Thilawa SEZ	×	0	×	×	-
	C7	NTC-Twantay	SC-Hlaingtharyar	△	2	×	×	Twantay Main Rd
	C8	NTC-Htantabin	SC-Hlaingtharyar	△	4	×	×	Amauk Pine University Rd
Link Between New Towns	D1	NTC-Hmawbi	NTC-Hlegu	△	4	×	×	No.7 Main Rd
	D2	NTC-Hlegu	NTC-East Dagon	△	4	×	×	No.7 Main Rd
	D3	NTC-East Dagon	NTC-Thanlyin	×	0	×	△	-
	D4	NTC-Dala	NTC-Twantay	×	0	×	△	-
	D5	NTC-Htantabin	NTC-Hmawbi	△	2	×	×	No.4 Main Rd

Note: ○: available, △: availabale,but limited, ×: not available
Source: YUTRA Project Team

3.2 Indicative Mass Transit Network in 2035

This study proposes an indicative mass transit network in 2035 following three steps: the first step is an estimation of future traffic volumes; the second step is an identification of public transport system using the estimated traffic volumes; and the third step is sketching an indicative public transport network incorporating physical constraints.

First, future traffic volumes of public transport links are analyzed. It assumes a zoning system where zone is equivalent to one or two district with an area of about 1-10 km^2 and a population of about 20,000-50,000 persons whereas it also assumes a simplified transport network as shown in Figure 7. Note that, based on modal share excluding walk explained in the section 2.3.2, it assumes that the share of public transport on each link is 60% of the total passenger demand. Table 4 summarizes the estimated traffic volumes in each public transport link.

Next, the public transport system is identified for each link: MRT, BRT/LRT and bus. It uses a simple criteria on the basis of estimated traffic volumes. The criteria is: (1) if a link has the estimated traffic volume, 60% of which is over 10,000 passenger during a per peak hour per direction, MRT is suggested; (2) if the link has a traffic volume between 6,000 and 10,000 passenger during a per peak hour per direction, BRT/LRT is suggested; and (3) otherwise a bus is suggested. Note that, based on experience in commuter railway lines in Japan, the traffic volume of the heavy direction during a peak hour is assumed to be 5% of the daily link volume (both directions). Table 4 also summarizes the result of suggested system of public transport. It shows that a triangular area formed by three centers, namely CBD, SC-Mindama, and SC-Bago Riverside, shown in Figure 8, has such potentially large traffic volumes that MRT or BRT/LRT should be introduced even in 2013. It also suggested that the area where

MRT or BRT/LRT should be introduced in 2035 is expanded to cover other SCs and NTCs as shown in Figure 9.

Table 4. Link volume and indicative public transport mode

Link		Link between		Person trip / day			Indicative PT modes, 2013			Indicative PT modes, 2035		
				2013	2035	2035/2013	Target passenger volume by PT (60%) per day	Peak-hour volume (passenger per hour per direction)	System	Target passenger volume by PT (60%) per day	Peak-hour volume (passenger per hour per direction)	System
CBD - Sub center Link	A1	CBD	SC-Mindama	698,000	644,000	0.92	418,800	20,940	MRT	386,400	19,320	MRT
	A2		SC-Dagon Myothit	264,000	344,000	1.30	158,400	7,920	BRT	206,400	10,320	MRT
	A3		SC-Bago Riverside	249,500	193,500	0.78	149,700	7,485	BRT	116,100	5,805	Bus
	A4		SC-Thilawa SEZ	88,300	196,000	2.22	52,980	2,649	Bus	117,600	5,880	Bus
	A5		NTC-Dala	72,000	299,000	4.15	43,200	2,160	Bus	179,400	8,970	BRT
	A6		NTC-Twantay	55,600	95,600	1.72	33,360	1,668	Bus	57,360	2,868	Bus
	A7		SC-Hlaingtharyar	138,000	118,000	0.86	82,800	4,140	Bus	70,800	3,540	Bus
Link Between Sub-cebters	B1	SC-Hlaingtharyar	SC-Mindama	144,000	360,300	2.50	86,400	4,320	Bus	216,180	10,809	MRT
	B2	SC-Mindama	SC-Dagon Myothit	178,400	612,700	3.43	107,040	5,352	Bus	367,620	18,381	MRT
	B3	SC-Dagon Myothit	SC-Bago Riverside	134,500	466,700	3.47	80,700	4,035	Bus	280,020	14,001	MRT
	B4	SC-Bago Riverside	SC-Thilawa SEZ	67,300	250,700	3.73	40,380	2,019	Bus	150,420	7,521	BRT
Sub-center and New Town Link	C1	NTC-Hmawbi	SC-Mindama	167,800	301,300	1.80	100,680	5,034	Bus	180,780	9,039	BRT
		Corridor inbetween C1 and C2		66,800	115,600	1.73	40,080	2,004	Bus	69,360	3,468	Bus
	C2	NTC-Hlegu	SC-Dagon Myothit	52,900	131,765	2.49	31,740	1,587	Bus	79,059	3,953	Bus
	C3	NTC-East Dagon	SC-Dagon Myothit	42,400	139,500	3.29	25,440	1,272	Bus	83,700	4,185	Bus
	C4	NTC-Thanlyin	SC-Bago Riverside	13,700	102,100	7.45	8,220	411	Bus	61,260	3,063	Bus
	C5	NTC-Thanlyin	SC-Thilawa SEZ	18,700	92,100	4.93	11,220	561	Bus	55,260	2,763	Bus
	C6	NTC-Dala	SC-Thilawa SEZ	5,100	20,200	3.96	3,060	153	Bus	12,120	606	Bus
	C7	NTC-Twantay	SC-Hlaingtharyar	19,400	118,800	6.12	11,640	582	Bus	71,280	3,564	Bus
	C8	NTC-Htantabin	SC-Hlaingtharyar	66,800	211,700	3.17	40,080	2,004	Bus	127,020	6,351	BRT
Link Between New Towns	D1	NTC-Hmawbi	NTC-Hlegu	62,700	175,400	2.80	37,620	1,881	Bus	105,240	5,262	Bus
	D2	NTC-Hlegu	NTC-East Dagon	4,100	58,700	14.32	2,460	123	Bus	35,220	1,761	Bus
	D3	NTC-East Dagon	NTC-Thanlyin	2,400	15,600	6.50	1,440	72	Bus	9,360	468	Bus
	D4	NTC-Dala	NTC-Twantay	18,700	33,900	1.81	11,220	561	Bus	20,340	1,017	Bus
	D5	NTC-Htantabin	NTC-Hmawbi	37,900	151,100	3.99	22,740	1,137	Bus	90,660	4,533	Bus

Source: YUTRA Project Team

Figure 8. Area needs high-order transit service (MRT or BRT/LRT) in 2013

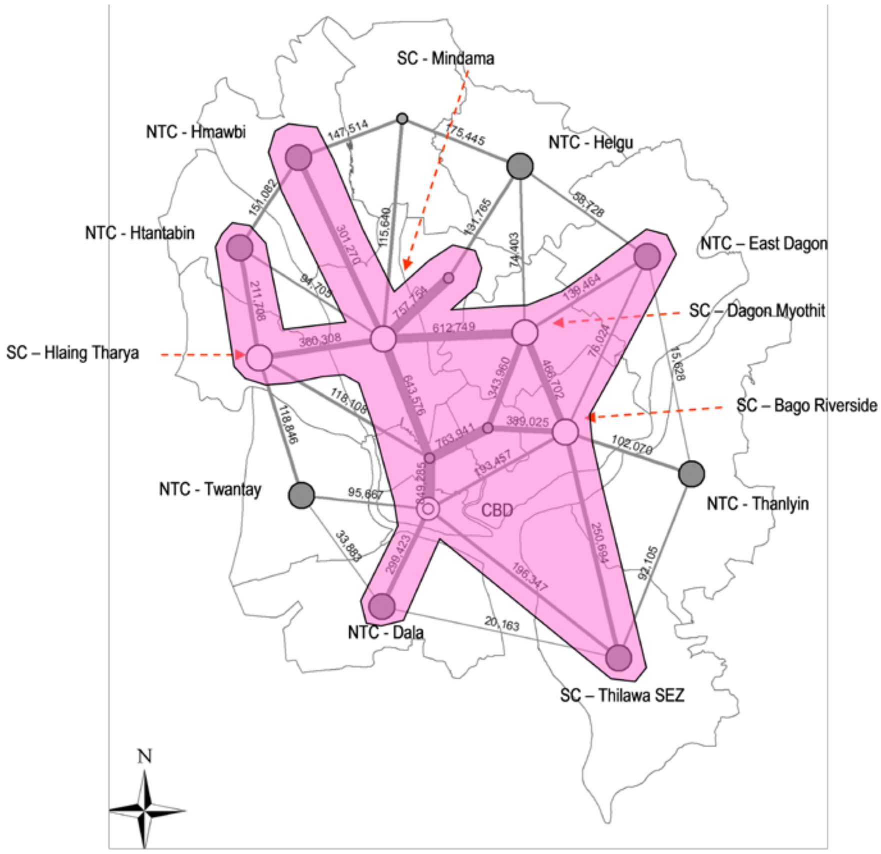


Figure 9. Area needs high-order transit service (MRT or BRT/LRT) in 2035

Finally, Figure 10 illustrates an indicative mass transit network with a consideration of physical constraints on the basis of the above analysis. Table 4 indicates that the link which has conventional railway (such as A2 connecting CBD with SC-Dagon Myothit) requires MRT to serve its huge demand, and a cost effective way is to upgrade the existing railway. Table 4 also implies that the links which do not have railway, such as A1 connecting CBD with SC-Mindama), B1 connecting SC-Hlaing Tharya with SC-Mindama, B2 connecting SC-Mindama with SC-Dagon Myothit) and B3 connecting SC-Dagon Myothit with SC-Bago Riverside, requires new installation of MRT to support their large demand in the future.

Figure 10 shows a new potential extension of MRT line in the south of CBD, an extension to connect NTC-Htantabin with SC-Hlang Tharya in the long run while it also shows a new MRT in the north of SC-Mindama connecting this area with existing Yangon Circular Line and with the depot at the north end. For the connection between the CBD and the SC-Thilawa SEZ, new MRT line is indicated rather based on optimistic expectation of industrial development of Thilawa area than the estimated traffic volume in this study.

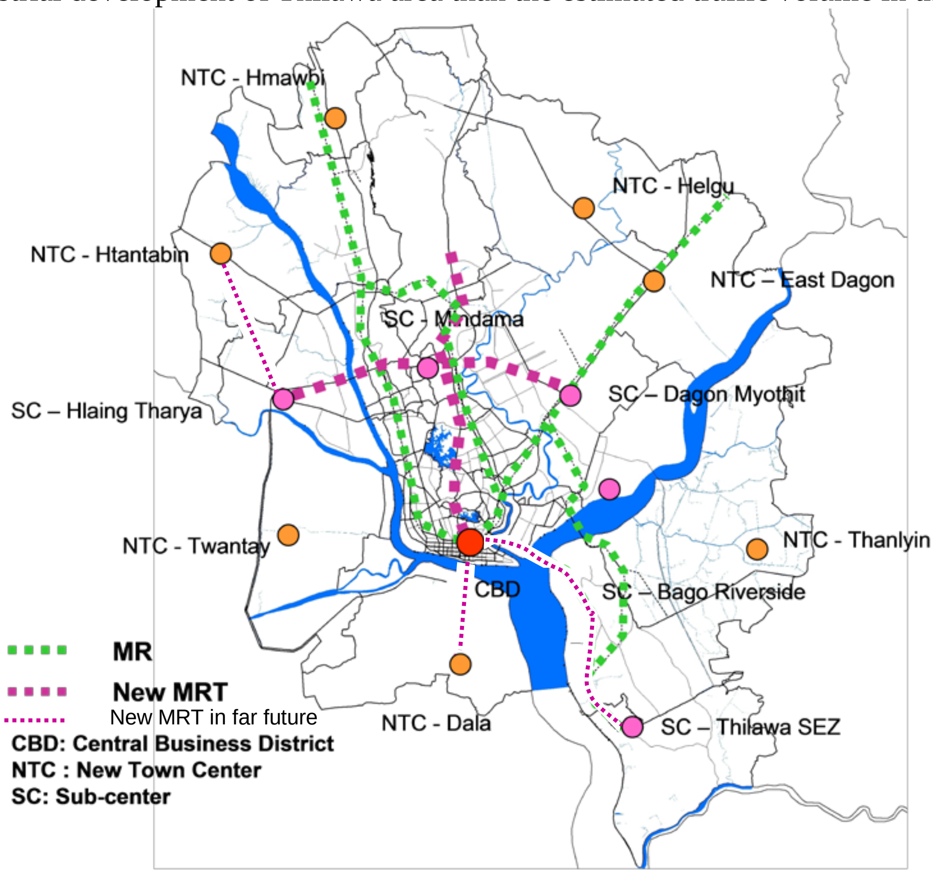


Figure 10. Indicative Mass Transit Routes in 2035

4. CASE STUDIES OF RAILWAY NETWORK DEVELOPMENT

4.1 Three Cases of MRT Network Development

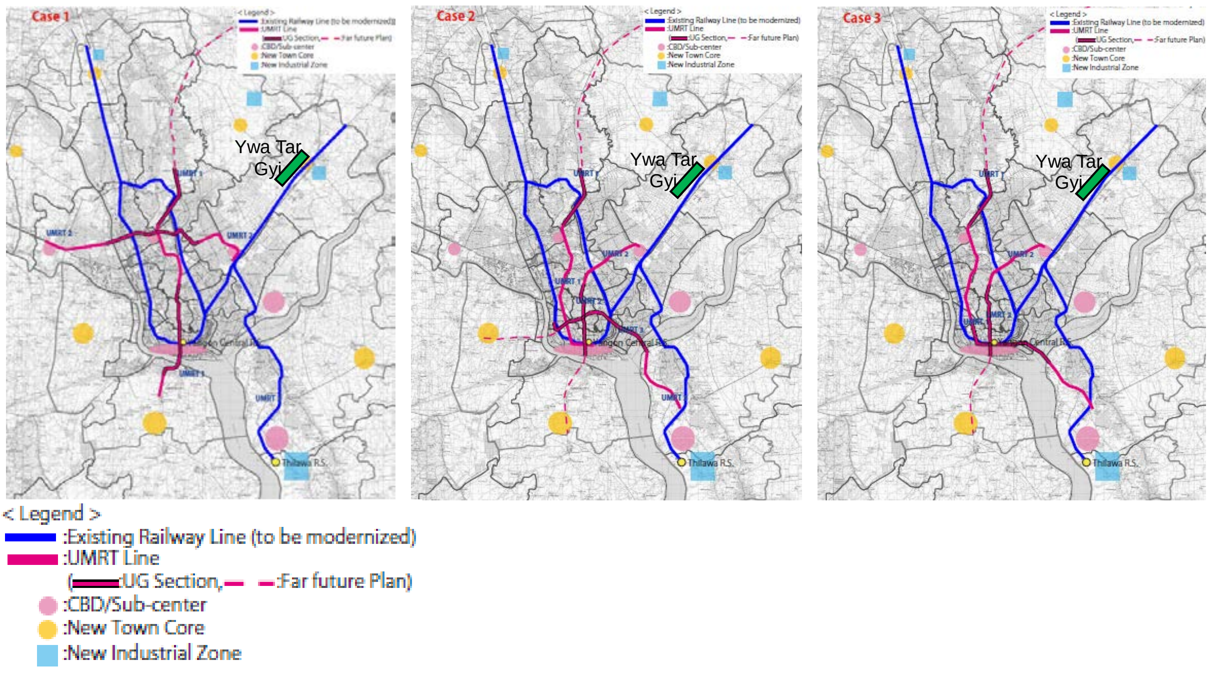
This study analyzes three cases of developing new MRT lines based on the above proposed indicative mass transit network. The MRT networks assumed in the three cases are presented in Figure 11. Note that they all assume modernization of existing railway lines of YCR and

Suburban lines of Yangon-Mandalay Line, Yangon-Pyay Line, and Thilawa Access Line to become MRT lines, to achieve an MRT network with low initial cost, before making plan for new MRT lines.

First, Case 1 assumes introductions of two new MRT lines. MRT-1 runs along a North-South corridor whereas MRT-2 runs along an East-West corridor. MRT-1 is assumed to run along Kaba Aye Rd. in consideration of its importance as a main street, its high population density, current traffic jam, etc. MRT-2 is assumed to connect sub-centers, named SC-Hlaing Tharya, SC-Mindama, and SC-Dagon Myothit.

Next, Case 2 assumes introductions of three new MRT lines. MRT-1 runs along the North-South corridor; MRT-2 run parallel with MRT-1, and MRT-3 runs along the East-West corridor. MRT-1 is assumed to run along Pyay Rd. in consideration of the easiness of construction work owing to sufficient width of road infrastructure. MRT-2 is assumed to connect Yangon Central R.S. with Dagon Myothit along Kaba Aye Rd., Parami Rd., and Pinlon Rd. MRT-3 is assumed to run along Shwe Gon Daing Rd. for reducing heavy traffic congestion.

Finally, Case 3 assumes introductions of two new MRT lines. MRT-1 runs along the the North-South corridor whereas MRT-2 runs partially parallel with MRT-1. MRT-1 is assumed to be the same as MRT-1 in Case 2 in its northern part between Yangon Central Station and the northern end of the line but be extended from Yangon Central Station to the southeast direction to connect the CBD with Thilawa. MRT-2 is the same as that in Case 2.



Source: YUTRA Project Team

Figure 11. New MRT lines in Three Cases

4.2 Evaluation of Three Cases

The three cases are evaluated from the viewpoints of multiple aspects, which are spatial structure balance of urban area, accessibility to urban functions, connectivity in railway network, project cost, and environmental and social impact. The project cost in each case is estimated using the unit cost by structure type of component. Its detail are presented in Appendix. The evaluation result are summarized in Table 5.

Table 5. Multi aspect evaluation of the three Cases

	Case1	**Case2**	**Case3**
Network Length	**175.9km** (0.117 km/km^2) - Existing Line Modernization: 122.1km - UMRT Line: 53.8km (UG: 27.2km, EV: 26.6km)	**181.6km** (0.121 km/km^2) - Existing Line Modernization: 122.1km - UMRT Line: 59.5km (UG: 25.3km, EV: 34.2km)	**173.2km** (0.115 km/km^2) - Existing Line Modernization: 122.1km - UMRT Line: 51.1km (UG: 22.0km, EV: 29.1km)
No. of Line	**6 lines** - Existing Line: 4 lines - New MRT Line: 2 lines	**7 lines** - Existing Line: 4 lines - New MRT Line: 3 lines	**6 lines** - Existing Line: 4 lines - New MRT Line: 2 lines
Balance of N-S axis and E-W axis	**Better** - N-S axis: 4 lines - E-W axis: 2 lines	**Moderate** - N-S axis: 5 lines - E-W axis: 1 lines	**Worse** - N-S axis: 5 lines - E-W axis: 0 lines
Accessibility to urban functions (CBD/SC, NTC, new industrial zone) and important transport hubs (airport, Yangon station)	**Better** - CBD/SCs: 6 points among total 6 points (connecting all) - NTCs: 3 points among total 7 points - New industrial zone: 3 points among total 4 points - link all transport hubs	**Moderate** - CBD/SCs: 5 points among total 6 points - NTCs: 2 points among total 7 points - New industrial zone: 3 points among total 4 points - link all transport hubs	**Moderate** - CBD/SCs: 5 points among total 6 points - NTCs: 2 points among total 7 points - New industrial zone: 3 points among total 4 points - link all transport hubs
Depot	One integrated depot for all lines nearby Ywa Tar Gyi.	One integrated depot for all lines nearby Ywa Tar Gyi.	One integrated depot for all lines nearby Ywa Tar Gyi.
Connectivity among railway lines	**Moderate** 9 transfer stations	**Better** 11 transfer stations	**Worse** 7 transfer stations
Cost aspect	**Middle among three Cases** US$ 10,915 mil. (Railway project only. Excluding railway related project such as station redevelopment, etc.)	**Highest among three Cases** US$ 11,086 mil. (Railway project only. Excluding railway related project such as station redevelopment, etc.)	**Lowest among three cases** US$ 10,285 mil. (Railway project only. Excluding railway related project such as station redevelopment, etc.)
Environmental and social impact aspect	During construction: Little negative impact; after completion: positive impact - Existing railway modernization: Few resettlements owing to existing railway improvement. Some influence to road traffic and some influence to neighboring citizens during construction. - MRT: Normal resettlement to be required. Some influence to road traffic and neighboring citizens during construction. - Give positive impact due to reducing traffic jam, improving convenience for all Yangon citizens (especially commuters), having higher energy efficiency than cars, etc.		
Remarks	Most appropriate network among three options in terms of layout balance of N-S and E-W, and connectivity with urban functions. The connectivity among railway and the cost is not the best option, but in moderate level.	Layout balance of N-S and E-W, and connectivity with urban function is lower than Case 1 but cost is highest.	Most poor network among three Cases in terms of layout balance of N-S and E-W, and connectivity among railway. The cost is lower than the others, but difference is not crucial.

Note: UG: Underground, EV: Elevated
Source: YUTRA Project Team

Case 1 gives a railway network with total length of 175.9 km, of which 122.1 km are modernization of existing lines and 53.8 km are belongs to two new lines. From the view point of urban structure, this network forms four axes in the North-South direction and two axes in the East-West direction. The network connects all of six points of SCs with the CBD. It also connects three among seven points of NTCs and three among four points of new industry zones in the area. From the view point of network connectivity, the network creates nine transfer points to ease the connection between lines. Estimated cost for its installation is approximately 10,915 mil. USD.

Case 2 makes three new lines with 59.5 km long in additional of modernization of the existing railway network to form a network of 181.6 km, longest in the three cases. The network have five axes in the North-South direction and only one axis in the East-West direction. This structure makes it be able to connect five among six points of SCs with the CBD, two among seven points of NTCs and three among four points of new industrial zones. The network also have eleven transfer stations, the most number in the three cases. It will cost about 11,086 mil. USD.

Case 3 has a network of 173.2 km, which includes 51.1 km of two new lines and the modernization of the existing network. Similar to Case 1, it has four axes in the North-South direction and two axes in the East-West direction. This network can connect five among six points of SCs with the CBD, three among seven points of NTCs and three among four points of new industry zones in the area. Thus, it has same urban connectivity function with Case 2. The network has only seven transfer points, the less number in the three cases. Cost for its installation is approximately 10,285 mil. USD.

All of three cases will give positive impact to the city through reduction of traffic congestion, reduction of gas emission and improve mobility for the citizens while few resettlements are anticipated for modernization of existing lines and normal resettlement may occur for the construction of the new lines.

As a result of comparison between the three cases, Case 1 is suggested as the most preferred because of its most appropriate network structure in terms of layout balance of N-S and E-W and connectivity with urban functions (SC, NTCs, industrial zones), which will support the multi-core structure of the city in the future, while costing a moderate budget.

It should be noted that the discussion in section 3.2 indicated that new MRT is necessary in this network, then this section only qualitatively analyse future structure of the network. Thus detail demand forecast on person-kilometre, average distance carried, as well as station distance etc. should be analyzed in the stage of Feasibility Study. All of these new lines should be constructed after the up-grade of existing lines, means that these are recommended to be construct in long-term, after 2025.

5. CONCLUSION

Compared with other large cities with more than five million populations in developing countries, the Greater Yangon has a favorable stock in terms of public transport, with nearly 150 km of railway network and a share as high as 60% of public transport in the whole traffic demand. Under the condition of tax relaxation against car ownership, the number of cars has drastically increased from the year of 2011 (Kojima *et al.*, 2015). While service level of public transport, including railway and traditional bus, is still low, there is a risk that the share of private car will increase, causing serious traffic congestion in the area. Thus the establishment of the MRT network, which combines the improvement of existing railway lines with construction of new lines in the area is an urgent issue for the Myanmar Government.

It should be noted that the improvement/construction of over 170 km-long urban railway network requires decades or more. The government must take hard efforts to maintain the high modal share of public transport. They may include (1) providing favorable condition to encourage private sector to improve service level of buses, (2) improvement of the connection of railway service with buses and taxis, (3) introduction of traffic management such as regulation of road encroaching and on-road parking, (4) formulation of long-term transport master plan to make the base for future development, and (5) acceleration of the design work of new railway lines to reserve land for future works.

With analysis at macro level, this study reveals that, in order to support the population growth in the future and to realize the multi-core urban structure, it is necessary to newly construct two or three lines of MRT besides the improvement of exiting railway lines. After a multi aspect evaluation, the study proposed to construct one MRT line on North-South and the other MRT line on East-West axis. However, it is indispensable to make careful examination to identify detail alignment, specification as well as construction timing of each line. Moreover, this study was conducted during the period when construction of three large scale flyovers were implemented in the Greater Yangon. At the same time, regulations and economic activities also drastically changed day by day. Therefore, it is recommended that traffic survey will be made after five years to update the transport master plan of the area.

APPENDIX

Table A1. Comparison of project cost per km

	Unit Project Cost per km (unit: mil. US$)	Remarks	Source
MRT/Heavy rail (At-Grade [AG] Section)			
Existing Line Improvement (Single Track)	8	exc. Depot/WS/Rollingstock	adjusted based on Note 3.
Applied cost per km for this study	8		
Existing Line Improvement (Double Track)	13	exc. Depot/WS/Rollingstock	adjusted based on Note 3.
Applied cost per km for this study	15		
Double-tracking of Existing Single Line	10	exc. Depot/WS/Rollingstock.	adjusted based on Note 3.
Applied cost per km for this study	10		
Electrification for Double Track	10	exc. Depot/WS/Rollingstock	adjusted based on Note 3.
Applied cost per km for this study	10		
MRT/Heavy rail (Underground [UG] Section)			
MRT "A"	150	17km length / Engineer's Estimate	own source
MRT "B"	162	2.3km length / Contract Price & Engineer's Estimate	own source
MRT "C"	145	10km length / Preliminary estimate	own source
MRT "D"	130	5.9km length / Engineer's Estimate	own source
Applied cost per km for this study	150		
MRT/Heavy rail (Elevated [EV] Section)			
MRT "B"	47	17.2km length / Contract Price & Engineer's Estimate	own source
MRT "D"	73.6	9.8km length / Engineer's Estimate	own source
BKK BTS Skytrain	73.9		see Note 1.
General	50-100		see Note 1.
Applied cost per km for this study	60		
Monorail			
General	35-40	Preliminary cost estimates	own source
Applied cost per km for this study	40		
LRT			
Lyon LRT	18.9	18km length,	see Note 1.
Bordeaux LRT	20.5	23km length,	see Note 1.
LA (Gold) LRT	37.8	23km length,	see Note 1.
Zurich LRT	42	20km length,	see Note 1.
General1	10-20(At-Grade) 30-50(Elevated)		see Note 2.
General2	15-40		see Note 1.
Applied cost per km for this study	20		
Tram			
General	10-25		see Note 1.
Applied cost per km for this study	15		
BRT			
Quito (Ecuador)	2		see Note 1.
Taipei BRT	0.5		see Note 1.
General	0.5-15		see Note 1.
Applied cost per km for this study	5		

Source
1: UNCRD (United Nations Centre for Regional Development)
http://www.uncrd.or.jp/env/est/docs/BRT-Training-Materials_Nov05/1-2_Introduction_to_BRT.pdf
2: MLIT (Japanese Ministry of Land, Infrastructure and Transport)
http://www.mlit.go.jp/road/sisaku/lrt/lrt_index.html
3: Example of Railway Project Cost per KM - Manual of Transport Infrastructure Development Planning for Developping Countries, Transport Economic Research Center.

Table A2. Comparison of preliminary cost estimation of three Cases

Case1			Case2			Case3		
	km	mil.US$		km	mil.US$		km	mil.US$
Existing Railway			Existing Railway			Existing Railway		
Improvement (At-grade)			Improvement (At-grade)			Improvement (At-grade)		
YCR (Western Half)	21.0	485	YCR (Western Half)	21.0	485	YCR (Western Half)	21.0	485
YCR (Eastern Half)	26.5	568	YCR (Eastern Half)	26.5	568	YCR (Eastern Half)	26.5	568
Yangon-Mandalay	28.3	144	Yangon-Mandalay	28.3	144	Yangon-Mandalay	28.3	144
Yangon-Pyay	20.1	500	Yangon-Pyay	20.1	500	Yangon-Pyay	20.1	500
Thilawa Branch Line	26.2	766	Thilawa Branch Line	26.2	766	Thilawa Branch Line	26.2	766
Sub-total		2,462	Sub-total		2,462	Sub-total		2,462
Electrified (YCR Western half is Elevated)			Electrified (YCR Western half is Elevated)			Electrified (YCR Western half is Elevated)		
YCR (Western Half)	21.0	1,260	YCR (Western Half)	21.0	1,260	YCR (Western Half)	21.0	1,260
YCR (Eastern Half)	26.5	398	YCR (Eastern Half)	26.5	398	YCR (Eastern Half)	26.5	398
Yangon-Mandalay (AG)	28.3	425	Yangon-Mandalay (AG)	28.3	425	Yangon-Mandalay (AG)	28.3	425
Yangon-Pyay (AG)	20.1	302	Yangon-Pyay (AG)	20.1	302	Yangon-Pyay (AG)	20.1	302
Thilawa Line (AG)	26.2	393	Thilawa Line (AG)	26.2	393	Thilawa Line (AG)	26.2	393
Sub-total		2,777	Sub-total		2,777	Sub-total		2,777
Existing Railway Total	122.1	5,239	Existing Railway Total	122.1	5,239	Existing Railway Total	122.1	5,239
UMRT			UMRT			UMRT		
UMRT1	21.8	2,253	UMRT1	21.4	1,554	UMRT1	35.2	3,417
(UG section)	10.5	1,575	(UG section)	3.0	450	(UG section)	14.5	2,175
(EV section)	11.3	678	(EV section)	18.4	1,104	(EV section)	20.7	1,242
UMRT1 Extension	6.0	693	UMRT2	15.9	1,629	UMRT2	15.9	1,629
(UG section)	3.7	555	(UG section)	7.5	1,125	(UG section)	7.5	1,125
(EV section)	2.3	138	(EV section)	8.4	504	(EV section)	8.4	504
UMRT2	26.0	2,730	UMRT3	22.2	2,664	-	-	-
(UG section)	13.0	1,950	(UG section)	14.8	2,220	-	-	-
(EV section)	13.0	780	(EV section)	7.4	444	-	-	-
UMRT Total	53.8	5,676	UMRT Total	59.5	5,847	UMRT Total	51.1	5,046
Total	175.9	10,915	Total	181.6	11,086	Total	173.2	10,285

Source: YUTRA Project Team

ACKNOWLEDGMENT

Descriptions in this paper are personnel opinions of the authors and do not represent viewpoint of JICA.

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