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DETAILED FEASIBILITY STUDY FOR ENVIRONMENTALLY FRIENDLY LINKAGE SYSTEM FOR KOWLOON EAST

/ Feasibility Study /

EFLS ENVIRONMENTALLY FRIENDLY LINKAGE SYSTEM 環保連接系統

Literature Review Report on Worldwide Application of Road-based and Rail-based Green Public Transport Systems

March 2017 Rev. 1

Disclaimer: All information collected and presented in this report is exclusively for the purpose of this Study and for the EFLS mode selection exercise. Information should not be used for any other external purposes.

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1 Introduction

1.1 Background

1.1.1 The Kai Tak Outline Zoning Plan, as approved in 2007 and revised in 2012, had undergone an extensive public engagement from 2004 to 2006. A preliminary idea of providing a possible rail-based Environmentally Friendly Transportation System (EFTS), running within the Kai Tak Development (KTD), had been raised. In December 2009, the Civil Engineering Development Department (CEDD) commissioned a study to examine the preliminary feasibility of the rail-based of the EFTS which was later renamed as Environmentally Friendly Linkage System (EFLS). In 2011, the government of the HKSAR announced the initiative to transform Kowloon East (KE)[1] into an attractive central business district (CBD) to sustain Hong Kong's economic development as well as establishing a leisure, recreation and tourism hub. As transportation provision forms a vital part in any world-class CBD, the need for an integrated Multi-Modal Linkage System (MMLS) to enhance connectivity in the Study Area was therefore ascertained.

1.1.2 An integrated MMLS comprises a proposed Environmentally Friendly Linkage System (EFLS) existing public transport, the Mass Transit Railway (MTR) and other existing/planned transport infrastructures and enhanced pedestrian facilities that enhance the connectivity and accessibility of KE at four different connectivity stages, namely strategic, inter-district, intra-district and local levels. The EFLS in the form of road- or rail-based transportation is the backbone of the MMLS that links up local districts in KE and interconnects with the existing MTR to connect KE with other parts of Hong Kong.

1.1.3 The preliminary Feasibility Study (PFS) suggested a 9-kilometer elevated monorail system that runs from MTR Kowloon Bay Station to MTR Kwun Tong Station via the former Kai Tak Airport Runway. Two stages of public consultation (PC) were conducted in 2012 and 2014 to collect views from the general public and related parties. The need to enhance connectivity in KE received general public support and urged for early implementation of the EFLS. However, there were diversified views on the proposed elevated monorail system which can largely be categorized into three key issues, i.e. (i) need for an elevated rail-based EFLS, (ii) alignment and coverage, and (iii) implications for the Kwun Tong Typhoon Shelter (KTTS).

1.2 The Study

1.2.1 The Civil Engineering and Development Department (CEDD) of the HKSAR commissioned Ove Arup and Partners Hong Kong Limited (Arup) in October 2015 to undertake the Detailed Feasibility Study for Environmentally Friendly Linkage System for Kowloon East to further investigate the EFLS to address various public concerns received during the PFS. The DFS will provide an in-depth evaluation on the most suitable green public transport mode(s) for the

1 Kowloon East (KE) is an area comprising the former Kai Tak Airport, Kwun Tong and Kowloon Bay Business Areas.

proposed EFLS and formulate a well-planned integrated multi-modal linkage system to enhance the connectivity of Kowloon East. The first stage of the DFS study is to identify the most suitable green transport mode as EFLS for KE before develop the EFLS scheme in the next stage including its alignment coverage, station locations, financial evaluation, procurement and implementation strategies.

1.3 Purpose of This Report

1.3.1 This report contains an in-depth desktop literature review and research on worldwide applications of various road-based and rail-based green public transport systems. The literature review shall cover, but not be limited to, the following green public transport modes: (i) monorail; (ii) modern tram; (iii) automatic people mover (APM); (iv) Bus Rapid Transit (BRT); (v) Urban Light Transit or Personal Rapid Transit (PRT); (vi) trolleybus; (vii) electric/hybrid bus; (viii) cable car; and (ix) travellator.[2]

1.3.2 The purpose of the literature review is to provide a documented inventory of operating and financial characteristics and performance of the said green public transport modes. Merits and demerits of each mode will be identified, with a view to providing reference information for subsequent assessment of green public transport mode(s) for the ELFS as well as the MMLS.

1.3.3 In addition, for selected monorail case studies, the relevant planning background, financial (where provided), safety and operational information for these applications were assessed with a view to demonstrating whether monorail technology is still technologically relevant and whether monorail is commercially viable. Where applicable, monorail systems that have suffered financial difficulties or eventually ceased operations in the past few years are also examined – this focuses specifically on the case of the Sydney Monorail, which was closed in June 2013.

1.3.4 With a view to address public concerns regarding the applicability, financial viability, safety and operational performance of monorail technology, the following operating or planned monorail systems were identified to assess for benchmarking and applicability to serve as EFLS for KE:

- Australia (Sydney)
- Brazil (Sao Paulo)
- China (Chongqing)
- Japan (Naha (Okinawa), Osaka, and Tokyo)
- Korea Monorail Systems (Daegu)
- Malaysia (Kuala Lumpur)

[2] The issue of "mixed mode" systems in which two or more modes operate in a single corridor has been raised. As the constituent modes of a mixed mode system will be covered in this report, mixed mode systems will not be discussed. However typically, mixed mode operations have been implemented in limited instances, typically between rail and bus. For such cases, rail and bus mixed mode operations might seem logical where demand would not currently support costs for building and operating a rail mode throughout the entire corridor.

1.4 Research Methodology

1.4.1 This literature review has been conducted through a variety of activities including: (i) review of publically available documents, plans and technical papers (primarily available online); (ii) survey questionnaires to prospective case study agencies (including the San Francisco Bay Area Rapid Transit District (BART), Transport for London, and the Tokyo Monorail); and (iii) phone interviews with staff and managers at prospective case study agencies (including Sydney's Transport for New South Wales, as well as Transport for London among others). These specific references, individuals and responses to data inquiries are referenced for each case study for each mode.

1.4.2 During the course of the activities, various operators and public transport agencies have been approached (including the Sydney's Transport for New South Wales, Tokyo Monorail, Daegu Metro, etc.) with requests to furnish capital cost, operating cost, and financial performance information. It has been found that financial performance information is considered proprietary and commercially sensitive, and was rarely provided as part of this study.

1.5 Organization of This Report

1.5.1 The report comprises the following elements:

- Chapter 1 (this chapter) provides an understanding and appreciation of the study
- Chapter 2 outlines the key system characteristics typically used to compare and evaluate modes and technologies
- Chapter 3 presents modal descriptions for road-based green public transport modes, including several case studies for each mode
- Chapter 4 presents modal descriptions for rail-based green public transport modes, including several case studies for each mode
- Chapter 5 presents the detailed monorail assessment
- Chapter 6 contains the conclusion and key findings from the review

2 Framework for Presenting Modes

2.1 Overview

2.1.1 Green transport connotes any transport strategy or system that is environmentally friendly and sustainable, with minimal negative impact on the surrounding environment. Green transport can come in many forms including hybrid/electric vehicles or buses, travellators to quicken walk times, and other mass transit systems such as trams, monorail, and heavy rail such as MTR. Another goal of green transport is to encourage alternate travel behaviour and modal shift away from driving.

2.1.2 The focus of this literature review will be to investigate and inventory relevant road-based and rail-based green transport systems adopted throughout the world and to describe key technical and operating and maintenance characteristics of each. The focus of this review is to objectively present capabilities of each system in terms of hourly passenger capacity, speed, general unit costs, etc. of both road and rail-based modes – regardless of potential alignment within KTD. Where quantitative information is not available, modes will be described qualitative. Therefore, a mix of both quantitative and qualitative elements will be described (as noted below in **Section 2.2**). Illustrative case studies will also be examined.

2.1.3 This "menu" of modal options will be used in the latter stages of this study to identify the most applicable modes for the MMLS as well as the EFLS for KE.

2.2 Description of System Characteristics

2.2.1 In general, each mode will be described under three types of characteristics (based on existing precedent and design guidelines) as described below. Note that not all characteristics of each mode will be applicable to a given mode.

Characteristic	Description	Potential Areas to Assess
System Characteristics	• Describes the type of riders, how the system fits within the overall network, and technology maturation • Describe how the mode operates, the propulsion technology and type of vehicle used, station layout, level of operating segregations, running surface, and costs, etc.	• System and vehicle technology (rubber-tire, rail, etc.) • Propulsion (diesel, hybrid, electric, catenary, third rail) • Runningway/guideway (mixed flow lanes, bus lanes, rail) • Level of segregation (no segregation, partial segregation, full segregation) • Reliability • Role of the system in the public transport network (feeder, trunk, or regional) and types of trips served (short, medium, or long distance trips)

Characteristic	Description	Potential Areas to Assess
		• Station configuration and design • Capital costs (overall and by km)[3]
Operating & Maintenance Characteristics	• Describes performance characteristics of the system (speed, headway, capacity, station spacing, operating costs, etc.)	• Service and routing • Headway (i.e., minutes between consecutive arrivals) • Capacity (in terms of line/route capacity per hour) • Operating and Maintenance Costs (per hour or per unit)[4] • Maintenance requirements
Other Key Characteristics	• Describes other modal characteristics that are not easily quantified	• Reliability • Impacts to other road users • Land requirements • Topside development implications • Safety and evacuation requirements • Environmental implications

[3] All costs are presented in Year of Expenditure (YOE) costs, unless expressly noted (for instance in comparison tables presenting the costs for different systems implemented in different years – costs are escalated to FY2015 for comparison). It is also noted that unit costs are provided for reference only and should not be strictly used to compare costs of different systems as the scale and magnitude of each project differs considerably.

[4] Operating cost information will be provided if publically available or if the operator has agreed to provide such information. Typically, such information is deemed confidential or proprietary and not shared.

3 Road-based Green Public Transport Systems

3.1 Introduction of Road-based Transport Modes

3.1.1 Road-based green public transport systems connote all rubber-tire based systems and non-rail guideway systems that provide high capacity and high quality mobility. This section summarises each of the road-based systems being examined. It is noted that aerial cable car is covered under this section as it is not considered a rail-based system. Modes evaluated under this Chapter are listed below and presented in alphabetical order.

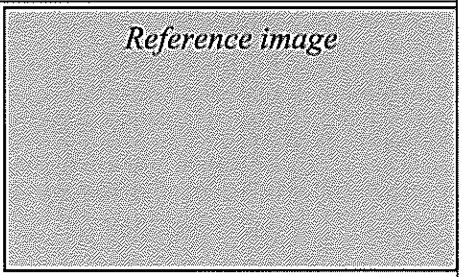
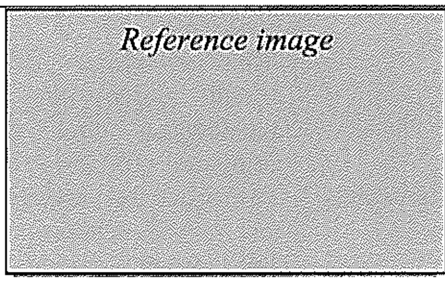
3.1.1.1 Aerial Cable Car (note – aerial cable car is placed under this category as it does not fall into the rail-based transport mode category)

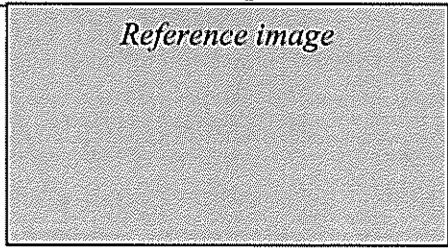
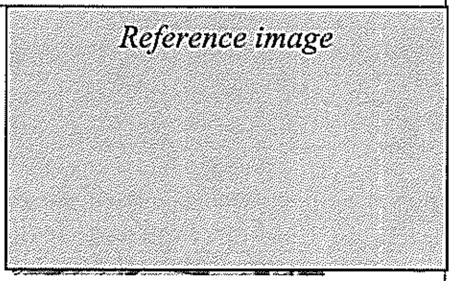
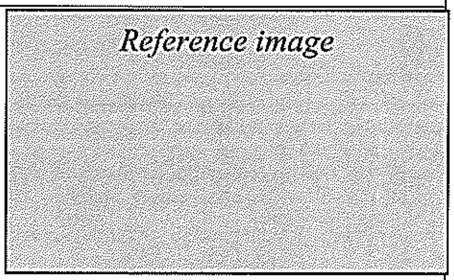
3.1.1.2 Bus

3.1.1.3 Bus Rapid Transit (BRT)

3.1.1.4 Travellator

3.1.1.5 Trolleybus

Mode	Brief Description	Example
Aerial Cable Car	Aerial cable car is a system in which cabins are pulled by a cable and lack on-board motors or engines. Aerial systems are primarily used for tourist purposes, but in Latin America, they function as urban public transport systems due to hilly terrain that complement metro or provide public transport services as conventional bus service is considered less effective.	 Singapore Sky Network
Bus (Electric/ Hybrid)	Bus provides a high degree of accessibility from local inter-district connectivity services, but operates in mixed flow conditions with other road traffic, generally without bus priority. Propulsion types vary, including green technologies such as electric and hybrid systems. Electric buses operate on battery power only, which could limit the distance travelled per charge (due to batter capacity). Hybrid buses use a combination of a battery and a conventional diesel combustion engine, which allows for a longer range, but is less environmentally friendly as emissions are still generated.	 Hong Kong Citybus Electric Bus

Mode	Brief Description	Example
Bus Rapid Transit (BRT)	BRT is a high quality bus-based transit system, providing riders with a faster, more reliable, journey compared to conventional bus or trolleybus if operating in a dedicated corridor, segregated from other road traffic and users. Dedicated corridors minimise interference from other vehicles and road users, and allow buses to operate more reliably. Depending on system design, off-board fare payment, level boarding, number of passing lanes, and station layouts, corridor capacity in theory could be similar to rail systems can be achieved – but with more flexibility, lower costs, and a quicker implementation timeframe. Most BRT systems in operation today use conventional diesel combustion engines – which could be replaced by green technology in the longer term, depending on technology development. Some systems have recently begun to operate electric BRT vehicles (for instance Kuala Lumpur's BRT Sunway).	 Bogota TransMilenio BRT System
Travellator	Travellator, also known as moving walkway, is a slow moving conveyor mechanism that transports people across a horizontal or inclined plane over a short to medium distance. Similar to a horizontal escalator, travellators are often provided in airports and transport facilities to offer better walking comfort and reduce effective walk distance and travel time.	 Macau Old Taipa Travellator
Trolleybus	Trolleybus operates similar to conventional bus, typically in mixed flow traffic conditions, but is powered by electricity from overhead catenary. Trolleybuses operate quieter and have more efficient acceleration and deceleration profiles compared to conventional diesel buses. Trolleybus technology has improved such that hybrid vehicles, with on-board battery and diesel engine, can now operate autonomously for short distance without contacting the catenary for overtaking during emergency situations. In general, the overhead wiring network makes the system much less flexible than conventional bus.	 Shanghai Trolleybus

3.2 Aerial Cable Car

3.2.1 Aerial Cable Car - System Characteristics

Background and System Technology

3.2.1.1 A cable car is defined as a transportation system in which vehicles, without motors or engines, are pulled by cables that are continuously moving at a constant speed. The definition of a cable car varies widely with many applications. Cable cars may operate at-grade (and be fully segregated or share right-of-way with mixed traffic) or operate in the air, fully grade-separated, either hanging or suspended from a cable (referred to as aerial cable cars). Depending on the system, vehicles may be permanently attached to the cable or able to grip the cable independently.

3.2.1.2 The Hong Kong Peak Tram or the San Francisco Cable Car are examples of traditional ground-based cable cars, where a cable network is run underground through special wheelhouses that propel the cable. The cable cars grip the moving cable and are propelled forward. Hong Kong's Ngong Ping 360 and the Singapore Cable Car Sky Network between Sentosa and the World Trade Center are both aerial cable cars, using overhead grips to attach to the overhead wire. While the ground-based cable cars will be briefly discussed in this section, the focus of this section is on the latter – aerial cable cars – as ground-based cable cars are covered under **Section 4.3**.

3.2.1.3 Cable cars have traditionally been used to climb steep grades and for tourist-related purposes for over 100 years. In several Latin American cities, aerial cable car networks have been developed as the primary public transport trunk system as bus and other mass transport modes are unable to operate effectively in steep environs. Aerial cable car operations are sometimes halted due to inclement weather conditions including low-visibility, windy, and rainy conditions. The remainder of this section focuses on aerial cable cars.

Role in Transport Hierarchy

3.2.1.4 Traditionally, cable cars have been used as a transportation system to scale steep slopes and cross valleys and bodies of water. In an urban context, traditional cable cars like those in San Francisco and Lisbon provide easy and direct service up and down steep terrain. Cable cars are also extensively used for tourist purposes, for instance linking to the top of a ski slope or in Ngong Ping's case, to the Tian Tan Buddha on Lantau Island.

3.2.1.5 Recently though, cable cars have seen a rebirth in dense, heavily congested cities with hilly terrain, less suitable for BRT or rail transit such as Medellin's Metrocable in Colombia and La Paz/El Alto's Mi Teleférico in Bolivia. In Medellin's case, cable car serves as a feeder to the metro system, while in La Paz, it is the principal trunk route.

3.2.1.6 Therefore, the role of a cable car depends on the context. In some cities it is for local service or tourist purposes, while in other cities, it is the principal public transport linkage network.

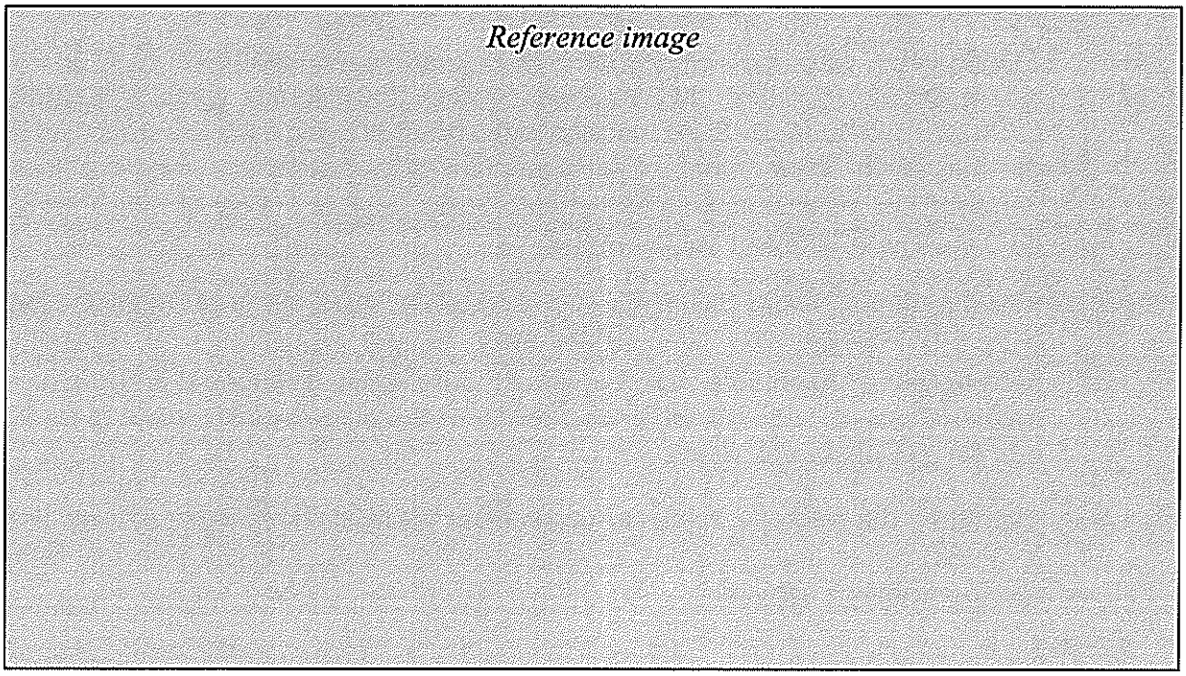
Key Infrastructure Elements and Vehicles

3.2.1.7 The main infrastructure elements include the cable propulsion system, the wheelhouse that moves the cable, the stations, yards as well as towers.

Propulsion System

3.2.1.8 There are two types of cable car systems operating today:

- **Bottom-Supported Cable Systems** – Ground-based cable cars are supported by tracks or rails underneath, yet are still propelled by a cable. This type of system includes "Heritage" cable cars (such as in San Francisco and Lisbon), funiculars (such as the Peak Tram), and cable-drawn shuttle (also known as cable liners which are discussed in **Section 4.3**). Heritage cable cars share the street with mixed flow traffic, while funiculars and cable-drawn shuttles operate in their own dedicated right-of-way.
- **Top-Supported Cable Systems** – Top supported systems, also known as aerial cable systems, are supported from above via a cable (which may or may not be the same cable that propels the cabins varies by technology.) Aerial cable technologies include MDG (Monocable Detachable Gondola), BDG (Bicable Detachable Gondola), 3S/TDG (Tricable Detachable Gondola), Aerial Tram, Funifor, Funitel, and Pulsed Gondola as shown in **Figure 3.2.1**. MDG, BDG and TDG are described below. The maximum span length between cable towers is smaller for a monocable system than a bicable. In general, MDG rope technology is improving allowing spans over 400m to be achieved (compared to 1,500m for BDG systems).



Source: Cable-Car-Confidential, The Essential Guide to Cable Cars, Urban Gondolas, & Cable Propelled Transit, CUP, 2013.

Figure 3.2.1: Types of Cable Propelled Transit

Table 3.2.1: Description of MDG, BDG and TDG Aerial Cable Car Systems

System	Acronymn	Description
Monocable	MDG	• Monocable systems, known as MDG (monocable detachable gondolas) are the most basic aerial ropeway system available. • A single cable provides both the propulsion and support of the cabins, circulating around two end terminals. • The cabins grip the moving rope using a spring loaded gripper mechanism. • This gripper is mechanically detached at stations allowing the cabin speed to be reduced for boarding and reattached on leaving the station.
Bicable	BDG	• Bicable systems, known as BDG (bicable detachable gondolas) also circulate continuously around two end terminals. • They utilise two cables, one for propulsion and one for support. The existing NP360 cable car uses a bicable system. • Rope technology for MDG systems has continuously improved allowing carrying capacities comparable to BDGs resulting in fewer bicable systems being supplied. • Bicable allow greater spans between towers to reduce the number of towers needed along the route. • The cabins run on the fixed support cable using a wheels carriage unit that is pulled by the propulsion or haul cable. At the stations the cabins detach from the haul cable and transfer onto a slow moving conveyor allowing boarding.
Tricable	TDG	• Tricable systems, known as TDG (tricable detachable gondolas) or 3S systems utilise three cables, one for propulsion and two for support. • Of the three systems mentioned here, these are the most technically advanced in terms of operational wind speed, cabin size, line speed and cable spans between towers. • The established aerial cableway suppliers prefer 3S systems over BDG systems for larger installations. • 3S systems can potentially span greater distances between towers. • They also can handle much larger cabins (typical carrying around 38 passengers) and are more stable at higher wind speeds than MDG or BDG systems. • The cabins are support on wheeled carriages running on the two fixed cables and pulled along by the haul cable. • At the stations like the BDG system, the cabins detach from the haul cable and transfer onto a slow moving conveyor allowing boarding.

Stops/Stations

3.2.1.9 Station size and spacing is highly dependent on local conditions and demand. Ngong Ping 360 only has two stations over a length of 5.7 km. Systems operating in Medellin and La Paz are principally for urban public transport and have stations every 500 to 1,000 m. Medellin's first line, Line K, is 1.8 km long with four stations. La Paz's first line, the Red Line, has 3 stations over a length of 2.4 km.

Vehicle

3.2.1.10 The size of a cable car is determined by desired cabin capacity. With different technology, the capacity range of the cabin can range from 1 passenger on an open ski lift, to 4-10 passengers per cabin in a gondola lift, till up to 200 passengers per cabin as an aerial tram or ground-based cable system.[5] The Ngong Ping 360 cabin can seat 10 passengers and up to 7 standees, although in typical operating conditions, operators fill the cabins with up to 10 passengers.

Capital Costs

3.2.1.11 Capital costs for aerial cable cars differ immensely due to system requirements, the adoption of a single, dual and triple cable system, demand, terrain, number of towers and stations, labour costs, etc. As a comparison, **Table 3.2.2** shows the capital costs for a lower capacity system (Portland, USA), a tourist centred system (Ngong Ping 360 in Hong Kong) and two of the more extensive urban cable car systems in the world (Medellin and La Paz). For these systems, capital cost per km ranged from HK$155.0 million/km in Medellin to HK$595 million/km in Portland.

Table 3.2.2: Equivalent FY2015 Capital Costs of Various Aerial Cable Car Systems

System	Length (km)	Type of Cable Car	Cabin Size (Passengers)	Year Opened	Capital Cost	Cost / km
Metrocable, Line K, Medellin, Colombia	1.8	High Capacity Urban (Monocable)	10	2004	HK$279 million (US$36 million)	HK$155 million/km
Mi Teleférico, La Paz, Bolivia	9.7	High Capacity Urban (Monocable)	8-10	2014	HK$1.85 billion (US$242 million)	HK$191 million/km
Ngong Ping 360, Hong Kong SAR	5.7	Tourist Based System (Bi-Cable)	17	2006	HK$1.3 billion	HK$236.3 million/km
Portland Aerial Tram, Portland, USA	1.0	Low Capacity Urban (Bi-Cable)	78	2006	HK$595 million (US$77 million)	HK$595 million/km

Source:
Hong Kong: http://www.hongkongextras.com/ngong_ping_360.html
La Paz: https://nacla.org/blog/2014/12/26/bolivia-revolutionizes-urban-mass-transit-streets-sky
Medellin: http://gondolaproject.com/2010/03/25/medellincaracas-part-7/
Portland: http://www.gobytram.com/about/

[5] Peak Tramway Ordinance, 2015, Legislative Council Panel on Economic Development Long-term Arrangements of the Peak Tramway Operation, LC Paper No. CB(4)650/14-15(03).

3.2.2 Aerial Cable Car - Operating Characteristics

Service and Passenger Capacity

3.2.2.1 Cable cars can offer a high level of service with cabins arriving every 30 seconds or even faster. Medellin's Metrocable Line K cabins arrive every 12 seconds. Ngong Ping 360 cabins arrive about every 30 seconds during the busiest time period.

3.2.2.2 Aerial systems can reach speeds of between 30 km/h for gondolas and up to 45 km/h for aerial trams, respectively. Detachable gondolas operate at slower average speeds due to as most gondola systems are relatively short. Therefore, the increase in speed would only result in marginal time savings, but generate higher station costs, energy demands, system wear and tear, and etc. Aerial trams by comparison are fixed-grip systems. They simply come to a full stop in a station which enables them to travel at higher maximum speeds. Also, aerial trams typically use larger cabins which are able to provide greater comfort and stability during high speed operations.

3.2.2.3 Individual cable car lines can be combined into a cohesive network with transfer stations. Therefore, actual capacity can be quite high for an entire system, although line capacity is still limited by factors such as the cabin capacity, system length, travel speed, and cabin number/frequency – all of which depend on the technology.

3.2.2.4 The different system types have different capacities in terms of passengers per hour per direction (pphpd). A rough guide to the potential capacities of each system is summarised in the table below. Observed capacity in passengers per hour per direction for Medellin is between 1,400 and 3,000.[6] Design capacity for Ngong Ping 360 is 3,500 passengers per hour per direction during the peak period. It is noted that these figures are lower than the maximum theoretical capacity for the three types of aerial cable car, likely due to the sizing of stations and the queuing area required to accommodate such high flows at very low headways.

Table 3.2.3: Equivalent FY2015 Capital Costs of Various Aerial Cable Car Systems

	Type of Aerial Cable Car System		
Element	**MDG**	**BDG**	**3S/TDG**
Theoretical Maximum Capacity (pphpd)	4,000	4,000	6,000
Maximum Passengers per Cabin	15	17	38

Source: http://gondolaproject.com/2010/01/12/technologies-module-1-introduction/

3.2.2.5 In terms of daily volumes, Medellin's system is purported to carry up to a full capacity of 30,000 passengers daily.[7] La Paz's Red Line estimated a daily patronage of about 38,000 (with 2.3 million passengers riding the line in its first two months of operation).[8]

[6] Julio D. Dávila and Diana Daste, Medellín's aerial cable-cars: social inclusion and reduced emissions, https://www.bartlett.ucl.ac.uk/dpu/metrocables/dissemination/Davila-Daste-2012-UNEP.pdf
[7] http://gondolaproject.com/medellin/ http://gondolaproject.com/medellin/
[8] http://thecityfix.com/blog/bolivias-mi-teleferico-to-become-worlds-longest-aerial-cable-car-system/

3.2.2.6 The table below compares operating characteristics of several aerial cable car systems:

Table 3.2.4: Service Profiles for Aerial Cable Car Systems (Individual Lines)

System	Line Name	Length (km)	Main Use	Average Speed (km/hour)	Peak Headway	Maximum Line Capacity (pphpd)	Average Daily Ridership
Ngong Ping 360, Hong Kong SAR	Ngong Ping 360	5.7	Tourism	14	30 sec	3,500 [A]	5,300
Mi Teleférico, La Paz, Bolivia	Yellow Line	3.9	Urban Commute	16	12 sec	3,000	38,000
Metrocable, Medellin, Colombia	Line K	2.1	Urban Commute	18	12 sec	3,000	42,000
Cable Car Sky Network, Singapore	Mount Faber Line	1.7	Tourism	11 (normal) 18 (design)	12 sec	2,400	2,000

Source:

Hong Kong: Various, see Case Study.

La Paz: http://www.oopp.gob.bo/uploads/FICHA_TECNICA_DEL_PROYECTO_TELEFERICO_06_03_20131.pdf

Medellin: https://www.metrodemedellin.gov.co/Portals/4/Images/Viajeconnosotros/Cuadro-sistema-2000x1624-25112015.jpg

Singapore: http://gondolaproject.com/2011/04/05/singapores-sentosa-island-gondola-part-1-the-essentials/

Note:

[A] NP360 actual capacity seems to be around 2,000 pphpd based on 20-30 second headway, although reference documents state a capacity of 3,500 pphpd)

[B] La Paz operates three cable car lines in total. Medellin operates three cable car lines in total. Singapore operates two cable car lines in total.

3.2.3 Aerial Cable Car - Other Key Characteristics

Reliability .

3.2.3.1 Aerial cable car systems operate along elevated cables and are not subject to mixed flow traffic impacts. Therefore, they can achieve a high degree of reliability under normal operations. Aerial cable car systems, however, are subject to delays and service stoppages during inclement weather conditions including high winds, rain, ice and thunderstorms. In addition, low visibility may also cause service stoppages. Maintenance on any part of the system would result in full closure of the entire aerial cable car system.

3.2.3.2 The operational wind speeds typically range from around 20m/s for MDG to 27.7m/s for the more stable 3S. The actual ability to operate at these wind speeds will depend on the local wind environment along the alignment and any specific features that may cause significant turbulence and uncomfortable cabin motions. It was noted that NP360 opted for a bicable system due to marginally better performance in high winds and fewer towers.

Impacts on Other Road Users

3.2.3.3 Aerial cable car is grade separated from road traffic and would have minimal to no impact on road users, except for column placement in the middle of a road, which would require some road width for a protected median.

Land Requirements

3.2.3.4 While the aerial cable cars themselves are suspended and do not require land, the stations, towers, wheelhouse, and yard will all require appropriate land. In addition, reception facilities including bus and vehicle pickup and dropoff areas need to be provided. Lastly, access roads or paths must be provided to the towers for maintenance and fire access. It is noted that in Hong Kong, Section 11 of the Aerial Ropeway (Safety) Ordinance, Cap. 211 stipulates that no part of an aerial cable car shall pass over any building.

Transit Oriented Development (TOD) Implications

3.2.3.5 In Medellin, community centres and other civic buildings have been constructed and centred on the aerial cable car stops. The system can be seen as a "permanent" and reliable form of public transport that encourages investment and densification.

Safety and Evacuation Requirements

3.2.3.6 In case of an incident, passengers are unable to exit the cabin by themselves when the cabin is suspended. One method is for rescue teams to access affected gondola cabins from the nearest tower and for rescue teams to lower passengers to the ground to the safety trail built beneath the line. The other method is for a rescue carrier from the nearest tower to be sent to transfer the passenger to the nearest tower (where they can descend to the ground).

Environmental Implications

3.2.3.7 Aerial cable car systems do not generate emissions as they are run on electricity. Cable cars generate little noise, except when entering stations/wheelhouses.

3.2.4 Aerial Cable Car – Case Studies

3.2.4.1 Two case studies are presented: (i) Hong Kong SAR – Ngong Ping 360; and (ii) Medellin, Colombia – High Capacity Urban Cable Car System.

3.2.4.2

Aerial Cable Car Case Study 1: Hong Kong SAR – Ngong Ping 360 (NP360)

System Description:

Operating since 2006, Hong Kong's Ngong Ping 360 (NP360) is a tourist cable car of 5.7 km linking Tung Chung MTR Station to the Tian Tan Buddha and Po Lin Monastery on Lantau Island. NP360 is a bi-cable gondola system which can accommodate up to 109 cabins on the line and cabins seating 10 and accommodating a total of 17 passengers. The 5.7 km journey takes about 25 minutes - equivalent to a 14 km/h journey. NP360 offers standard cabins, crystal cabins with transparent glass floors, as well as private cabins. NP360 was constructed over a period of over 2.5 years from early 2004 to fall 2006. NP60 is owned by the MTR Corporation (MTRC) and built by Leitner Ropeways, an Austrian firm.

Reference image

Planning Background:

The proposal to construct a cable car system between Tung Chung and Ngong Ping for enhancing tourism in the area was first mooted in the North Lantau Development Study in 1992. This concept was further developed by the Visitor and Tourism Study for Hong Kong prepared for the Hong Kong Tourist Association (HKTA) and Planning Department in 1995. A preliminary appraisal of the engineering feasibility, ridership, cost and revenue was undertaken by the MTR in 1996. The proposal was further studied under the "Remaining Development in Tung Chung ant Tai Ho Comprehensive Feasibility Study" commissioned by the Territory Development Department in 1997.

The Government announced in 1998 that the MTRC would take the lead in developing a proposal for the cable car project and to mastermind the way forward. The Tung Chung Cable Car Feasibility Study was commissioned by the MTRC in 1998 with the specific objective of examining the merits of providing such a system. After a series of studies and a competitive bid process, the Government and MTRC entered into a provisional agreement for the project in 2002. During this period the Government enacted the Tung Chung Cable Car ordinance and MTRC carried out and obtained approval of an environmental impact assessment and a scheme design. In 2003, the Government and MTRC signed a project agreement for the cable car. The franchise commenced on 24 December 2003 and will last for 30 years, after which the system will be transferred to the Government for continued operation as a tourist attraction.

System & Service Characteristics:

- Total Number of Lines: 1 line
- Network Length: 5.7 km
- # of Stations: 2
- Vehicle Type/Size: Cabins can seat 10 and hold up to 17
- Average Speed: 14 km/h (based on 25 minute journey over 5.7 km)
- Service Hours: 10:00AM-6:00PM on weekdays; 9:00AM-6:00PM on weekends
- Headway: 20-30 seconds
- Peak Capacity: 2,000-3,500 passengers per hour (actual capacity seems to be around 2,000 pphpd based on 20-30 second headway, although reference documents state a capacity of 3,500 pphpd)
- Capital Cost (FY2015): HK1.3 billion (or FY2006 HK$1.0 billion)
- Construction Timeframe: 2.5 years (early 2004 to fall 2006)

Performance Characteristics:

- Ridership: 5,300 average daily riders; 1.8 million passengers per year (2014) and 1.6 million passengers per year (2015 – due to 28 fewer operating days due to rope maintenance)

Aerial Cable Car Case Study 1: Hong Kong SAR – Ngong Ping 360 (NP360)

References:

- http://www.ifma.org.hk/download/Cable%20Car%20System%20(General%20Purpose).pdf
- http://www.jcdecaux.com.hk/np360_fact.html
- http://www.np360.com.hk/en/
- MTRC Annual Report 2014 and 2015
- Ngong Ping 360: http://www.hongkongextras.com/ngong_ping_360.html

Aerial Cable Car Case Study 2: Medellin, Colombia – High Capacity Urban Cable Car System

System Description:

Medellin is Colombia's second largest city after Bogota and has three urban cable car lines in addition to two Metro lines. The three urban cable car lines, known as Metrocable, are also operated by the same company running the Metro system, Metro de Medellin. The Metrocable uses Monocable Detachable Gondola (MDG) technology. The line can handle between 90-120 cabins with seats for 8 and capacity for 10 (thus 2 additional standees).

Reference image

The first Metrocable line, Line K, was opened in 2004 as a feeder line to the existing Metro lines. It is 2.1 km long, has four stops and costed US$26 million. Line J was opened in 2008 (2.8 km) and a Line L (4.6 km) was inaugurated in 2009. Lines K and J are intended as urban commuter lines, while Line L is primarily for tourists. These lines provide access up steep mountainsides that line the Valley of Medellin.

Reference image

Journeys that once took 2 hours now take 30 minutes on the Metrocable. All lines can achieve speeds of up to 18 km/h with maximum headways of 12-14 seconds depending on the line. Line K of the Metrocable System handles up to 42,000 daily passengers and has a capacity of 3,000 pphpd. Average distance between pylons is about 100m.

Aerial Cable Car Case Study 2: Medellin, Colombia – High Capacity Urban Cable Car System

Planning Background:

Medellin is Colombia's second largest city and is located in a valley, surrounded by steep hills. Many of those hills are home to underdeveloped and low-income neighbourhoods, which are inaccessible by Medellin's metro system. These neighbourhoods are located on very steep slopes. Operating conventional buses in these areas is infeasible due to grades. In areas accessible for buses, operators found them to be financially infeasible. Before the implementation of the Metrocable Line K, residents of the Santo Domingo barrio, had extremely long commute times of nearly 3 hours each day.

An urban aerial cable car system called Metrocable was established in 2004 to feed into Medellin's metro system. Metrocable was designed specifically to provide connectivity to some of these hillside neighbourhoods of Medellin. Metrocable Lines J and K connect directly to the Medellin Metro system (see Yellow and Green lines on the Metro map respectively) and are well integrated into the Medellin Metro System. Selection of an aerial cable car was based on several key factors including: (i) maximum demand to be handled; (ii) projected capital and operating costs; (iii) land and topographic conditions; (iv) social implications; (v) environmental implications; and (vi) project life cycle costs.

The system has been well received by local residents and has received international acclaim. Interesting, at some stops, community centres and other civic buildings have been built next to cable car stations – a form of transit-oriented development – which benefits local residents and provides better access to social services. Two additional lines urban commuter lines, Line H and M, are under construction.

System & Service Characteristics:

- Total Number of Lines: 3 lines (Lines K and J are urban commute lines, while Line L is for tourists)
- Network Length: 9.5 km (2.1 km for Line K; 2.8 km for Line J; 4.6km for Line L)
- # of Stations: 4 for Line K; 4 for Line J; 2 for Line L
- Vehicle Type/Size: Cabins can hold up to 10 passengers (8 seated)
- Average Speed: 18 km/h (5-6 m/s)
- Service Hours: 5:00AM-10:00PM
- Headway: 12-14 seconds (depends on how many cabins are on the line, but the line can accommodate between 90-120 cabins at a time)
- Peak Capacity: 3,000 passengers per hour (Lines J and K); 1,200 passengers per hour (Line L)
- Capital Cost (FY2015): HK$279.0 million for Line K only (or FY2004 HK$201.5 million (US$26.0 million))

Performance Characteristics (2015):

- Peak Daily Ridership: 42,000 passengers per day (Line K); 28,000 passenger per day (Line J); 4,200 passengers per day (Line L)
- Peak Hourly Ridership: 2,850 passengers per day (Line K); 2,500 passengers per day (Line J); 850 passengers per day (Line L)

References:

- Email from Felipe Montoya Pino, Director of Business Negotiations, Metro de Medellin – April 12, 2016.
- http://gondolaproject.com/medellin/
- Julio D. Dávila and Diana Daste, Medellín's Aerial Cable-Cars: Social Inclusion and Reduced Emissions, https://www.bartlett.ucl.ac.uk/dpu/metrocables/dissemination/Davila-Daste-2012-UNEP.pdf

Aerial Cable Car Case Study 2: Medellin, Colombia – High Capacity Urban Cable Car System
• http://thinkprogress.org/climate/2012/03/13/443330/medellin-metro-system-colombia-public-transport/ • http://www.fta.dot.gov/images/photos/TRO_4/5.14_1530_Forgotten_Modes.pdf • http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3353133/ • http://www.thesundaily.my/news/939791 • https://www.metrodemedellin.gov.co/Portals/4/Images/Viajeconnosotros/Cuadro-sistema-2000x1624-25112015.jpg

3.2.5 Aerial Cable Car - Summary and Broad Applicability within KE

Pros	Cons
• Provides scenic and reliable journey that is not subject to road traffic or impacts from road users • Able to operate in mountainous terrain or to span a body of water that may be difficult or costly with a bus or rail-based system • Serves as both a commute and a tourist service in several cities • Requires minimal land takes compared to BRT or other rail-based systems • Less impact on roadways since mode does not operate at-grade • Provides sense of "permanence" that can encourage joint development • Aesthetically pleasing and limited visual impact compared to system requiring guideway	• Capacity on par with conventional bus or trolleybus, but much lower than rail or BRT • Evacuation issues if system breaks down • Unable to operate in inclement weather including heavy rains or high winds • More difficult to expand compared to other road-based modes • If demand patterns change, not flexible to allow route to be changed easily • Generally less accessible than street-running, at-grade mode for passengers, especially those with mobility issues • Requires specialised depot on-site • Section 11 of the Hong Kong Aerial Ropeways (Safety) Ordinance, Cap. 211 stipulates that no part of an aerial cable car shall pass over any building

Key Findings and Broad Applicability within KE

- Cable car typically plays a specialised role in the transport network, often as a feeder system to climb a steep gradient. The limited capacity of a single cable car system means that this mode is typically for lower capacity routes. Lastly, cable cars are impacted by the weather more than other modes and service stoppages are not uncommon during high wind and rain periods. Evacuation of cable cars is not as straightforward as other public transport modes and requires special rescue teams.
- The Ngong Ping 360 example is a successful demonstration of this technology in Hong Kong, although it is intended for tourists. Medellin and other South American cities show that cable car can be deployed in an urban context as a daily commute mode, rather than just a tourist mode. However, the rationale for selecting aerial cable car over other public transport modes is typically cost and physical constraints such as grade. Regardless of context (either as an urban or tourist mode), aerial cable car provides a low-moderate level of capacity due to weight limitations of the cable, which constrains the number of cabins and thus the hourly carrying capacity. The systems in Ngong Ping, Medellin, as well as La Paz are considered some of the highest volume systems in the world, with capacities up to 3,000-3,500 pphpd.
- The attractiveness of a cable car as both a commute and tourist mode may be appealing to KE, although the limited capacity means that cable car cannot play the role of a high-capacity system. Cable car would likely serve as a specialized feeder in a niche role. Integration of the cable car with other modes would need to be carefully planned to create a seamless journey if planned for commute purposes as the placement of the wheelhouse, stations and cable towers within KE would be limited due to tight spatial constraints in KE. Cable car crossing over KTTS between the tip of the runway and the Kwun Tong Promenade would possibly impose height restrictions on high mast vessels using the typhoon shelter unless the cable car system could allow an air draft of 41m or above. This would make the cable towers extremely tall and would occupy a large footprint along the shoreline. As noted by the Aerial Ropeway (Safety) Ordinance, no part of an aerial cable car shall pass over any building.

3.3 Bus

3.3.1 Bus - System Characteristics

Background and System Technology

3.3.1.1 Buses are motorised, rubber-tire vehicles operating on roads in mixed flow conditions. Buses can be powered by a variety of sources including diesel, gasoline, battery, or other alternate engines (including hybrids that combine an electric propulsion system with another powertrain system, usually a diesel system). Buses typically provide local service and play an essential public transport role in the overall transport network, providing a high degree of coverage and accessibility of all other motorised public transport modes.

3.3.1.2 Hong Kong franchised bus operators have begun testing of battery-electric buses for revenue service by the end of 2015. KMB's trial of supercapacitor buses is expected to commence progressively by the 2nd quarter of 2016. The largest hybrid bus fleets in the world are operated in Zhengzhou, London and New York City. Shenzhen operates the largest electric fleet.

3.3.1.3 For this section, the review will focus on typically manually operated buses. It is understood that driverless (autonomous) buses are being tested in several locations around the world – notably: (i) Singapore's Nanyang Technical University starting in early 2017 holding up to 15 passengers;[9] (ii) Trikala, Greece with 10-person electric vehicles operating along a 2.5 km route including in dedicated bus lanes;[10] (iii) Lyon, France operating 15 passenger minibuses on a 10 minute route, with average speeds of 10 km/hour;[11] and (iv) Zhengzhou, China, which is testing a self-driving bus between Kaifeng and Zhengzhou.[12] Buses are equipped with cameras, laser radars, and other sensors to allow lane changing and self-driving. These tests are relatively small-scale tests with smaller vehicles operating in relatively confined areas or segregated corridors. Given the evolving nature of this technology and the lack of adoption along a high demand route and in heavy traffic conditions, it is considered premature to assess the feasibility of driverless buses for KE at this time.

Role of Bus in Transport Hierarchy

3.3.1.4 Buses typically function as the local public transport system, and in some cases could also serve as the primary regional system, when no rail system exists. Buses can provide circulator, local, express and regional service. Where rail systems serve as the backbone, buses provide feeder services to/from the station to "extend" the catchment zone of the rail line and serve as the main public transport mode on secondary corridors.

[9] Source: http://fortune.com/2016/12/19/driverless-bus-singapore
[10] Source: http://gizmodo.com/5-cities-with-driverless-public-buses-on-the-streets-ri-1736146699
[11] Source: http://www.telegraph.co.uk/news/2016/09/03/worlds-first-driverless-bus-service-begins-carrying-passengers-i/
[12] Source: https://www.busbud.com/blog/will-driverless-buses-reality/

Key Infrastructure Elements and Vehicles

3.3.1.5 The main infrastructure elements for bus are the stops and vehicles. Buses are assumed to operate in mixed flow conditions without bus lanes or signal priority (to differentiate from Bus Rapid Transit, presented in **Section 3.4**, whose vehicles operate in segments of dedicated bus lanes). Buses are thus subject to traffic and intersection delays, as well as obstructions such as parked vehicles that can delay trips.

Runningway and Stops/Stations

3.3.1.6 Buses operate in mixed flow lanes and are thus subject to road traffic conditions and interference from mixed flow traffic, turning movements, parked vehicles and intersection delays.

3.3.1.7 Bus stops are of simple design that could be in the form of a sign post, placed along the kerb adjacent to the footpath. Some bus stops may have shelters, seats, or real-time bus information panels, etc. Typical stop spacing for conventional bus is between 250-400 m, although spacing may be even shorter in downtown and very dense areas.

Vehicles

3.3.1.8 Buses come in a variety of sizes as follows:

- **Single Deck 12 m Buses** – KMB operates 12 m buses that accommodate between 50-60 passengers including standees.
- **Double Deck 12 m Buses** – KMB also operates double deck 12 m buses that can accommodate up to 130 passengers. Singapore and London also operate double deck buses.
- **Articulated 18 m Buses** - Other systems outside Hong Kong also operate 18 m single deck articulated buses that can hold a similar number of passengers as a double deck 12 m bus (with capacity ranging from 120-170 passengers). Examples include Vancouver as well as New York City.

3.3.1.9 Vehicle propulsion varies and includes the following types of buses:

- **Diesel Bus** – Diesel buses are the most prevalent type of bus and use an internal combustion engine. Diesel models are increasingly being replaced with more environmentally friendly modes and efficient modes that pollute less and are quieter.
- **Hybrid-Electric Bus** – Also known as hybrids, these buses combine an electric propulsion system with another powertrain system, usually a diesel system. Hybrids may also run on compressed natural gas (CNG) or liquefied natural gas (LNG). Zhengzhou operates a fleet of over 3,000 hybrid vehicles, while London deploys over 600. Compared to a diesel bus, hybrids accelerate better from a stop, and operate more quietly and energy efficient.[13] One type of hybrid is a plug-in hybrid, whereby the electric

[13] In-use testing and industry reports indicate that particulate matter (PM) emissions can be reduced by as much as 75% when compared to conventional diesel buses, with nitrogen oxide (NOx) emissions reduced by 30-40%. Fuel savings is a key benefit of such vehicles – London estimates that a 35-45% reduction in fuel use has been

battery is charged by an external power source (when the bus is "plugged in" or connected to the source). Plug-in hybrids also have an on-board engine that can recharge the battery – Shenzhen and Zhengzhou have large plug-in fleets.

- **Electric Bus** – Electric buses operated completely on battery power and are considered a zero-emission vehicle. Electric buses accelerate better from a stop, and operate more quietly and efficiently than a diesel bus. Batteries must be recharged daily, however, some operators switch batteries throughout the day to minimise down time. In trials in New York City, 12 m electric buses had a range of up to 250 km on a full charge of about 3-4 hours.[14] Articulated 18 m electric buses from BYD have a similar range and charge time according to manufacturer specifications, under a two month pilot test in New York City.[15] Compared to hybrids, electric buses are lighter and have more room for passengers as the powertrain system is no longer needed. However, range is shorter due to battery capacity, which requires recharging or replacement. Shenzhen has a fleet of over 250 fully electric buses produced by BYD.[16] Electric bus technology is still evolving. Some examples include:
  - Hong Kong's Kowloon Motor Bus Co., Ltd. has trialled the supercapacitor bus (the gBus[2]), which has fast charging batteries that enable a range of 8-10 km. Each km of operation requires a 30 second charge.
  - Beijing is planning to deploy a remote, fast-charge system along its routes that would eliminate the need to swap batteries. The Beijing system is similar to the charging system trialled for the Shanghai 2010 World Expo where buses were recharged at stops during passenger loading and unloading.
  - Montreal, Canada will begin testing of a "fast-charge" system similar to the Shanghai trial in 2016 that will remotely charge vehicles at stops either through induction pads beneath the bus stop or overhead contact charging units (see **Figure 3.3.2**) – providing a 400 kW boost in 15 seconds.[17]

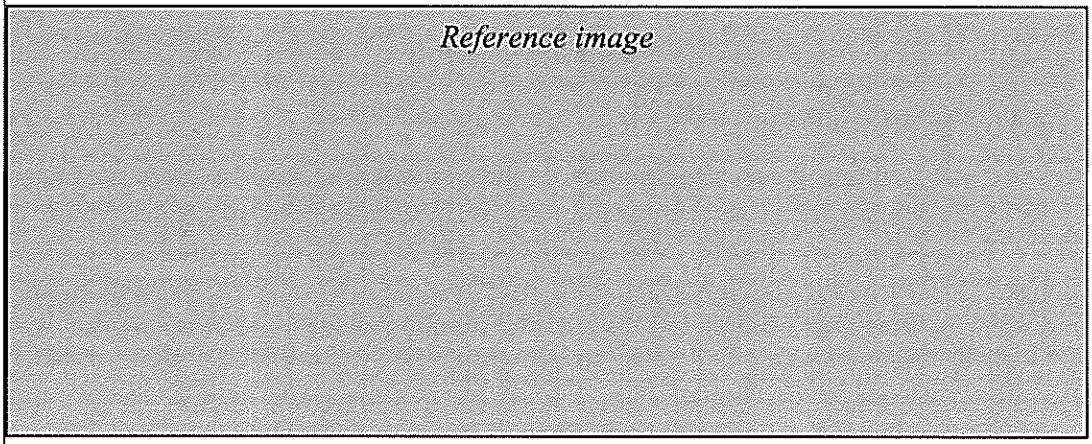
achieved, while New York City estimates a savings of 20-30%. Currently, hybrid-electric buses are heavier than conventional diesel buses due to the battery size and weight.

[14] BYD Electric Bus Provides 30-h Service on Single Charge, SAE International, retrieved 2016 May 3 from: http://www.articles.sae.org/12804/

[15] BYD, 18M Articulated Electric Bus from http://www.bydeurope.com/downloads/eubs_specification/BYD_18_Meters_Electric_bus.pdf

[16] Earley, R., Kang, L., An, F., Weiskel, L., *Vehicles in the Context of Sustainable Development in China*, United Nations, Department of Economic and Social Affairs, Commission on Sustainable Development, Nineteenth Session, New York, 2-13 May 2011.

[17] Flash Charging, retrieved 2015 Dec. 12 from: http://www.stm.info/en/about/major_projects/electrification-surface-system



Source: http://www.abb.us/cawp/seitp202/f32c9ded54dc0b20c1257b7a0054972b.aspx

Figure 3.3.2: Proposed Fast Charge Scheme in Montreal

- **Fuel Cell Bus** – This type of bus uses a hydrogen fuel cell as its power source, sometimes augmented in a hybrid fashion with batteries or a supercapacitor. Fuel cell buses are also considered a zero-emission vehicle. The propulsion system is powered by combining hydrogen and oxygen in an electro-chemical process. Fuel cell technology is still evolving and widespread adoption of such vehicles has not occurred. Deployment is mostly on a trial or demonstration basis – the largest fuel cell fleet is operated in Whistler outside of Vancouver, Canada.

Capital Costs and Operating Costs

3.3.1.10 The table below compares acquisition price for various types of buses by region. This survey was based on findings from China, India, Russia, Latin America, Europe and North America and averaged together to provide a composite amount for comparison. Prices range from HK$1.6 million for a diesel bus to HK$3.7 million for an electric bus. Markup for a hybrid is about 65% over a diesel, while that for an electric is about 140% over a diesel model. Electric buses have higher average costs than hybrids due to costs associated with charging infrastructure as well as the limited number of suppliers.

Table 3.3.5: Average Unit Cost Comparison for Buses by Propulsion Type (in FY2012 and in Equivalent FY2015 Costs)

Average Unit Cost	Diesel	Hybrid	Electric	Mark-up Hybrid vs. Diesel	Mark-up Electric vs. Diesel
US$2012	$200,000	$330,000	$480,000	65%	140%
HK$2012	$1.55 million	$2.56 million	$3.72 million		
HK$2015	$1.74 million	$2.87 million	$4.18 million		

Source: Frost & Sullivan, Strategic Analysis of Global Hybrid and Electric Heavy-Duty Transit Bus Market, 08/2013; original figures are based on regional market price in US$2012. Conversion based on Hong Kong Consumer Price Index changes. The escalation factor from 2012 to 2015 is 1.123.

3.3.1.11 Vehicle cost is only one part of the overall picture. Capital costs are assumed to include the vehicle purchase price and infrastructure modification. Also though, operating costs must be considered (i.e., fuel, parts support, personnel training, labour and additional insurance) in the total decision. **Table 3.3.6** presents a comparison of the investment price for a hybrid, electric, and diesel 12 m bus. Key components are as follows:

- **Investment Cost** - The investment cost of hybrid/electric buses vary considerably according to the transit agency specification and the order number. In the table below, investment cost ranges from (HK$1.2 million or US$150,000) for a diesel bus, to nearly (HK$2.4 million or US$300,000) for either a hybrid or electric bus.
- **Maintenance Cost** - For hybrids, maintenance costs are comparable to those for conventional diesel units. Battery replacement or leasing costs for hybrid and electric buses are significant cost components that can potentially offset fossil fuel savings. The differential investment between hybrids and diesel units is, next to the fossil fuel price, the core factor determining the profitability of hybrid buses. Price differences between manufacturers of hybrid buses are significant and greatly influence profitability. It is estimated additional investment in hybrids can be repaid in 5-6 years if diesel prices are at least US$1.10/litre and annual distance driven is 60,000 km or more.[18]

Table 3.3.6: Equivalent FY2015 Investment Cost of a 12 m Vehicle (Hybrid vs. Electric vs. Diesel)

	Diesel Hybrid Bus		Electric Bus	Diesel Bus
City, Country	Bogota, Colombia	Zhengzhou, China	Shenzhen/Zhengzhou, China	
Manufactory	Volvo	Yutong	Yutong/BYD	-
Investment Cost (FY2015 US$)	US$290,000	US$185,000	US$300,000 (Outside China the BYD bus is known to be sold at US$650,000)	US$150,000
Investment Cost (FY2015 HK$)	HK$2.25 million	HK$1.44 million	HK$2.33 million (or HK$5.04 million outside of China)	HK$1.16 million
Fuel Cost	Diesel: US$1.12/l	Diesel: US$1.16/l CNG: US$0.52/m3 Electricity: US$0.08/kWh	Electricity: US$0.08/kWh	Diesel: US$1.16/l
Annual Distance Driven	65,000 km	55,000 km	60,000 km	60,000 km
Lifespan of Bus (Years in Use)	12-15	8	8	8

Source: Grutter Consulting, Real World Performance of Hybrid and Electric Buses, 2014.

[18] Grutter Consulting, Real World Performance of Hybrid and Electric Buses, 2014.

3.3.2 Bus – Operating Characteristics

Service and Passenger Capacity

3.3.2.1 As noted, buses may be used for local, circulator, express or limited service. Local buses operating in mixed flow urban street conditions can operate anywhere from 6 to 15 km/h depending on traffic conditions and period of the day. Express buses operating on highway can operate considerably faster due to fewer stops and faster highway speeds. Headway varies based on demand, with typical peak headways as low as 5 minutes (or 12 trips per hour) in Hong Kong, with longer headways during the mid-day and off-peak periods (one sample route operating at such headways is KMB Route 42A between Cheung Hang and Jordan (To Wah Road), which operates at 4-6 minute headways during the weekday 5:30AM-6:30PM period).

3.3.2.2 Assuming a double decker bus in Hong Kong carrying 130 people and operating at 5 minute headways, in theory, the maximum load (in terms of passengers per hour per direction) at any given location could be up to 1,560 passengers. Within a corridor, several routes may provide overlapping service along a common segment which could increase corridor capacity, but issues with bus interference and merging, as well as station sizing could reduce capacity, service reliability, and efficiency of the corridor without dedicated stations and bus lanes (which are some of the key advantages of Bus Rapid Transit as described in **Section 3.4**).

3.3.3 Bus – Other Key Characteristics

Reliability

3.3.3.1 Buses operate in mixed flow traffic and are thus subject to conflicts from mixed flow traffic, turning movements, parked vehicles, and intersection delay. Depending on the design of bus stops/stations, buses may interfere with one another at stops due to queuing, boarding, and alighting that could affect service reliability and efficiency.

3.3.3.2 In terms of reliability of the technology, conventional diesel bus is still the most reliable and durable form of bus. The Grutter study concluded that hybrids have a reliability on par with conventional fossil fuel buses, although electric bus reliability is below that of conventional diesel and hybrid buses.[19] In terms of bus availability to provide service, hybrids often have slightly lower availability (one study found a 10% lower availability than diesel buses) due to a smaller hybrid versus conventional fleet and lack of know-how and spare parts.[20]

3.3.3.3 The Grutter study found that electric buses suffer more frequent breakdowns than diesel or hybrid buses, while also taking longer to return to service due to lack of spare parts. The study found the electric buses have a 30% lower availability rate than conventional diesel units. The study also concluded that electric buses are still evolving and thus have more "technical difficulties, less trained maintenance staff, and not readily available spare parts due to the limited amount of units". [21]

[19] Grutter Consulting, Real World Performance of Hybrid and Electric Buses, 2014.
[20] PE International, Abschlussbericht Plattform Innovative Antriebe Bus, realized for BMVBS, 2011
[21] Grutter Consulting, Real World Performance of Hybrid and Electric Buses, 2014.

Impacts to Other Road Users

3.3.3.4 Buses operate in mixed flow traffic conditions and share lanes with other road users. Thus, buses will take up some road space and affect other road users.

Land Requirements

3.3.3.5 Buses require kerbside stops that may require limited width along a sidewalk. Since buses operate in mixed flow, no dedicated bus lanes are required. Electric buses that are remotely charged in the field would require space for charging pads or overhead charging units. Buses would use existing depots – although these depots may need modification to handle batteries or charging units.

Transit Oriented Development (TOD) Implications

3.3.3.6 Buses operating in mixed flow conditions with other traffic on public roads without designated infrastructure. Furthermore, bus routes can be easily changed to deal with changes in demand. Thus compared to fixed guideway systems such as rail or BRT, bus typically does not support TOD along a route.

Safety and Evacuation Requirements

3.3.3.7 Bus safety regulations and requirements are stipulated by TD. Safety and evacuation guidelines for conventional bus are applicable.

Environmental Implications

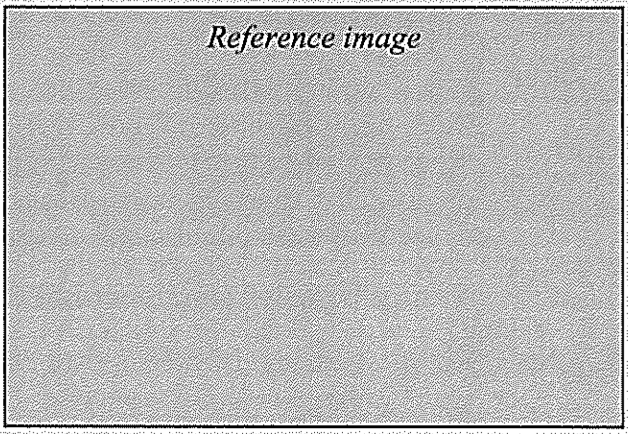
3.3.3.8 Hybrids operate cleaner and more environmentally-friendly than those using diesel. Electric vehicles generate no emissions are operate cleaner than either hybrid or diesel vehicles. Buses still generate noise, although noise can be minimised with fully electric operations.

3.3.4 Bus – Case Studies

3.3.4.1 Three case studies are presented: (i) Hong Kong SAR – Electric Bus Trials; (ii) Shenzhen Electric Buses; and (iii) New York City Hybrid Buses.

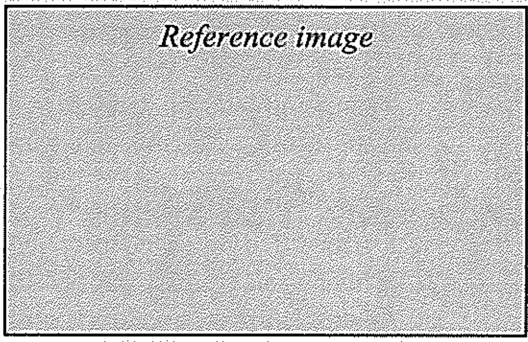
Bus Case Study 1: Hong Kong SAR, China - Electric Bus Trials

System Description:



Franchise bus operators in Hong Kong operate some of the largest fleets in the world, consisting of both single deck buses and double deck buses. Collectively, over 5,800 franchised buses operate in Hong Kong. In 2010, the Hong Kong Government announced its policy objective was to eventually have a fully zero-emission bus fleet. As a start, the Hong Kong Government approved a trial to purchase eight super-capacitor buses and 28 battery-electric buses (for a total of 36) and related charging facilities for trial in Hong Kong. The total subsidy amounts to HK$180 million. These vehicles are zero-emission vehicles.

Kowloon Motor Bus Co. (1933) Ltd. (KMB) began its own trials of supercapacitor vehicles in 2010 and 2012. Known as the "gBus", the buses would rapidly charge at bus stops during boarding and alighting. The first generation of gBus (manufactured by SUNWIN) in 2010 could run for 4-5 km after a 30 second charge, while the next generation of $gBus^2$ (manufactured by Youngman) in 2012 could run for 8-10 km. These trials were only for testing purposes and no passengers were allowed to board. $gBus^2$ could operate at speeds up to 70 km/h and climb grades up to 15%.



Citybus and New World First Bus (NWFB) are being fully subsidised by the Government to purchase 10 single-deck electric buses. The first batch of five government subsidised single-deck electric buses began operation in late December 2015 on three Citybus and two New World First Bus (NWFB) routes on Hong Kong Island. The first batch of electric buses is manufactured by BYD. These buses are 11.6 m pure electric buses using iron-phosphate batteries. The buses have a total capacity for 68 passengers including 31 seats. According to BYD, the bus can travel continuously for about 250 km upon a full charge of about 4 hours at the bus depot.

During the trial, one of the prototype buses caught fire on 13 December 2015. It was found that human error that "comprised the water sealing of the batter casings during performance tuning and inspection allowed water to seep into the casings and eventually led to short-circuiting of the battery. As a precaution against future incidents, the manufacturer pledge to tightly seal the battery casings to prevent water seepage.

Planning Background:

Hong Kong has one of the highest public transport mode shares in the world. The rail and franchise bus networks account for the majority of trips. Some 5,800 franchised buses operate on the streets of Hong Kong every day, with the majority of these run on diesel. In 2010, the Government announced its policy objective to operate a fully zero-emission bus fleet in the territory in the future. Subsequently it provided funding of HK$180 million to fully subsidized five franchised bus companies to purchased eight super-capacitor buses and 28 battery-electric buses for trails over a two-year period. The scope of the trials focus on the reliability of buses, batteries/supercapacitors and charging facilities, as well as maintenance requirements and economic feasibility. All vehicles must be Road Traffic Ordinance (Cap. 374) and its subsidiary regulations before the vehicle can run

Bus Case Study 1: Hong Kong SAR, China - Electric Bus Trials

on the road.

System & Service Characteristics (Citybus and NWFB):

- Total Number of Lines: 5 (Citybus and NWFB have deployed the vehicles on 5 lines)
- Vehicle Type/Size: 11.6 m (electric) with a total capacity for 68 passengers (including 31 seats)
- Average Capital Cost (FY2015): HK$5 million per unit with charging facilities (average cost based on total subsidy amount for 36 vehicles)

References:

- http://www.info.gov.hk/gia/general/201512/27/P201512240752.htm
- http://www.epd.gov.hk/epd/english/news_events/legco/files/EA_Panel_20120528b_eng.pdf
- http://www.kmb.hk/en/news/press/archives/news201204261651.html
- https://www.nwstbus.com.hk/en/uploadedPressRelease/8237_30072015_eng.pdf
- http://www.scmp.com/news/hong-kong/article/1937749/technical-staff-mainland-china-blame-hong-kong-electric-bus-prototype
- LegCo Q17 (27 Jan 2016) – Reply by Secretary for the Environment

Bus Case Study 2: Shenzhen, China – Hybrid and Electric Bus Fleet

System Description:

Reference image

Shenzhen is a leader in electric bus technology and deployment. As of 2011, Shenzhen operated a fleet of 1,750 single-deck hybrid buses, 20 double-deck hybrid buses, as well as 253 fully electric buses. These hybrid and electric vehicles are operated on 136 routes. Several routes use electric vehicles exclusively, including Route 226, which is 28.5 km long and has 50 stations.

Planning Background:

The Shenzhen Municipal Government aims to replace its entire bus and taxi fleets with electric vehicles. In 2011, this represented some 10,000 buses and 13,000 taxis. Its 2010-15 fleet electrification plans call for 150 charging centres to be in place by the end of 2015. The impetus for this effort was the 2011 World University Games, whereby green and sustainable were key themes. These low and zero-emission vehicles would help Shenzhen better deal with emissions and dangerous fine respirable particles from its growing population of over 13 million and increasing motorisation. Shenzhen is the home of several major electric and zero-emission bus manufacturers which has expedited on-street trials.

System & Service Characteristics:

- Total Number of Lines: 136 routes (using hybrid or electric buses)
- Vehicle Type/Size: 1,750 single-deck hybrids, 20 double- deck hybrids, and 253 fully electric vehicles (as of 2011)

References:

- http://www.plugincars.com/all-shenzhen-buses-and-taxis-be-electric-five-years-110398.html
- http://www.swinburne.edu.au/fset/csi/news/half-shenzhens-buses-to-be-electric-or-hybrid-/
- 226 路 深圳首条纯电动大巴公交路线开通, 2012
  http://www.evdays.com/html/201209/38496.html

Bus Case Study 3: New York City, United States – Hybrid Bus Deployment

System Description:

Reference image

New York City's Metropolitan Transportation Authority (MTA) operates the largest bus fleet in the United States with over 5,700 vehicles. In 2013, diesel-hybrid vehicles comprised over one quarter of the total bus fleet with 1,677 hybrids. The first 10 hybrids cost US1.0 million (HK$7.8 million) each. Purchase price per vehicle decreased to US$700,000-US$800,000 (HK$5.4 to HK$6.2 million) in the last contract.

Since 2010, MTA decided to stop purchasing hybrid buses due to fuel efficiency issues in New York City's stop and go congestion, and due to improved efficiency of newer diesel models. Hybrid battery replacement generated higher operating costs due to the cold New York climate.

A trial in 2014 was held to assess the performance of a BYD electric bus. Results found that under New York City's harsh operating environment, with frequent stops and slower operating speeds, the electric bus performed well with an average range of 140 miles per charge in heavy traffic (at about 4 miles/hour or 6.5 km/h). This was equivalent to 30 hours of operation per full charge.

Planning Background:

In responding to the air pollution on city streets in the mid-1990s, New York City officials looked at alternatives means to reduce bus related emissions. Trials of hybrid technology were undertaken to look for alternatives besides CNG technology (which was considered infeasible due to space constraints at existing depots). The first of 10 heavy-duty hybrid buses began MTA (New York Metropolitan Transportation Authority) operations in 1998.

System & Service Characteristics:

- Vehicle Type/Size: 12 m and 18 m hybrid vehicles (1,677 vehicles as of 2013)
- Capital Cost (FY2015): HK$5.8 to HK$6.7 million/vehicle for hybrid only (or FY2013 HK$5.4 to HK$6.2 million/vehicle)

References:

- http://insideevs.com/byd-and-new-york-metropolitan-transportation-authority-complete-successful-pilot-test-of-byd-electric-bus/
- MTA Hasn't Purchased a Hybrid Bus in Three Years-and New Diesel Engines Could Make a Return, retrieved 2015 Dec. 12 from: http://nypost.com/2013/06/30/mta-hasnt-purchased-a-hybrid-bus-in-three-years-and-new-diesel-engines-could-make-a-return/

3.3.5 Bus - Summary and Broad Applicability within KE

Pros	Cons
• Most flexible motorised public transport mode that can operate where demand warrants • More accessible than grade separated modes, especially for passengers with mobility issues • Reduced emissions from hybrid or electric vehicles compared to traditional diesel buses • Minimal capital investment required to initiate service • Easy to amend routes and stops • Lowest operating costs of all motorized public transport modes • Smallest footprint requirement • Depot may be off-site reducing overall footprint requirements	• Operates on-street in mixed flow traffic conditions, which reduces operating speeds and reliability • Frequent stops at intersections and at bus stops decrease average speed • Low capacity and operating speed compared to other bus-based systems and rail systems • Increases number of vehicles on the road and congestion • Does not facilitate TOD or a sense of "permanence" compared to other modes

Key Findings and Broad Applicability within KE

- Bus, regardless of propulsion technology (diesel, hybrid, or electric), operates in mixed flow lanes and provides a high level of accessibility and convenience for passengers. It is an essential public transport service of the overall public transport network. Compared with railway, bus is constrained by its low capacity, low operating speed and susceptibility to road conflicts and reliability issues as it operates in mixed flow lanes and is often interfered with by other road users.
- Green bus (either hybrid or electric) are similar to conventional bus in transport performance, except they utilise green energy. Subject to development and on-going trials, green bus will progressively replace conventional diesel buses. Regardless, bus will still serve a key role as the principal mode for local service and in a feeder role for higher capacity systems.
- The case studies in Hong Kong, Shenzhen and New York City show that "clean" and "zero-emission" bus technologies have quickly evolved and such vehicles have been adopted and shown to function sufficiently within a congested urban environment, without harsh weather conditions. The Hong Kong examples are particularly interesting to see how performance aligns against current hybrid or clean diesel models.
- In the context of KE, conventional bus can play various roles in the public transport system, as a local circulator or distributor, or as inter-district or express services connecting KE with other parts of the territory via strategic routes. Bus service would always be required in KE. As the railway system serves as the backbone of the transport system, bus could supplement this in areas not covered by the railway network. Bus could also play a feeder role, providing shuttle services to better connect the railway system. Where there is no railway system, bus would play a more essential role in the public transport system by providing necessary connectivity at local, intra-district, intra-district and strategic levels.

3.4 Bus Rapid Transit (BRT)

3.4.1 BRT - System Characteristics

Background and System Technology

3.4.1.1 Bus Rapid Transit (BRT) is a premium level of bus-based public transport within a defined corridor, operating with dedicated lanes, bus signal priority, off-board fare payment, level boarding, and all-door boarding and alighting.[22] Semi- or fully dedicated bus lanes minimise conflict with mixed flow traffic and pedestrians and allow BRT to operate more reliably and faster than conventional bus systems. BRT also can serve higher ridership volumes per hour relative to other conventional road-based public transport modes due to its dedicated route and signal priority at junctions.

3.4.1.2 BRT is typically implemented on longer corridors dotted with higher density activity centers or development nodes that provide connections between downtowns, employment centers and outlying residential and commercial centres. BRT vehicles are often stylized to give a modern appearance and can include bi-articulated vehicles that can accommodate up to 270 passengers per vehicle.

3.4.1.3 The first BRT system was implemented in Curitiba, Brazil in the mid-1970s. The most well-known and highest capacity BRT systems are found in Asia and South America such as the Guangzhou BRT in Guangzhou, China and TransMilenio in Bogota, Colombia – both of which have been shown to carry upwards of 25,000 pphpd. More medium capacity systems, in the range of about 10,000 pphpd, include the: (i) Xiamen BRT in Xiamen, Fujian, China; (ii) Lanzhou BRT in Lanzhou, Gansu, China; (iii) Seoul BRT in Seoul, South Korea; (iv) TransJakarta in Jakarta, Indonesia; and (v) Metrobús in Mexico City, Mexico.

3.4.1.4 Most BRT systems operate at-grade with bus lanes delineated on city streets and grade crossings, although some operate on fully grade-separated guideways (without grade crossings) such as the systems in Ottawa, Canada and Pittsburgh, United States. There are also some systems that operate principally on elevated viaducts including: (i) the Xiamen BRT; (ii) the BRT Sunway in Kuala Lumpur, Malaysia; and (iii) the Nagoya BRT in Nagoya, Japan.

Role in Transport Hierarchy

3.4.1.5 BRT's role in the overall transport hierarchy depends on the context. In some locations, BRT serves as the principal public transport trunk system, with multiple BRT routes, operating on the main corridors without an accompanying urban rail network. This is currently the case for BRT in Curitiba, Brazil and TransJakarta in Jakarta, Indonesia. In larger cities with established urban rail networks, BRT plays a role as a major feeder system to the urban rail network and providing higher capacity service on secondary corridors with space or physical limitations or lack of supportive population densities to warrant an urban rail line.

[22] So-called Rapid bus systems in the United States and Canada deploy bus signal priority and branding, but not dedicated bus lanes. BRT in the context of this Working Paper refers to those systems with dedicated bus lanes.

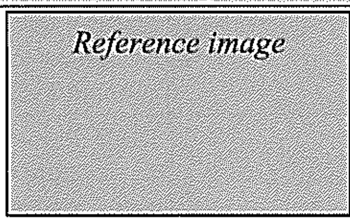
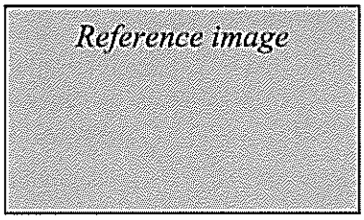
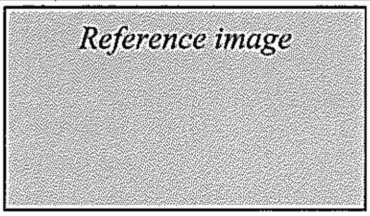
Key Infrastructure Elements and Vehicles

3.4.1.6 The main difference between bus and BRT service is the level of segregation and priority provided to BRT vehicles. Buses normally operate in mixed flow traffic conditions, subject to delay from conflicts with other street users (including motorised vehicles, cyclists, and pedestrians), as well as delay at intersections and bus stops. BRT seeks to minimize conflicts with road users by providing priority for vehicles through a combination of segregated bus lanes, and bus signal priority. BRT can consist of a single line, or multiple lines within a given corridor using the same infrastructure.

Runningway and Stops/Stations

3.4.1.7 In 2012, the Institute for Transportation and Development Policy (ITDP) published a "BRT Standard" to facilitate standardisation and comparison of different BRT systems. According to the standard, there are five essential infrastructure features that define BRT (these features represent the highest standard of BRT such as those in Guangzhou and Bogota) as described in **Table 3.4.7**.

Table 3.4.7: Essential Defining Infrastructure Features of Various BRT Systems

BRT Feature	Description	Example
Dedicated Bus Lanes	Dedicated lanes for BRT operations may be at-grade, elevated, or underground. The Guangzhou BRT, the former Taichung BRT, and Jakarta's TransJakarta systems are examples of at-grade BRT. The Xiamen BRT, BRT Sunway in Kuala Lumpur, and Nagoya BRT are examples of elevated systems. Xiamen's system has 35 km of elevated route out of the total 49 km network. Boston's Silver Line BRT operates a portion underground, although fully underground BRT systems do not exist. Dedicated lanes can be physically segregated with varying degrees of permeability (necessary in case of breakdowns). Physical segregation could be achieved with one or more of the following elements: physical barriers such as raised kerbs or small blocks, bollards, colorized pavement, and camera enforcement. In some systems, passing lanes are provided at stations as well. Bus lanes are typically 3.5 m in width, with passing lanes at stations typically 3.0 m to 3.5 m in width.	 TransJakarta BRT (At-Grade)  Xiamen BRT (Elevated System)
Bus Lane Alignment	The bus lanes are best located where conflicts with other traffic can be minimized, especially from turning movements from mixed-traffic lanes. In most cases, bus lanes in the central median of a roadway have fewer conflicts with turning vehicles compared to kerbside bus lanes. The Guangzhou BRT and Bogota's TransMilenio both are "centre-running" systems with bus lanes and stations in the middle of the road.	 Guangzhou BRT (Centre-Running)

BRT Feature	Description	Example
Off-board Fare Collection	Conventional buses are slowed at stops when passengers pay for fares upon entering the bus. Off-board fare collection eliminates delay from passengers paying fares at the entrance and can significantly reduce station dwell time and allow faster boarding and alighting. The faregates are similar to those used for a rail system.	*Reference image* Bogota TransMilenio – Off-Board Fare Payment
Intersection Treatments	To minimise intersection delay, BRT systems often adopt several strategies. Bus signal priority seeks to elongate the green time for approaching vehicles to allow them to pass through the intersection. Priority also can shorten the red cycle time for BRT vehicles during a red light. Such systems detect an approaching vehicle. Turning restrictions may also be adopted to reduce delay at intersections with high volumes of vehicles and pedestrians. Queue jump lanes and bus-only signals are deployed to allow buses to enter the intersection before other vehicles. Lastly, pedestrian and vehicular crossings may be grade-separated to allow vehicles to pass through an intersection without stopping.	*Reference image* Las Vegas BRT – Bus-Only Signal/Sign
Platform-level Boarding	High floor vehicles experience longer dwell time as passengers must "step-up" to enter the vehicle and "step-down" to exit the vehicle. Level boarding reduces boarding and alighting times. The BRT systems in Mexico City, Jakarta, and Bogota all use level boarding. Some systems also installed platform screen doors for safety as well as to increase effective queuing area such as Guangzhou and Bogota.	*Reference image* Bogota TransMilenio – Platform-Level Boarding

Source: Institute of Transportation and Development Policy (ITDP), BRT Standard, 2012.

3.4.1.8 Some BRT stations have rail-like amenities including turnstiles, ticket vending machines, real-time bus arrival panels, and platform screen doors. Stations can be on centre platform or side platforms. Key attributes for BRT stations are as follows:

- **Station Spacing** – BRT station spacing is typically 500 m to 1,500 m. Example station spacing by system include the following: (i) Bogota BRT – 790 m; (ii) Guangzhou BRT – 880 m; (iii) Hangzhou BRT – 1,100 m; (iv) Lanzhou BRT – 650 m; (iv) Mexico City BRT – 600 m; and (v) Xiamen BRT – 1,300 m.
- **Station Width** – BRT station platforms are typically between 4.0 m to 5.0 m including walls and doors and depend on the demand and number of routes simultaneously served. Examples include: (i) Guangzhou BRT – 5 m side platforms; (ii) Lanzhou BRT – 4 m centre platforms; and (iii) Bogota – 5 m centre platforms. Addition of bus lanes on each side results in a station profile width of about 11 m to 12 m.

- **Station Length** – Station length is highly variable depending on the number of boarding bays, and the size of the vehicle. Those stations accommodating multiple vehicles simultaneously will be longer. Those stations with multiple, separate boarding areas will be even longer. Example station lengths by system are as follows: (i) Bogota – 55 m-365 m (includes multiple, separate boarding areas); (ii) Guangzhou – 55 m-285 m (includes multiple, separate boarding areas); (ii) Jakarta – 15 m-90 m; (iii) Mexico City – 65 m-160 m; (iv) Nagoya - 30 m; and (v) Xiamen 40 m-70 m;

3.4.1.9 Longer stations and passing lanes allow for higher capacities to be achieved as described in **Table 3.4.8**.

Table 3.4.8: Additional Station Elements for a High Capacity BRT System

BRT Feature	Description	Example
Passing Lanes at Stations	Passing lanes at stations allow a BRT system to provide express or limited stop services to improve travel time savings. Passing lanes at stations also allow for greater capacity as multiple boarding areas for a single station may be used simultaneously. A single lane system with multiple boarding areas is constrained as the vehicle in the first bay would block vehicles from entering the station unless vehicles arrive in convoys.	*Reference image* Bogota TransMilenio – Passing Lanes and Elongated Station
Elongated Stations with Multiple Boarding Platforms	More robust BRT systems have longer stations with multiple docking bays, which along with passing lanes allow multiple routes to serve the same station simultaneously. This can significantly increases capacity of a station and corridor and is one of the key reasons how BRT can accommodate higher demands than a normal bus. The Bogota TransMilenio station shown in this table has three separate boarding areas in each direction and can handle up to six BRT vehicles simultaneously. The station shown above is approximately 200 m long.	*Reference image* Bogota TransMilenio – Elongated Station with Multiple Boarding Areas

Vehicles

3.4.1.10 BRT vehicles are similar to normal buses. They are often stylized and branded to give off a rail-like appearance and are designed for quick boarding and alighting with fewer seats than typical buses and designed for level boarding (without a step up or step down). Vehicle capacity varies from 60-270 passengers per vehicle, depending on the type of vehicle (please refer to **Table 3.4.9**) and can include typical 12 m buses, articulated 18 m buses, and bi-articulated 24 m buses.

3.4.1.11 **Table 3.4.9: Typical Size and Capacity of BRT Vehicles**

	Standard Vehicle	Articulated Vehicle	Bi-Articulated Vehicle
Photo	*Reference image*	*Reference image*	*Reference image*
Vehicle Length (m)	12	18	24
Capacity (Passengers/ Vehicle)	60-80	120-170	240-270
Examples	Guangzhou, Mexico City, Nagoya, Xiamen	Bogota, Curitiba, Mexico City, Guangzhou, Jakarta, Seoul, Taichung, Xiamen	Bogota, Curitiba, Mexico City

Source: ITDP, BRT Bus Rapid Transit Guide – Complete Guide, 2007.

Note: Most BRT systems operate with articulated vehicles, although some specific routes may use smaller vehicles depending on demand. Nagoya is one of the few systems that operates exclusively with smaller, 12 m vehicles.

3.4.1.12 BRT vehicles typically operate on CNG (compressed natural gas), clean diesel, or as hybrids. The table below provides an overview of vehicle type by propulsion used around the world. Systems using various types of vehicles. Currently, electric vehicle deployment for BRT operations is not widespread. The Quito BRT (Ecuador) and Boston Silver Line (United States) operate on electric catenary for portions of the route – which can be considered trolleybuses.

3.4.1.13 Deployment of independent, battery-powered electric BRT vehicles without catenary has yet to take hold throughout the industry. Kuala Lumpur's Sunway BRT is purported to be the only BRT system in the world operating with a fully electric fleet (operating a fleet of 15 x 12m vehicles up to 250 km on a 3-4 hour charge, with average speeds of 30-40 km/hour). Jakarta has come to an agreement with the Chinese electric vehicle manufacturer, BYD, to supply electric BRT vehicles for the TransJakarta. The Indianapolis BRT (United States) is currently under construction and will be North America's first all-electric BRT system when it opens in 2018 using 18 m articulated units.[23]

[23] Based on previous analysis undertaken by the consultants for other BRT systems around the world, electric BRT vehicles currently have the following disadvantages compared to hybrid or clean diesel units: (i) battery technology is still not sufficiently cheap or fully reliable for articulated vehicles, full of passengers (as noted in the bus section, electric vehicles are still considerably more expensive than hybrid or diesel units); (ii) the battery would require recharging during the day, which increases the layover time and the number of peak vehicles needed for service (and thus overall fleet required for service); (iii) cost recovery for a standard 12m bus was calculated as 8-10 years for an electric versus a diesel, however, if battery replacement is required within this period, then electric bus costs are likely to be marginally greater than for a conventional diesel bus; and (iv) payback for an articulated 18m unit is likely to be even higher. In addition, agencies have been reluctant to deploy electric vehicles into BRT services as they have yet to be tested and vetted, while special maintenance facilities and personnel are needed for electric units. As seen by the Kuala Lumpur Sunway BRT and the upcoming deployments for TransJakarta and the Indianapolis BRT, as technology, range and costs of electric units continues to improve, it is likely operators will shift to fully electric BRT fleets in the future.

3.4.1.14 **Table 3.4.10: BRT Vehicle Propulsion Type (as of May 2016)**

System	Year Built	KM	# of Stations	Propulsion Type		
				Electric	Hybrid	Diesel / LPG / CNG
BRT Rio, Rio de Janeiro, Brazil	2012	140.0	215			X
BRT Sunway, Kuala Lumpur, Malaysia	2015	5.4	7	X [A]		
Eindhoven BRT, Eindhoven, Netherlands	2004	12.0	32			X
Guangzhou BRT, Guangzhou, China	2010	22.5	26		X	X
Health Line BRT, Cleveland, USA	2008	15.0	58		X	
Indianapolis BRT, Indianapolis, USA	2018	21.1	28	X [B]		
Metrobus, Istanbul, Turkey	2007	50.0	45		X	X
Metrobus, Mexico City, Mexico	2006	81.5	115		X	X
Metronit, Haifa, Israel	2013	60.0	101		X	X
Taichung BRT Blue Line, Taichung, Taiwan	2014	17.2	21		X	
TransMilenio, Bogota, Colombia	2000	84.0	142			X
TransJakarta, Jakarta, Indonesia	2004	148.0	210	X [C]		X
Tschwane, Pretoria, South Africa	2014	80.0	51			X
Xiamen BRT, Xiamen, China	2008	52.0	42			X

Source: http://www.worldbrt.net, supplemented by sources noted below.

Notes:

[A] Kuala Lumpur's BRT Sunway uses BYD (Shenzhen manufacturer) lithium ion phosphate batteries on this elevated busway. Buses can purportedly operate up to 250 km on a single charge of 3-4 hours (allowing for up to 23 roundtrips per day). So far, a fleet of 15 x 12m buses has been in operation, carrying up to 67 passengers, and operating at an average speed of 30-40 km/hour. It is considered to be the first BRT system to deploy electric buses on a regular (non-trial) basis. (http://www.thestar.com.my/business/business-news/2015/03/18/brtsunway-line-nears-completion/?style=biz)

[B] The planned Indianapolis BRT is slated for completion in 2018 and is planned to be North America's first all electric BRT, with 12 x 18 m articulated buses. (http://www.indygo.net/redline/)

[C] TransJakarta has agreed in September 2015 to partner with BYD (Shenzhen manufacture) to supply pure electric buses for BRT operations. Introduction date is unclear. (http://www.byd.com/na/old/news/news-299.html)

Capital Costs

3.4.1.15 Infrastructure costs for BRT systems can vary considerably depending on the complexity and sophistication of the system as well as local characteristics and economic conditions. Examples of costs for various types of systems are shown in the table below – with costs ranging from HK$50.0-105.0 million per km (in equivalent FY2015 HKD)).

Table 3.4.11: Equivalent FY2015 Capital Costs for Various BRT Systems (in Ascending Order by Capacity)

System	Length (km)	Type	Year Opened	Cost (HK$)	Cost (HK$) / km
Eindhoven BRT, Eindhoven, Netherlands	12	Low Capacity with Dedicated Right of Way	2004	1,289 million	107 million
Guangzhou BRT, Guangzhou, China	22.5	High Capacity with Centre Running and Passing Lanes	2010	1,372 million	61 million
Health Line BRT, Cleveland, USA	15	Medium-Capacity with Centre Running Lanes	2008	1,651 million	110 million
Lanzhou BRT, Lanzhou, China	12	Medium-Capacity with Centre Running Lanes	2013	763 million	64 million
TransMilenio, Bogota, Colombia	Phase I: 41 Phase II: 43	High Capacity with Centre Running and Passing Lanes	2000	Phase I: 2,157 million Phase II: 5,688 million	Phase I: 53 million Phase II: 132 million

Source:
Cleveland - http://www.nbrti.org/docs/pdf/Inserts_summaries/Cleveland.pdf
Eindhoven and Bogota - ITDP BRT Bus Rapid Transit Guide, 2007
Guangzhou - ITDP Guangzhou, China Bus Rapid Transit, 2011
Lanzhou - http://www.worldbrt.net/en/cities/lanzhou.aspx

3.4.2 BRT - Operating Characteristics

Service and Passenger Capacity

3.4.2.1 BRT systems typically operate "all-station" service, while some also operate express or "limited" service that only stop at particular stations. Where limited stop service is provided, passing lanes at stations are sometimes provided. Some systems such as Bogota's system operate as "closed" systems in that BRT vehicles only operate on the BRT corridor, while systems such as Guangzhou's or Xiamen's are considered "open" systems as BRT vehicles also operate outside of the BRT corridor.

3.4.2.2 **Table 3.4.12** presents operating performance statistics for several BRT systems. Bus operating speeds for these cases ranges from 15-30 km/h, which are also facilitated by the presence of dedicated bus lanes and bus signal priority.

3.4.2.3 Combined peak headway for multiple routes at any point in the BRT corridor can range from every 15-20 seconds to every 10 minutes as shown in **Table 3.4.12** – equivalent to up to 240 buses per hour. This high throughput is achieved in Guangzhou and Bogota with passing lanes and longer stations with multiple boarding areas and multiple routes operating on a common segment.

3.4.2.4 Corridor capacity considers the number of bus routes running in the corridor, the headway of these routes, vehicle size, station sizing, existence of passing lanes, etc. Thus, capacity focuses on the combined corridor-level capacity in a common segment, rather than the capacity of a single route. A new BRT lane will typically have the capacity to handle as many as 10,000 passenger/hr/direction per direction (pphpd). **Table 3.4.12** shows the estimated hourly corridor capacity for various systems - with Guangzhou and Bogota able to achieve capacities of over 25,000 passengers (with passing lanes and stations with multiple boarding areas).

Table 3.4.12: Service Profiles for Various BRT Systems (in Ascending Order by Capacity)

System	Network Length (km)	# of Corridors	Average Speed (km/h)	Combined Peak Headway in Peak Segment (min) [A]	Corridor Capacity (pphpd)	Daily Ridership
Cleveland BRT, Cleveland, United States	15.0	1	15	5.0	1,200	15,000
Guangzhou BRT, Guangzhou, China	22.5	1	24	20 seconds	27,500	850,000
Metrobus, Mexico City, Mexico	81.5	4	18	1.0	7,550	710,000
TransJakarta, Jakarta, Indonesia	134	12	15-25	1.5	3,400	350,000
TransMilenio, Bogota, Colombia	105	11	16-30	15 seconds	38,000	1,650,000
Xiamen BRT, Xiamen, China	52.0	3	27-30	15 seconds	10,000	200,000

Sources:
Cleveland: http://www.ntdprogram.gov/ntdprogram/pubs/profiles/2013/agency_profiles/5015.pdf
Jakarta: http://www.worldbrt.net/en/cities/jakarta.aspx
Mexico City: http://www.nyc.gov/html/ia/gprb/downloads/pdf/Mexico%20City_Metrobus.pdf
Xiamen: https://www.worldbrt.net/en/cities/xiamen.aspx & http://www.doc88.com/p-2671097340494.html
Guangzhou: https://www.chinabrt.org/en/cities/guangzhou.aspx
Bogota: http://www.worldbrt.net/en/cities/bogota.aspx

Notes:
[A] Headways indicated in the table represent the combined headway of multiple routes running on a common section. To a passenger heading to a station served by multiple routes, they would board any bus, regardless of the route, if they could reach their destination. In the Hong Kong context, this is similar to the Yau Ma Tei – Prince Edward section of the MTR network, where the Kwun Tong Line and the Tsuen Wan Line both operate on this common segment. Therefore, the combined headway for both routes would be lower than that for only one of those routes. Furthermore to achieve such low headways, the BRT system should have passing lanes in each direction, extended stations with multiple boarding bays, as well as level boarding, all-door boarding/alighting and off-board fare payment.

3.4.3 BRT - Other Key Characteristics

Reliability

3.4.3.1 Reliability of BRT is highly dependent on the level of system integration with external traffic. BRT that mixes with external traffic is obviously more susceptible to delays however, the higher the level of segregation and prioritisation of BRT, the higher the level of trip duration reliability. Full-grade separated systems such as Xiamen BRT operating in elevated guideways would be more reliable than those at-grade systems such as Guangzhou BRT that cross junctions at-grade.

3.4.3.2 BRT has typically deployed diesel or hybrid buses, with several systems introducing electric vehicles. Similar to the issues outlined for conventional bus, electric vehicles have a shorter range and appear to have more frequent breakdowns and lower availability than diesel or hybrid buses. It is still an evolving technology and reliability will likely improve in the future.

Impacts to Other Road Users

3.4.3.3 As discussed in the land requirements section, when provided with a dedicated bus lane, BRT would typically require at least one lane of traffic for the bus lane in each direction. This would reduce the number of general purpose lanes for traffic and could have implications on traffic. Furthermore, where stations and passing lanes (if any) are provided, additional road width would be required, which could further reduce capacity. Cross traffic at junctions would also be impacted.

Land Requirements

3.4.3.4 BRT requires land for bus lanes and stations (regardless of whether the bus lanes are in the median or alongside the kerb). The typical width of a bus lane is approximately 3.5 m, while station platforms typically have a width of 4-5 m. Therefore, a representative cross-section of a two-way BRT corridor for a centre platform station would require around 11-12 m including buffer from adjacent traffic. If passing lanes are provided at stations or dual bus lanes are provided along the entire corridor, this width could be up to 17-19 m wide (as passing lanes are typically between 3.0-3.5 m wide). Typically this width is reallocated from existing median and general purpose travel lanes in urban areas.

3.4.3.5 BRT vehicles would use the same depots and maintenance facilities as normal buses. Utilities are typically relocated outside of the bus lanes to facilitate easy maintenance access and to minimise disruption to operations during servicing.

Transit Oriented Development (TOD) Implications

3.4.3.6 BRT systems with dedicated bus ways create a perception of "permanence" along a fixed alignment. This is important in that developers and retailers know that a high-capacity and high-quality urban public transport line will provide reliable service all day. Greater densification of land uses and higher land values has been observed along BRT lines in many locations.

Safety and Evacuation Requirements

3.4.3.7 Safety or evacuation requirements for BRT are similar to those for conventional bus. For BRT on at grade designated corridor, passengers could evacuate from the vehicles quickly to street level. For BRT on elevated viaduct, hard shoulders should be designed for parking of stranded vehicle or allowing passenger refuge during incident.

3.4.3.8 Dedicated bus lanes often have mountable kerbs to allow vehicles to be removed or accessed by emergency service vehicles. The mountable kerbs also allow stranded vehicles to be bypassed. At-grade BRT stations have open air designs and passengers can escape to the bus lane or to another station area. Elevated BRT stations and guideways require safety and evacuation facilities.

Environmental Implications

3.4.3.9 Typically, BRT is operated with diesel, CNG or hybrid vehicles. Those using CNG or hybrid vehicles operate cleaner and more environmentally-friendly than those using diesel, but all of them still generate some level of carbon emission. Electric BRT vehicles have not been widely deployed for BRT operations at this point – although with improvements in technology and reduced costs, this may change in the near future. BRT similar to buses generate noise, although noise can be minimised with fully electric operations. Therefore in this respect, BRT is no different than conventional bus.

3.4.4 BRT - Case Studies

3.4.4.1 Three case studies are presented: (i) Guangzhou, China – One of World's Highest Capacity BRT Systems; (ii) Xiamen, China – Elevated BRT; and (iii) Taichung, Taiwan – Taichung, Taiwan – At-Grade BRT Subsequently Closed.

BRT Case Study 1: Guangzhou, China – One of World's Highest Capacity BRT Systems

Reference image

System Description:

The Guangzhou BRT system, known as GBRT, is located along Zhongshan Avenue, a major east-west thoroughfare radiating out from the traditional city centre. GBRT consists of 22.5 km of dedicated median bus lanes and 26 stations. Intersections are crossed at-grade, therefore bus movements are facilitated by bus signal priority. Stations have multiple boarding areas and are elongated, allowing for simultaneous boarding of several vehicles. Some stations exceed 260 m long and can accommodate 8-9 buses at a time in the same direction. For some stations, passenger viaducts are provided to access station medians to reduce interference from crossing pedestrians.

The system operates as an "Open BRT" whereby buses may also operate outside of the dedicated bus lanes on Zhongshan Avenue. Some 44 routes operate within the BRT corridor. Some 350 buses per hour per direction can operate through the corridor at any given time. Therefore combined capacity on the common segment can reach up to 27,500 passengers per hour per direction at any given point, giving GBRT the second highest capacity of all BRT systems in the world. Routes B1 and B2 operate exclusively in the bus lanes. Each weekday, it is estimated that 850,000 passengers use the corridor.

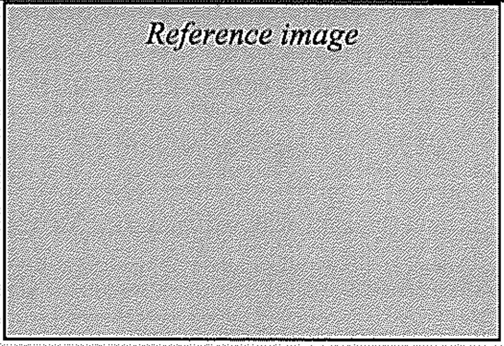
Planning Background:

In the late 2000s, Guangzhou was already served by a five line Metro system in addition to an extensive urban bus system. The Zhongshan Avenue corridor was one of the busiest in the city without its own Metro line at the time. Guangzhou's bus system was overloaded along Zhongshan Avenue with numerous routes and buses merging into and out of traffic lanes creating significant congestion and reducing bus travel times. The decision to select BRT over other modes including Metro was made due to several factors. The BRT would have lower capital and operating costs compared to a traditional Metro line. BRT could still deliver high capacity if designed properly with passing lanes and stations with multiple boarding locations. Lastly, BRT would be more flexible and could be constructed much quicker than a Metro line.

Planning for GBRT started in 2005 and culminated in opening of the system in 2010. GBRT is tightly integrated with the Metro system as well as crossing bus lines as well as a cycle rental system to improve connectivity. GBRT achieves high throughput due to its passing lane and station designs and is an integral part of the overall urban public transport network in Guangzhou. It serves its role as a trunk route along a secondary corridor that does not have a Metro line.

System & Service Characteristics:

BRT Case Study 1: Guangzhou, China – One of World's Highest Capacity BRT Systems



- Total Number of Lines: 44 lines (including B1 and B2 which operate only within BRT corridor)
- Network Length: 22.5 km (busway only)
- # of Stations: 26 (880 m spacing)
- Vehicle Type/Size: 12 m and 18 m diesel, LPG or hybrid vehicles (differs by route)
- Average Speed: 18-24 km/h
- Service Hours: 5:30AM-11:00PM
- Headway: 20 seconds (combined within the Zhongshan Avenue BRT Corridor); individual routes may have peak headways of 5 minutes or less
- Peak Capacity: 27,500 passengers per hour per direction (combined within the BRT Corridor)
- Capital Cost (FY2015): HK$1,372 million (or FY2010 HK$825 million (based on RMB725 million))
- Construction Timeframe: 15 months (construction began on 30 November 2008 and serve was commenced on 20 February 2010)

Performance Characteristics:

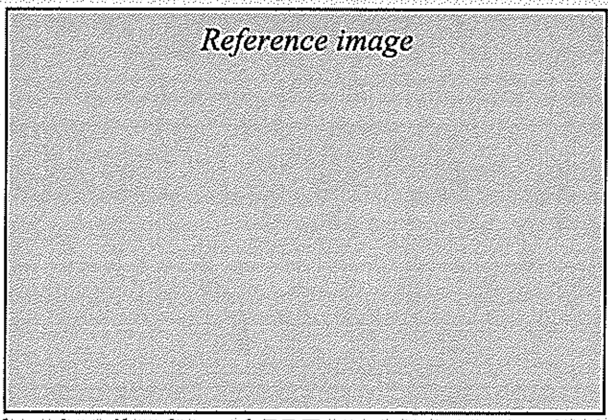
- Ridership: 850,000 passengers per day (recorded on May 2014)

References:

- "广州 BRT", https://www.chinabrt.org/cn/cities/guangzhou.aspx
- "GBRT 公司简介", http://www.gz-brt.cn/About.asp
- 广州 BRT", http://baike.baidu.com/view/3182040.htm#2
- "广州 BRT 今年 6 岁了", 4th Feb 2016, http://www.gzkyz.com.cn/NewsView.asp?ID=7066&SortID=24
- http://gz.bendibao.com/news/201046/content39206.shtml
- http://jt.gz.bendibao.com/news/2010810/60602.shtml
- http://www.tranbbs.com/news/cnnews/news_30819.shtml
- http://epaper.southcn.com/nfdaily/html/2012-11/12/content_7141556.htm

BRT Case Study 2: Xiamen, China – Elevated BRT

System Description:



The Xiamen BRT system consists of a network of five BRT lines with a total length of 163 km. BRT service was first initiated in 2008. Four of the five BRT lines are intended for urban trunk service, while a fifth (Line 4) connects to the airport. BRT is currently the only high-speed and high-capacity urban public transport system in Xiamen and acts as a trunk service, although a Metro system is being constructed and expected to open by 2017.

Xiamen's BRT is unique as it is one of the only primarily elevated BRT systems operating in the world (for instance, Line 1 operates on 15.3 km of elevated viaduct). The viaduct consists of two lanes with guard railings (with the narrowest section about 8-9m in width). Columns and support structures require 4 m in width at the ground level. Elevated stations are side loading with platforms

BRT Case Study 2: Xiamen, China – Elevated BRT

and vertical circulation. Stations vary from 40-68m long and have 3-4m wide side loading platforms. Fares are collected at the stations prior to boarding the vehicles on the separate concourse level beneath, separated by faregates. Of the 42 stations in the network, two stations are equipped with passing lanes to allow buses to bypass one another and to serve multiple boarding areas within a single station.

Reference image

Planning Background: In the early 2000s, Xiamen's public transport system consisted of buses and there was no rail system. The average bus speeds had fallen to 16 km/h and high peak loads on the existing bus system spurred Xiamen to consider Heavy Rail, Light Metro, and BRT as potential high capacity systems and TOD catalysts. Rail-based solutions were viewed as having a high investment cost and long implementation timeframe that would be unable to meet Xiamen's immediate short-term traffic congestion issues and quickly growing public transport demand. BRT was thus chosen as a means of building stable ridership along key corridors, which could be upgraded to a rail-based system in the future. Unlike a rail project, BRT did not require approval from the national level to begin construction.

An elevated BRT was selected over an at-grade BRT to minimise the land use and traffic implications of taking right-of-way for bus lanes and stations. In addition, the elevated BRT would reduce conflicts between BRT and other vehicles at signalised intersections. The elevated BRT guideway has been designed to accommodate upgrade to future rail service if demand warrants. Thus turning radius, slope, setback and structure load all comply with rail transport guidelines. Discussions are currently underway to convert the BRT guideways for rail use.

System & Service Characteristics:

- Total Number of Lines: 5
- Network Length: 163 km (Line 1 - 33.4 km; Line 2 - 41.3 km; Line 3 - 18.7 km; Line 4 - 30.6 km; and Line 5 - 39.0 km)
- # of Stations: 42
- Vehicle Type/Size: Three types (10 m, 12 m and 18 m buses – all diesel)
- Average Speed: 27 km/h (in the city centre) (60 km/h has been achieved)
- Service Hours: 5:30AM-11:00PM
- Headway: 1-3 minutes in the peak; 5-8 minutes in the off-peak
- Peak Capacity: 10,000 passengers per hour per direction
- Capital Cost (FY2015): HK$292.3 million/km (or FY2008 HK$231.0 million/km (RMB205.0 million/km))
- Construction Timeframe: 2 years

Performance Characteristics:

- Ridership: 200,000 daily riders

References:

- Ding Ming, "Developments of the Elevated BRT System in Xiamen City".
- http://www.dimts.in/pdf/Symposium-on-Publi-Transportation/Best-Practices-fo-Bus-Rapid.pdf
- http://www.doc88.com/p-2671097340494.html (Slide 18)
- http://www.huoche.net/show_317998/

BRT Case Study 2: Xiamen, China – Elevated BRT

- http://itdp-china.org
- http://taiwansustainablecities.blogspot.hk/2010/10/bus-rapid-transit-in-taichung.html
- https://www.worldbrt.net/en/cities/xiamen.aspx

BRT Case Study 3: Taichung, Taiwan – At-Grade BRT Subsequently Closed

Reference image

System Description:

The Taichung BRT Blue Line was a 17.2 km at-grade BRT system in operation for less than 12 months from July 2014 to July 2015. The Blue Line crossed street at-grade. The Blue Line linked the Taichung Railway Station and Provident University along Taiwan Avenue. The Blue Line was originally part of a much larger scheme consisting of six BRT lines. The Blue Line consisted of 21 kerbside BRT stations with off-board fare payment. Dedicated bus lanes were provided at the kerbside, although no passing lanes were provided at stations. Bus lanes had different pavement colouring, but were otherwise not physically segregated from adjacent mixed flow traffic lanes.

Stations had multiple boarding areas for simultaneous use of stations in the same direction. Stations were also designed in the likeness of a Chinese White Dolphin to represent speed. The Blue Line deployed 18 m articulated hybrid units that could hold up to 180 passengers each. A total of 25 vehicles provided service. BRT service averaged 25 km/h with 5 minute peak headways and 10 minute off-peak headways.

Reference image

Planning Background:

Taichung has the highest per capita car ownership rate among Taiwan's major cities. Prior to initiation of BRT service, Taichung's public transport system including a network of buses, but no urban rail system. The first MRT Heavy Rail Line (the Red Line) has been under construction since 2009 and was expected to cost in excess of NTD51.0 billion (HK$12.9 billion/US$1.67 billion). As a quicker option to reduce congestion along Taiwan Avenue, the most congested street in Taichung, the Blue Line was proposed to create a more comprehensive public transport system, revitalise old city areas with the BRT line, and integrate the line into the city's urban design, greenways, and tourist attractions.

BRT Case Study 3: Taichung, Taiwan – At-Grade BRT Subsequently Closed

Taiwan Avenue has a dual configuration – with three express lanes and a slow lane separated by a median for bicycles and turning/parking vehicles. Due to the fact that 60% of adjacent corridor land was privately owned, land acquisition was considered too expensive. It was thus decided to build bus lanes at the kerbside of the express lanes and stations on the median between the express and slow lanes. This meant that turning vehicles from the express lanes would need to cross the bus lane. No mixed flow lanes were reallocated to the bus lanes – the width required was procured by reducing the width of existing lanes and the median width. Furthermore, no bus priority signals were provided at intersections, thus subjecting buses to intersection delay.

After several months, the Blue Line came under heavy criticism as follows:

- Blue Line vehicles were slowed at intersections as they lacked bus priority signals.
- Blue Line vehicles were subject to mixed flow vehicle conflicts from vehicles trying to merge to/from the express and slow lanes (as the BRT was built between them). Drivers also complained about these difficulties.
- The public was unsatisfied with service. Public opinion polls in August 2014 found that only 16.9% of riders were satisfied with the ride, and a further 25.5% would change the way they travel. Despite providing free rides on the BRT (this policy was also applicable to all public transport trips under 8.0 km), only 5.3% of Greater Taichung residents had ridden the Blue Line.
- Criticism of the high capital cost was levied.
- Lastly, the incoming Mayor accused the former Mayor of opening the system prematurely in order to win votes.

These factors collectively contributed to the cessation of BRT service. The BRT lanes have been converted to dedicated bus lanes for select routes operating on Taiwan Avenue. Subsequent BRT plans have been cancelled. While some reasons may be political, the Blue Line was not optimally designed in that bus lanes were placed between the express and slow lanes, creating dangerous merge situations that delay buses and drivers. Second, the lack of functioning bus signal priority effectively negated many of the benefits of a dedicated bus lane. Therefore, envisioned travel time savings could not be realised.

Reference image

System & Service Characteristics:

- Total Number of Lines: 1
- Network Length: 17.2 km
- # of Stations: 21 (820 m spacing)
- Vehicle Type/Size: 18 m hybrids (32 in total)
- Average Speed: 25 km/h
- Service Hours: 5:00AM-11:00PM
- Headway: 5 minutes in the peak; 10 minutes in the off-peak
- Peak Capacity: 8,000 passengers per hour per direction
- Capital Cost (FY2015): HK$9.2 billion (or FY2014 HK$8.9 billion (US$1.2 billion) or HK$520 million/km (US$67 million/km))

Performance Characteristics:

- Ridership: 50,000 daily passengers

References:

- http://brtdata.org/location/asia/taiwan/taichung
- http://easts.info/on-line/proceedings/vol9/PDF/P261.pdf, pg. 12
- http://www.nownews.com/n/2015/07/08/1741417

BRT Case Study 3: Taichung, Taiwan – At-Grade BRT Subsequently Closed
• http://www.taipeitimes.com/News/taiwan/archives/2014/08/11/2003597160 • http://www.taiwansustainablecities.blogspot.hk/2010/10/bus-rapid-transit-in-taichung.html • http://tptis2015.blogspot.hk/2015/06/300-brt.html

3.4.5 BRT - Summary and Broad Applicability within KE

Pros	Cons
• Highest capacity road-based mode, equivalent to most medium-capacity rail-based systems • Faster and more reliable than other road-based modes as BRT operates in dedicated bus lanes physically segregated from mixed flow traffic • Shorter signal delay compared to other road-based modes due to bus signal priority • Rail-like amenities including enhanced stations, level boarding, off-board fare collection, and sleek vehicles create improved passenger experience • Capable of operating at-grade, elevated on a viaduct, or in tunnels • Provides sense of "permanence" similar to a rail line and can encourage joint development • More accessible than grade separated modes, especially for passengers with mobility issues • More flexible and easier to expand than rail-based modes, especially if system is "open" and BRT vehicles can operate outside of lanes • Shorter construction timeframe than a rail system • Lower capital costs compared to rail modes and can use existing roadways • Depot may be off-site	• Most capital-intensive road-based mode requiring specialized stations, lanes and buses • Requires reallocation of general purpose travel lanes for bus lanes and stations (and potentially relocation of utilities beneath bus lanes), thus permanently occupies traffic lanes in developed areas and thus has land implications • Passing lanes and multiple boarding zones at stations are required to achieve highest range of capacity making station areas long and wide • At-grade BRT systems still subject to level crossing of intersections and may be subject to congestion and/or accidents despite provision of signal priority • Prohibited vehicles may enter bus lanes and impact BRT service, therefore enforcement/monitoring required • Currently, most systems deploy hybrid or diesel units instead of electric vehicles due to cost and reliability issues

Key Findings and Broad Applicability within KE
• BRT provides a premium level of road-based bus service that operates similar to a rail-based system with dedicated bus lanes, enhanced stations, and fast boarding – this allows BRT to provide serve the highest ridership of all road-based modes. At the same time though, road width for bus lanes, stations, as well as passing lanes, if any, would occupy road space in congested areas, which would impact road traffic and displace traffic from the corridor. Vehicles are branded and stylized to give a rail-like appearance, although electric vehicle deployment is not widespread. BRT can handle volumes similar to medium-sized rail systems, if passing lanes and long stations are provided for multi-route operations, but can be built faster and more cheaply, while being more flexible to expand or modify than rail. • The Guangzhou BRT case study shows that high capacities can be achieved similar to moderate rail systems with passing lanes and long stations. Elevated BRT similar to the Xiamen BRT could be one part of the overall BRT network where street level operations are infeasible given sits conditions, tight space and road traffic impacts. As shown by the Taichung BRT experience, poor design and lack of bus signal priority can generate significant opposition and dissatisfaction with service.

- BRT would require right-of-way for stations and the bus lanes, as well as passing lanes and stations with multiple boarding areas to achieve demand levels envisioned in Kowloon East. BRT operating on-street, even in dedicated lanes, would still be subject to mixed flow impacts at junctions. In the context of Kowloon, BRT would occupy portions of the existing carriageway to form designated corridor and require signal priority at junctions to achieve high capacity and high reliability. However, this would cause traffic impact to other road users given the tight space available in Kowloon East. Without the privilege of a designated corridor and junction priority, BRT would function similar to conventional bus, which would share the road space with other traffic.

3.5 Travellator

3.5.1 Travellator - System Characteristics

Background and System Technology

3.5.1.1 Travellators, also known as moving walkways, are a slow-moving form of mechanised transport that functions similar to a horizontal escalator. An electric motor beneath the travellator runs and cycles the moving surface of the walkway that passengers can either stand on or walk on. Travellators are intended to reduce effective walking distances and enhance walking comfort. Travellators may be installed indoors and outdoors, although overhead protection from rain is needed for outdoor travellators.

3.5.1.2 The earliest forms of the travellators have been operating since the early 1920s. Examples in Hong Kong include those in Hong Kong International Airport, between Central and Hong Kong stations, between Tsim Sha Tsui and East Tsim Sha Tsui stations, and at several of the Border Crossing Facilities (BCFs) including Futian BCF. In Hong Kong, travellators are also used to link hilly and steep areas together with one another – the Central to Mid-levels Escalator and Walkway System, stretching over 800 m. Other airports use inclined travellator systems for passengers and luggage carts such as at Bangkok's Suvarnabhumi Airport and Singapore's Changi Airport.

Role in Transport Hierarchy

3.5.1.3 Travellators are typically used for short, localized trips. Travellators can reduce effective walking distance for pedestrians, including those with luggage and cargo. They are built to handle passengers, luggage carts, baggage, etc., but not designed to handle motor vehicles, although small one-seat motorized carts for disabled users could be accommodated. Travellators are free to use and are provided for the convenience of passengers or users of a facility. Travellators are often found in airports to reduce walking distance within terminals or between terminals, and between or within large transport facilities to reduce walking distances.

Key Infrastructure Elements

3.5.1.4 Travellators consist of three principal infrastructure elements: (i) the moving surface; (ii) the motors underneath propelling the surface; and (iii) the railings.

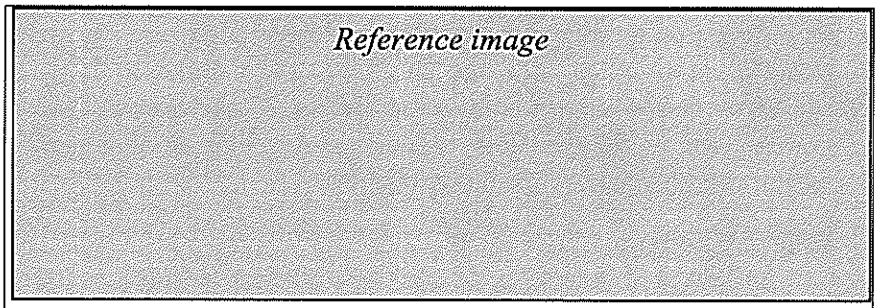
3.5.1.5 The moving surface of the walkway can be of two types: (i) pallet – this is similar to an escalator as a series of continuous small metal plates are joined together to form a walkway, similar to the concept behind an escalator; and (ii) moving belt –

this is similar to a conveyor belt in that a single metal or rubber belt moves over metal rollers.

3.5.1.6 Travellators can be completely horizontal or inclined. For inclined travellators, the angle of inclination from horizontal should not exceed 3° within 0.9 m of the entrance or egress points and shall not exceed 12° at any point.[24] Travellators are equipped with moving railings on each side to allow passengers to hold railing while the walkway moves.

3.5.1.7 Other key infrastructure attributes are as follows:

- Travellators are typically installed indoors, although outdoor travellators can be provided as long as the system is protected from the weather with an overhead cover (for instance the travellator at Huanggang BCF as well as the Central to Mid-Levels Escalator and Walkway System are open air, but covered). Travellators are often installed in pairs for use in both directions depending on peak demand as well as space considerations. Travellators can be provided along sidewalks, in separate right-of-way, or within buildings.
- The length of a travellator can vary. As noted, several smaller travellators may be strung together to create a longer system – such as the Central to Mid-Levels Escalator and Walkway System and travellators at HKIA. For the travellators connecting Tsim Sha Tsui and East Tsim Sha Tsui stations, the average length for an individual travellator is about 70 m in length.
- The width of travellators varies, with the widest travellators up to 1.4 m wide. Some systems only are designed for one "lane" for passengers and are not wide enough for passing.



Source: Planning Guide for KONE Escalators & Autowalks, KONE (http://cdn.kone.com/www.kone.us/images/kone-escalator-autowalk-planning-guide.pdf?v=1)

Figure 3.5.3: Typical Travellator Widths

Capital Costs

3.5.1.8 Capital costs for travellators varies by terrain, location and desired speed. Capital costs for a variety of travellators in both indoor and outdoor settings are presented in Table 3.5.13.

3.5.1.9

[24] ASME A17.1 (Section 6.2.3.1); http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_067.pdf

Table 3.5.13: Equivalent FY2015 Capital Costs for Various Travellator Systems

System	Length (km)	Location	Year Opened	Cost (HK$)	Cost / km (HK$)
Central–Mid-Levels Escalator and Walkway System, Hong Kong SAR, China	0.80	Outdoor	1993	390 million	487.5 million
Estrade da Baia de Nossa Senhora da Esperanca Travellator, Macau SAR, China	0.25	Outdoor	2012	50 million	200.0 million
Mechanical Ramps, Vitoria-Gasteiz, Spain	0.15	Outdoor	2007	40 million	266.7 million
Montparnasse—Bienvenüe Metro Station Travellator, Paris, France	0.19	Indoor	2002	50 million	263.2 million
Toronto's Pearson International Airport	0.275	Indoor	2007	50 million	181.8 million

Source:

Hong Kong and Paris: Peter D. Kauffmann, 2011, Traffic Flow on Escalators and Moving Walkways: Quantifying and Modelling Pedestrian Behaviour in a Continuously Moving System

Macau: Various – see Case Study for references.

Spain: http://www.citylab.com/commute/2012/07/filling-city-moving-walkways-good-idea/2488/

3.5.2 Travellator – Operating Characteristics

Service and Passenger Capacity

3.5.2.1 Typical operating speeds can vary significantly by system – but must account for peak demand, safety considerations, and acceleration and deceleration near the starting and ending points of the travellator. Hong Kong MTR's design speed for its travellators is 0.75 m/s based on its design standards. This is actually slower than the typical walking speed for a full-bodied adult at 1.0 m/s.

3.5.2.2 The most notable high speed systems have been in Paris (at the Montparnasse-Bienvenue Metro Station) and in Toronto's Pearson International Airport. The Paris system was opened in 2002 and operated at a speed of up to 2.5 m/s between two Metro stations.[25] Due to safety and reliability issues, it was subsequently replaced with a slower system. Toronto's system, opened in 2007, carries passengers at speeds up to 2.2 m/s.[26]

3.5.2.3 Capacity depends on width of the travellator (i.e., is passing allowed or not), whether luggage and/or luggage carts are allowed on the travellator, the operating speed of the walkway, tread width of the individual pallet (for pallet type systems), incline, and typical distance between passenger (for the Washington DC Metro, the acceptable level of service for passengers on a travellator was designated as LOS C – equivalent to a space per pedestrian of 0.9-1.4 sqm). Empirical observations estimate that a higher capacity travellator system could theoretically carry between 3,500-6,000 passengers per hour, assuming a speed of

[25] William Minchin, 2010, Transportation Modeling in Hyperstructures, https://ceen.et.byu.edu/sites/default/files/snrprojects/609-william_minchin-2010-ggs.pdf

[26] Airport Passenger Conveyance Systems Planning Guidebook, Airport Cooperative Research Program (ACRP) Report 67, Airport Cooperative Research Program 2012. http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_067.pdf

0.5 m/s and occupancy of one person per step and no luggage.[27] In actual conditions, occupancy of one person on each step is atypical as most people will space themselves accordingly and take longer to board if the travellator is high speed.

Operating Costs

3.5.2.4 Annual operating costs can range from about HK$850,000 (US$110,000) per km to HK$1.3 million (US$170,000) per kilometre per year for a typical, horizontal travellator.[28]

3.5.3 Travellator – Other Key Characteristics

Reliability

3.5.3.1 Travellators are effective and proven systems. Reliability of a journey on a travellator is dependent on the volume of users, behaviour of other users (i.e., whether they stand to one side to allow passing) and presence of luggage (which may block the path and prevent passing). Indoor and outdoor travellators operate in different conditions – indoor travellators are within climate and moisture controlled environments, while outdoor ones are exposed to such elements. Thus in general, outdoor travellators are more prone to breakdowns and shut downs from materials getting stuck in the travellator as well as moisture.

Impacts to Other Road Users

3.5.3.2 Travellators are typically grade separated from road traffic and would have minimal to no impact on road users, except for column placement in the middle of a road, which would require some road width for a protected median.

Land Requirements

3.5.3.3 Travellators require land for the moving walkway and underlying systems. A single travellator can be up to 1.4 m width, excluding railings. Therefore, if two travellators are installed for travel in each direction, a minimum 3.0 m width corridor would be required. In addition, a separate non-mechanised walkway would normally be provided along the travellator for bi-directional travel or as an alternative means of access in case of emergency. The overall corridor includes both the widths of the travellators and the walkway. Furthermore, it is uncommon to have a travellator on an open public footpath, as most travellator and escalators are provided within buildings or footbridge/ tunnels. The width of the supporting structures would also need to be taken into account.

Transit Oriented Development (TOD) Implications

3.5.3.4 Travellators typically provide enhanced access to higher density land uses that may be located further away from higher capacity public transport bus and rail-based modes. It is noted that the Mid-Levels Escalator helped to revitalise areas within walking distance of access point and encourage new businesses and

[27] Peter D. Kauffmann, 2011, Traffic Flow on Escalators and Moving Walkways: Quantifying and Modelling Pedestrian Behaviour in a Continuously Moving System; WMATA, 2008, Site Planning Manual.
[28] Indraswari Kusumaningtyas, 2009, Mind Your Step - Exploring Aspects in the Application of Long Accelerating Moving Walkways.

restaurants. Besides this example though, travellators are typically tools to quicken the journey from one point to another and do not in themselves encourage development.

Safety and Evacuation Requirements

3.5.3.5 Travellators have emergency stop buttons located alongside the moving walkway. Passengers may climb over the railing to safety. Gratings or combs are placed over the entry and exit points of the travellators to minimise the chance that items or clothing become lodged in the motor.

Environmental Implications

3.5.3.6 Travellators are generally regarded as a pedestrian facility to enhance walking comfort, which can help to reduce driving for short distance trips. Furthermore, it operates by electricity and does not generate carbon emissions (and has a minimal noise footprint).

3.5.4 Travellator - Case Studies

3.5.4.1 Three case studies are presented: (i) Hong Kong SAR - Central to Mid-Levels Escalator and Walkway System; (ii) Macau SAR - Estrade da Baia de Nossa Senhora da Esperanca Travellator; and (iii) Paris, France and Toronto, Canada - High Speed Travellators.

Travellator Case Study 1: Hong Kong SAR, China - Central to Mid-Levels Escalator and Walkway System

System Description:

Reference image

In operation since 1993, the Central to Mid-Levels Escalator and Walkway System stretches for over 800 m, rising 135 m, and bisecting 13 streets linking these districts of Hong Kong Island. The escalator links streets in Central and ends at Conduit Road. Typical configuration is for one escalator adjacent to an aisle for stairs due to geographic constrains and space limitations beneath a canopy. Thus in the morning peak (6:00AM-10:00AM), the system operates downhill for commuters heading to Central. Between 10:00AM-12:00 midnight, the system reverses and operates uphill.

The system consists of 18 separate escalators and 3 inclined moving walkways, connected in places by footbridges. The travellators have inclinations ranging from 8° to 12°. Step width is 1,000 mm and the travelling speed is 0.65 m/sec. A one-way journey on the entire system takes about 20 minutes. Based on Government surveys conducted in 2016, daily two-way pedestrian trips reached 78,000 for the entire system. Similar hillside travellators have been implemented in Hong Kong or are in the works. The system is currently managed by the Electrical and Mechanical Services Department (EMSD), which is a department in the HKSAR Government. In addition to its function as a transport facility, restaurants and small businesses have developed alongside the escalator.

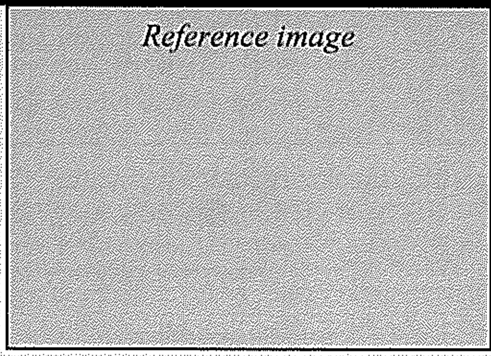
Planning Background:

According to a Government release, the Hong Kong Government built the escalator system to both encourage members of the public to walk to the relieve pressure on congested roads in the Mid-Levels. According to the Hong Kong Transport Department's subsequent assessment, although the Central to Mid-Levels Escalator and Walkway System is useful in relieving demand for public

Travellator Case Study 1: Hong Kong SAR, China - Central to Mid-Levels Escalator and Walkway System

transport services, it has not facilitated a large mode shift from driving or significantly reducing traffic flow in the Mid-Levels area.

The system allows passengers to access MTR Heavy Rail lines to Central and Hong Kong Stations from the Mid-Levels and plays a role as a feeder system to the MTR and bus routes in Central and internal circulator within the Mid-Levels.



System & Service Characteristics:
- Total Number of Lines: 1 (includes 3 separate travellator sections)
- Network Length: 800 m (combined)
- Average Speed: 0.65 m/s
- Peak Capacity: 11,700 passengers per hour per direction (note – this figure counts passengers that use the entire system and may get on and off, not the number of passengers passing a specific point at one time)
- Service Hours: 6:00AM-12:00 midnight (6:00AM-10:00AM downhill; 10:00AM-12:00 midnight uphill)
- Capital Cost (FY2015): HK$390.0 million (or FY1993 HK$240.0 million)

Performance Characteristics:
- Ridership: 78,000 daily trips (in both directions, measured in 2016)

References:
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- http://www.td.gov.hk/en/transport_in_hong_kong/pedestrianisation/hillside_escalator/
- http://www.hongkongextras.com/_midlevels_escalators.html
- http://www.emsd.gov.hk/filemanager/conferencepaper/en/upload/61/cnfrnc-paper-20150705-09-3.pdf

Travellator Case Study 2: Macau SAR, China - Estrade da Baia de Nossa Senhora da Esperanca Travellator

System Description:

Opened in April of 2012, the Macau Travellator is a combined travellator and footbridge connecting Old Taipa Village and the northwest parking lot of the Venetian Macao Casino. The travellator portion consists of dual moving walkways that are under a covered canopy. The travellator is open to the air.

The combined facility is 350 m including: (i) a 250 m travellator between Taipa Village and the base of a footbridge across Estrada Da Baia De Nossa Senhora Da Esperanca, which is a main thoroughfare linking the rest of Macau and the Cotai Strip and casino; and (ii) a 100 m footbridge across Estrada Da Baia De Nossa Senhora Da Esperanca. The walkway provides a convenient linkage between restaurants and tourist facilities in Taipa Village and the casinos.

Planning Background:

Travellator Case Study 2: Macau SAR, China - Estrade da Baia de Nossa Senhora da Esperanca Travellator

As background for the implementation of the Macao travellator, since 2007, the Government initiated a strategy to prioritise public transport and promote walking. One component of this effort was to develop dedicated pedestrian systems to reduce driving and reduce emissions. Also though, another goal was to separate pedestrians and vehicular traffic to improve road safety and to create a pedestrian-friendly walking environment.

Reference image

In October 2009, the Macao Construction Association announced a proposal for eight pedestrian footbridges in Macao. The travellator across Estrada Da Baia De Nossa Senhora Da Esperanca has so far been the only travellator to be built so far. In the future, this travellator will also provide connectivity to/from a future elevated Macao LRT Station across from the Galaxy Hotel, within the median of Estrada Da Baia De Nossa Senhora Da Esperanca.

System & Service Characteristics:

- Total Number of Lines: 1
- Network Length: 250 m (travellator section only)
- Service Hours: 7:00AM-12:00AM
- Capital Cost (FY2015): HK$50.0 million (or FY2012 MOP45.41 million (HK$44.1 million)).
- Construction Timeframe: 2 years

Reference image

References:

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- 望德聖母灣全澳首個步行系統試運, http://www.chengpou.com.mo/news/2012/4/4/23660.html
- 當局擬建八行人天橋", Oct 2009, http://www.macauca.com/indnews/indnews_ne.asp?id=391

Travellator Case Study 3: Paris, France and Toronto, Canada - High Speed Travellators

System Description:

Paris, France and Toronto, Canada both installed high-speed travellators. Both such systems were/are inside buildings or structures and not exposed to the open air.

The Paris system was first implemented in the Montparnasse-Bienvenüe Metro Station in 2002 between two subway stations and operated at 3.3 m/s (12 km/h) when first opened – the fastest in the world. The system was 185 m long and located underground. Travellators were installed in each direction. The speed was subsequently reduced to 2.5 m/s after riders reported losing their balance. The system was subsequently shut down in May 2009 due to reliability issues and accidents and replaced with a standard travellator operating at 0.56 m/s.

In 2007, Toronto's Pearson International Airport installed the world's fastest system in operation today, allowing speeds of up to 2.2 m/s in the middle of the system and 0.56 m/s at the entry and exit points. Travellators are installed in both directions and are 275 m long. The system is designed with individual grooved pallets that expand when accelerating and compress together when decelerating. Warning signs are posted above the entrance.

Reference image

Planning Background:

Montparnasse-Bienvenüe Metro Station is a key interchange between four metro lines. Walk distance between lines is up to 185 m. It was decided to install a high speed travellator to reduce journey time to under a minute. Speed was subsequently reduced to 2.5 m/s or about 75 seconds travel time as passengers were losing their balance. At this lower speed, passengers were estimated to save 15 minutes/week and 10 hours/year, assuming use of the walkway twice per day. The walkway was closed in 2011 due to reliability and accident issues and replaced with a standard 0.56 m/s travellator. The travellator functioned as a connector between rail lines.

Reference image

Toronto Pearson International Airport is Canada's busiest airport hub. Expansion of the airport has resulted in some long distances for passengers. To reduce these walking distances, a high-speed travellator was installed in Pier F by ThyssenKrupp of Terminal 1 to connect it to the rest of the terminal. The travellator functions as a feeder/connection between the boarding areas.

Paris System & Service Characteristics:

- Total Number of Lines: 1
- Network Length: 180 m (travellator section only)
- Average Speed: 2.5-3.3 m/s (before closure)
- Service Hours: 5:00AM-12:30AM (weekdays)
- Capital Cost (FY2015): HK$50.0 million (or FY2002 €4.5 million (or about HK$38.0 million))

Toronto Pearson System & Service Characteristics:

- Total Number of Lines: 1
- Network Length: 275 m
- Average Speed: 2.2 m/s (maximum)
- Service Hours: 24 hours

Travellator Case Study 3: Paris, France and Toronto, Canada - High Speed Travellators
References: • Airport Passenger Conveyance Systems Planning Guidebook, Airport Cooperative Research Program (ACRP) Report 67, Airport Cooperative Research Program 2012. , http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_067.pdf • Indraswari Kusumaningtyas, 2009, Mind Your Step - Exploring aspects in the application of long accelerating moving walkways • William Minchin,2010, Transportation Modeling in Hyperstructures, https://ceen.et.byu.edu/sites/default/files/snrprojects/609-william_minchin-2010-ggs.pdf

3.5.5 Travellator – Summary and Broad Applicability within KE

Pros	Cons
• Shortens effective walking distance • Shortens journey time if passengers walk on the travellator • Relatively inexpensive to implement compared to other road or rail-based green transport systems • Can be installed indoors or outdoors, on flat surfaces or steep grades	• Primarily for localised and shorter distance trips • Very slow operation compared to other modes • Limited capacity compared to other modes • Actual capacity may be lower than demand capacity due to luggage, manner in which users space themselves, and whether users walk or stand • Often operates slower than typical walking speeds so capacity of a walkway may actually be reduced with a travellator

Key Findings and Broad Applicability within KE
• Travellators are pedestrian facilities that shorten walking distance and enhance walking comfort. They exist in everyday life in Hong Kong and have been implemented in the Mid-Levels, in Central and in Tsim Sha Tsui MTR stations, respectively, and at the Boundary Crossing Facilities (BCFs) between Hong Kong and China. • The case studies illustrate various applications of travellators including in outside climates so long as they are covered. Higher speed travellators are also possible to further reduce journey times although specific operators must be identified for maintenance and upkeep (this is likely why high speed travellators are only found in public facilities such as airports and rail stations). • In the context of KE, travellators are most applicable as a pedestrian linkage system. They could be implemented within developments, but also between developments. Travellators are applicable to link employment, tourism and residential nodes to nearby public transport stations and the EFLS. Travellators may be particularly suited to reduce walking distances to areas located in hilly areas, similar to the role of the Mid-Levels Escalator system.

3.6 Trolleybus

3.6.1 Trolleybus - System Characteristics

Background and System Technology

3.6.1.1 Trolleybuses are motorized rubber tire vehicles similar to buses (as defined in **Section 0**), but operate solely on electric power from overhead catenary via the rooftop contact. Operationally, trolleybuses are considered a zero-emission green transport mode as they run completely on electricity. Trolleybuses run quieter, accelerate and decelerate faster and smoother, and have better climbing ability than diesel buses. Trolleybus typically operates in mixed flow conditions, but also operates in dedicated bus lanes in some locations. Trolleybus can play several roles in the overall transport network including local, trunk and feeder service depending on the existence of a rail network.

3.6.1.2 Trolleybus systems have been operating for over 100 years. Extensive trolleybus systems exist in Shanghai, as well as overseas including Boston, Geneva, Mexico City, San Francisco, Seattle, Zurich and numerous Eastern European cities. Many trolleybus lines were replaced in the mid-1950s by diesel bus lines due to flexibility and reduced operating costs. The high fixed investment cost of the catenary and power supply system is one reason that few cities have built new trolleybus systems over the last few decades.

Role in Transport Hierarchy

3.6.1.3 Trolleybus typically provides circulator or local service. Trolleybus can also provide trunk service, for instance along a major street or boulevard, if overhead catenary is provided along the route, when no rail lines are provided. Where rail systems serve as the main trunk lines, trolleybuses provide feeder services to/from the station to "extend" the catchment zone of the rail line. Few new trolleybus routes are being introduced where new overhead wiring infrastructure is required.

Key Infrastructure Elements and Vehicles

3.6.1.4 The main infrastructure elements for trolleybus are the running way, overhead catenary and power supply, the trolleybus stops and the vehicles.

Runningway

3.6.1.5 Trolleybus typically operates in mixed flow conditions similar to a bus. However in some cases, trolleybus operates in dedicated bus lanes, particularly at approaches to intersections (as is done in San Francisco and Seattle).

Propulsion System

3.6.1.6 Trolleybus is powered by the overhead electric wires connected through the overhead catenary. In addition to the overhead wiring, sub-stations are required throughout the route to power the lines. Previously, trolleybuses were unable to operate when contact was lost between the catenary and the electric wires. Thus the general routing for a trolleybus would be limited by the provision of the overhead wire network. Advances in battery powered buses has allowed trolleybus to operate in joint fashion - with on-board batteries able to store energy and allow the vehicle to operate for up to 10 km without contact with the catenary. These types of vehicles are known as "hybrid" trolleybuses as they can operate on catenary as well as on battery. However, the capacity and weight of the battery affects the distance the trolleybus can travel without contact to the catenary.

3.6.1.7 Minimum height must be maintained to keep vehicles and objects from contacting the catenary, yet must be low enough to allow for maximum maneuverability. The most common specification for wire height is a minimum of 5.5m at the lowest point, requiring support heights of 5.6-5.8m.[29] This is based on United States, National Electrical Safety Code (NESC). The State of California requires a height of 5.8m.

Stops/Stations

3.6.1.8 Trolleybus stops are similar to bus stops, often found at the kerb. Some trolleybus systems also use small raised islands in the street to allow vehicles to load/unload without having to merge to the kerbside lane. These raised islands also allow level boarding to reduce dwell times. Typical stop spacing for trolleybus is 250-400 m in urban areas, similar to that for bus.

Vehicles

3.6.1.9 Trolleybus vehicles are similar to buses and may come in 12 m and 18 m articulated versions. In some cities such as Zurich, 25 m bi-articulated vehicles are operated. Although used in the past, no double decker trolleybuses operate in the world (one such vehicle was tested in Hong Kong in the early 2000s, but was not adopted). Capacity per vehicle is similar to that for buses, ranging from 60-80 passengers in a 12 m vehicle to 170 passengers in an 18 m vehicle. Longer bi-articulated 25 m vehicle can hold up to 270 passengers.

3.6.1.10 **Table 3.6.14: Typical Size and Capacity of Trolleybus**

	Standard Trolleybus	Articulated Trolleybus	Bi-Articulated Trolleybus
Photo	*Reference image*	*Reference image*	*Reference image*
Vehicle Length (m)	12	18	24
Capacity (Passengers/ Vehicle)	60-80	120-170	200-270
Examples	Boston, Mexico City, San Francisco, Shanghai, San Francisco, Vancouver	Boston, Geneva, San Francisco, Seattle, Zurich	Geneva, Zurich

Source: ITDP, BRT Bus Rapid Transit Guide – Complete Guide, 2007.

Note: Carrying capacities per vehicle assumed to be same as similarly sized BRT vehicles, although Zurich's bi-articulated units hold 200. Also, the Boston articulated vehicles are deployed on the Silver Line, which is a BRT line that operates as a diesel line on street, and as a trolleybus (using catenary) underground.

3.6.1.11 Due to electric propulsion, trolleybus can achieve high torque and accelerate faster and smoother, and possess greater climbing ability than a diesel bus. Trolleybus vehicles also operate much quieter than diesel buses. Trolleybus requires a specialised depot specific for such vehicles, which differ from buses.

29 *Transit Cooperative Research Program Report 7, Reducing the Visual Impact of Overhead Contact Systems*, Transportation Research Board, National Academy Press, Washington D.C., 1995.

Capital Costs

3.6.1.12 Trolleybus investment costs include the vehicles, overhead wires, and electric sub-stations as well as specialised depots and maintenance facilities. A comparison study for trolleybus in Seattle estimated that the infrastructure cost for electric trolleybuses (including the noted three elements) is about HK$87.6-HK$100.0 million/km (or US$11.3-US$12.9 million/km) in FY2008 equivalent currency (or HK$110.8-HK$126.5 million/km for FY2015).[30] Another study in Seattle estimated that the average cost per trolleybus vehicle ranged from HK$0.13-HK$0.16 million (or US$1.03-US$1.29 million for FY2011) for a 12 m and 18 m vehicle. This is equivalent to HK$0.15-HK$0.19 million for FY2015.[31]

3.6.1.13 The table below presents the capital cost estimates for overhead wires and power substations.

3.6.1.14 **Table 3.6.15: Equivalent FY2015 Capital Costs by Trolleybus Component**

	Component	
Cost Basis	**Overhead Wires**	**Power Substations**
FY2010 (Original)	HK$7.8 million/km (FY2010) (US$1.0 million/km)	HK$8.6 million/km (FY2010) (US$1.1 million/km)
FY2015 (Current)	HK$9.6 million/km (FY2015) (US$1.24 million/km)	HK$10.6 million/km (FY2015) (US$1.36 million/km)

Source: Arieli Associates, Electric Trolleybuses for the LACMTA's Bus System, 2010

3.6.2 Trolleybus - Operating Characteristics

Service and Passenger Capacity

3.6.2.1 Trolleybuses can operate local service, as well as trunk service. Trolleybuses typically operate at average speeds ranging from 6 to 15 km/h depending on level of segregation (i.e., whether it only operates in mixed flow lanes or also in dedicated lanes). Trolleybus operates at similar headways as bus, with combined peak headways of between 3-5 minutes (for multiple routes) as observed in San Francisco for instance.

3.6.2.2 The table below compares operating characteristics of several trolleybus systems. From these examples it is found that peak line capacity can be up to 2,400 passengers per hour per direction (based on Zurich's use of 25 m bi-articulated vehicles holding 200 passengers at 5 minute peak headways).

[30] Seattle Streetcar: Network Development Report, Seattle Department of Transportation, May 2008.
[31] King County Metro, King County Trolley Bus Evaluation, May 2011.

Table 3.6.16: Service Profiles for Various Trolleybus Systems

System	Network Length (km)	Total Number of Lines	Average Speed (km/h)	Peak Headway (min)	Line Capacity (pphpd)
San Francisco, United States	163	14	10	3	1,600
Seattle, United States	113	15	11	6	800
Shanghai, China	120	12	13-15	3-4	1,200
Zurich, Switzerland	56.6	7	N/A	5-7	2,400

Source:

San Francisco: https://www.sfmta.com/sites/default/files/agendaitems/7-10-2014%20City%20Services%20Benchmarking%20Report.pdf

Seattle: King County Trolleybus Evaluation, 2011

Shanghai: http://www.idealshanghai.com/travel/117891/

Zurich - https://www.stadt-zuerich.ch/vbz/

3.6.3 Trolleybus – Qualitative Characteristics

Reliability

3.6.3.1 Trolleybuses typically operate in mixed flow, but also can operate in segments of segregated lane. For operations in mixed flow, trolleybuses are subject to conflicts from mixed flow traffic, turning movements, and parked vehicles, and to intersection delay. In addition, whenever trolleybus catenary loses contact with the overhead wires, the vehicle must be stopped and re-connected to the catenary. Trolleybuses operating in segregated lanes are still subject to cross traffic interactions at intersections.

Impacts on Other Road Users

3.6.3.2 Trolleybus operates in mixed flow traffic conditions and share lanes with other road users. Thus, trolleybus will take up some road space and affect other road users.

Land Requirements

3.6.3.3 In general, trolleybuses require kerbside stops that may require limited width along a sidewalk. If trolleybuses use segregated lanes, typical lane width is 3.5 m. Land is also required for catenary poles as well as sub-stations. Substation land needs to be allocated. Normally, the distance between substations is 2-3 kilometres, but not to exceed 3 km.

3.6.3.4 In addition, overhead wiring systems for trolleybus occupies air space above the road, which limits the use of road space along the route.

Transit Oriented Development (TOD) Implications

3.6.3.5 Trolleybus systems with their overhead wire network represent a fixed alignment and investment and create a perception of "permanence". This is important in that developers and retailers know that a fixed urban public transport line will provide reliable service all day and could potentially facilitate greater densification of land uses.

Safety and Evacuation Requirements

3.6.3.6 Safety or evacuation requirements for trolleybus are similar to that for conventional bus. The main difference is the underlying infrastructure. Overhead catenary systems carry live voltage and are hazardous if touched. Minimum safe clearance height of at least 5.5m must be maintained such that vehicles and other objects do not touch the catenary.

Environmental Implications

3.6.3.7 Trolleybuses are powered by electricity. This allows them to operate quieter and more environmentally friendly than diesel or hybrid buses.

3.6.4 Trolleybus - Case Studies

3.6.4.1 Two case studies are presented: (i) Zurich, Switzerland; and (ii) Shanghai, China.

Trolleybus Case Study 1: Zurich, Switzerland – Trolleybus Network

System Description:

Reference image

Seven trolleybus routes are operated in Zurich today, spanning a length of 56.6 km (including short segments of dedicated lanes, including a 300m stretch of a major downtown street called the Langstrasses for Line 31). Trolleybus complements the extensive tram (15 routes), bus (18 routes), and suburban S-Bahn system. Trolleybus routes operate as cross-city and radial routes, bringing passengers to and through the city centre. Trolleybuses link to the suburban S-Bahn as well as the downtown tram routes. Zurich operates two types of trolleybuses, an 18 m articulated trolleybus (carrying up to 155 passengers) as well as a 25 m bi-articulated trolleybus (carrying up to 200 passengers). The trolleybus system is operated by Verkehrsbetriebe Zurich (VBZ), which also operates the tram and bus services.

Planning Background:

The Zürich trolleybus system was opened on 27 May 1939, by the then Städtischen Strassenbahn Zürich ("Zurich Municipal Tramway") (St. St. Z.). Initially, trolleybus routes were created on new routings intended to complement, rather than compete with, the city's existing tram network. In the 1950s, as tram was seen as inflexible and subject to worsening congestion, the tram lines were replaced with trolleybus lines. However, no new trolleylines have been implemented since the 1950s. Thus, the origin of today's seven trolleybus lines is the original system opened in the 1930s.

There are plans to convert bus Lines 69 and 80 into trolleybus lines as these routes operate in hilly areas. One portion of trolleybus Line 31 will be removed due to expansion of Tram Line 2. Trolleybuses, as well as the extensive bus and tram systems receive transit signal priority throughout downtown, with exclusive transit-only lanes provided for joint use of all public transport modes, but primarily for the modern tram system. This decision to reallocate road space to public transit is rooted in a public referendum in 1973 that sought public opinion on whether to build an underground subway system or to improve surface transport through extensive implementation of transit priority measures.

Trolleybus Case Study 1: Zurich, Switzerland – Trolleybus Network

Reference image

System & Service Characteristics:

- Total Number of Lines: 7
- Network Length: 56.6 km (including some segments of dedicated lanes)
- # of Stations: 149 (may include stops used by more than one more)
- Vehicle Type/Size: 18 m articulated (63 units) and 25 m bi-articulated (17 units)
- Service Hours: 5:00AM-1:00AM
- Headway: 5-7 minutes in the peak; 7-8 minutes in the off-peak
- Peak Capacity: 2,400 passengers per hour per direction (5 minute headway using bi-articulated vehicle with 200 passenger capacity)

Performance Characteristics:

- Ridership (2015): 57.6 million annual passengers (about 160,000 daily passengers, with Line 32 being the busiest with 13.6 million annual passengers)
- On-Time Performance (2015): Ranges from 79%-96% for all trolleybus lines
- Farebox Recovery (2013): 85+% for Lines 31, 32, 33 and 72; 73% for Line 46; 60% for Line 34

References:

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- http://www.trolleymotion.eu/www/index.php?L=3&id=37&sy_ID=277

Trolleybus Case Study 2: Shanghai, China – Trolleybus Network

Reference image

System Description:

Shanghai has an extensive urban public transport network including 14 rail lines (including Heavy Rail and Light Metro), a modern tram (the Zhangjiang Tram), and one of the world's densest urban bus networks. Shanghai also operates 12 trolleybus routes comprising a network of about 120 km – it is the oldest continuously running trolleybus network in the world. Average operating speed is 13-15 km/h (based on Routes 6 and 8). Trolleybuses are 12 m long vehicles. The traditional trolleybus fleet has started to be replaced with hybrid models in 2014 that allow operation off the catenary. As of 2014, 360 such

Trolleybus Case Study 2: Shanghai, China – Trolleybus Network

vehicles are in operation today.

Planning Background:

The first trolleybus line in Shanghai was operated in 1914. Starting with this initial 3.5 km line, the system was expanded quickly by 1924 to 33 km. At its peak in 1985, more than 40% of all passenger trips on the public transport system were on trolleybus. Trolleybus serviced was operated on major trunk routes in the city including along the Bund and Zhongshan Road. After the opening of the first urban rail lines in the mid-1990s, the mode share and ridership on trolleybuses has dropped and several of these routes have been converted to bus operations.

System & Service Characteristics:

- Total Number of Lines: 12
- Network Length: 120 km
- Vehicle Type/Size: 12 m trolleybus and 12 m hybrid trolleybus (for operation off the catenary grid)
- Service Hours: 4:30AM-12:00AM
- Headway: 3-4 minutes in the peak; 8-12 minutes in the off-peak
- Peak Capacity: 1,200 passengers per hour per direction (3 minute headway using 12 m vehicle with an assumed passenger capacity of 60)

Reference image

Performance Characteristics:

- Operating Speed: 13-15 km/h

References:

- D. Budach, 2014, Shanghai [CN] - U-Turn: Renewal of the Trolleybus Fleet, http://www.trolleymotion.eu/www/index.php?L=3&id=38&n_ID=1970
- http://www.84000.com.cn/
- http://116.228.188.150/84000 mapTemp/webMonitor.WebMonitorAction.do?CMD=getBusLineInfo&LineName=6
- Jane's Urban Transport Systems, 2015.

3.6.5 Trolleybus - Summary and Broad Applicability within KE

Pros	Cons
• Minimal noise and emissions compared to conventional diesel or hybrid buses as trolleybuses are powered by electricity from overhead catenary • More flexible and easier to expand than rail-based modes • More accessible than grade separated modes, especially for passengers with mobility issues • Shorter construction timeframe than a rail-based system • Lower capital costs compared to rail-based modes and can use existing roadways • Hybrid vehicles allow independent battery operation for short stretches	• Overhead wiring system limits potential expansion of the system compared with conventional road based systems • Operates partially in mixed flow conditions, which can reduce speed and reliability • Increases number of vehicles on the road and congestion • Lower capacity compared to other bus-based systems and rail systems • Reduced flexibility as trolleybuses are less able to manoeuvre around street incidents, catenary maintenance or blockages (unless hybrid) • Higher capital costs than conventional bus due to overhead catenary • Visual impact of catenary wires • Requires specialised depot separate from typical bus depots

Key Findings and Broad Applicability within KE

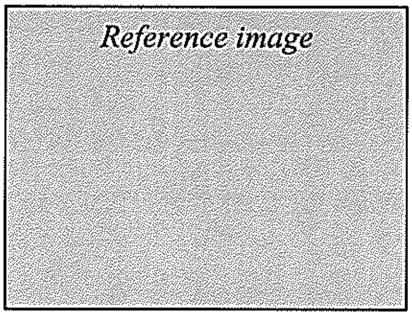
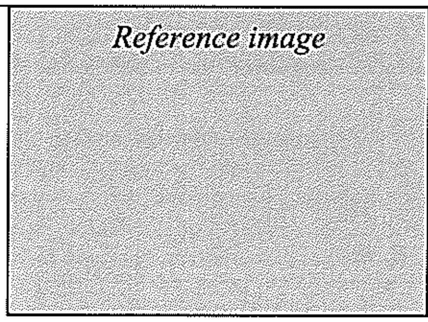
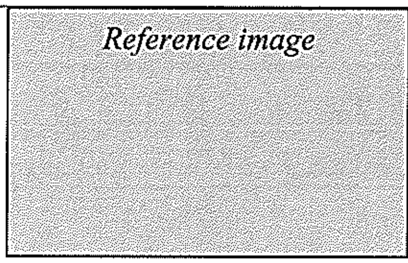
- Trolleybus operates similar to bus in that it operates primarily on-street in mixed flow conditions, although limited segments of dedicated lanes may be provided – particularly at approaches to intersections. Signal priority can help to minimise delays at junctions for trolleybuses, similar to bus, BRT, and modern tram. However, capital infrastructure requirements and fixed infrastructure costs are much higher than buses due to the need for overhead wiring as well as sub-stations.
- In the context of KE, trolleybus will be subject to mixed flow conflicts and delay while operating on the surface, although dedicated lanes and transit signal priority could help to improve reliability and speed. Trolleybus wires would require sufficient overhead clearance, but would still have visual implications. Trolleybus would likely require its own depot separate from existing bus depots in the area. Given the advancement of electric bus technology, trolleybus has no distinct advantage over green buses due to the provision of the overhead catenary system.

4 Rail-based Green Public Transport Systems

4.1 Introduction of Rail-based Transport Modes

4.1.1 Rail-based green public transport systems connote all rail guideway systems that provide high capacity and high quality mobility. This section summarises each of these modes. Modes assessed include the following:

- Automated People Mover (APM)
- Cable Drawn Shuttles
- Heavy Rail
- Light Metro
- Modern Tram
- Monorail
- Personal Rapid Transit (PRT)

Mode	Brief Description	Example
Automated People Mover (APM)	APM systems use automated vehicles with rubber tires that run on a flat guideway or two parallel plinths.	 Tokyo Yurikamome APM
Cable Drawn Shuttles	Cable drawn systems use cables to haul trains along the track, hence no traction motors are installed in the trains. The cables can be permanently attached to the trains, or, alternatively, the cables can be detached when the trains are stopping at stations. The funicular railway is a system with 2 trains permanently connected to the same cable. The system forms a single track railway with a passing loop on the middle of the line.	 Oakland Airport Connector
Heavy Rail	A Heavy Rail system is based on about 25 m long vehicles running on steel rails. Urban trains are typically 200 - 300 m long. Alignment criteria are much more restrictive than other types of rail-based modes.	 Hong Kong MTR

Mode	Brief Description	Example
Light Metro	Light metro systems are a smaller scale of rail systems with lighter and shorter vehicles. The most modern light metro systems are operating with driverless vehicles (for example Docklands Light Railway and Copenhagen Light Metro).	*Reference image* London Docklands Light Rail
Modern Tram	Modern tram systems are based on vehicles that can operate on guideway mixed with road vehicles. Hence, the vehicles cannot be driverless. Many systems operate with low-floor trams, for convenient access.	*Reference image* Dublin Luas
Monorail	Monorails are vehicles running on a single beam guideway. The two major categories of Monorails are straddling monorail and suspended monorail (also called under-slung monorail).	*Reference image* Tokyo Monorail
Personal Rapid Transit (PRT)	Personal Rapid Transit (also known as "Urban Light Transit" or "Automated Transit Network", ATN) , is a system of automated, electric small vehicles (sometimes called "pods" for 2-6 passengers) that run on segregated guideway. Stations are located off the main line, enabling non-stop journeys.	*Reference image* London Heathrow ULTra

4.2 Automated People Mover (APM)

4.2.1 APM - System Characteristics

Background and System Technology

4.2.1.1 Automated People Mover (APM) systems use self-propelled automated vehicles with rubber tires that run on a flat guideway or two parallel plinths. In Japan, these systems are known as Automated Guideway Transit (AGT). APM typically play a feeder and circulator role in the overall network for higher capacity modes such as Heavy Rail. APM systems are found in many airports, but also have been implemented in urban and suburban context. Examples include the APM at Hong Kong International Airport operating between T2, T1 and boarding gates along the "Y". Other airport-related APM systems include AirTrain New York City's JFK Airport, AirBART at San Francisco International Airport, as well as the Crystal Mover at Singapore Changi International Airport.

4.2.1.2 In an urban context, APMs can be used in different contexts, but are typically implemented in central business districts, serving as feeders to other rail lines. Singapore has three APM systems in outlying residential areas that connect to its Heavy Rail MRT System. Detroit and Miami in the United States both operate short APM systems that circulate throughout the central business district (CBD). Tokyo's Yurikamome connecting Shimbashi to Odaiba is an example of a higher capacity APM system, operating with up to six-car trains, as an urban feeder and circulator. Montreal's Metro and Santiago, Chile's Metro are both high-capacity APM systems that operate in lieu of Heavy Rail or Light Metro.

Role in Transport Hierarchy

4.2.1.3 APM's role in the overall transport hierarchy is typically as a low-moderate capacity feeder system or local circulator within a defined area including a central business district, business park, university, airport, etc. APMs can also play a more prominent role as a trunk line when no other higher capacity rail system exists – this is the case for Santiago and Montreal.

Key Infrastructure Elements and Vehicles

4.2.1.4 Key infrastructure elements include the guideway, station and vehicles.

Runningway and Track

4.2.1.5 Most APM suppliers use concrete running surfaces poured separately and on top of the viaduct or tunnel structure. Typical heights of these elements vary with supplier and range from approximately 10 to 30 cm. The guideway needs to be completely segregated from other modes of transport as well as pedestrians.

4.2.1.6 As an automated system, there is no driver and thus all crossings must be fully grade separated. Frequent train departures and the live third rail/catenary would generate significant safety problems if at-grade crossings were allowed through the corridor. Furthermore, the APM must operate in a guideway with guide rails either in the middle or at the side of the guideway (subect to technology) to allow vehicles to make turns / maneouvre without the driver or manual steering mechanism. Due to these requirements, APM cannot operate at the road level unless in a completely segregated corridor without conflict from pedestrians or other road users including vehicles.

4.2.1.7 The lower limit for horizontal radius varies within a range from 18 to 30 m. However, such small radii will require speed limitations so they should be avoided wherever possible Maximum gradient is in the range from 6% to 12%. However, gradients more than 6-7% are not preferred since they generate passenger discomfort (due to high longitudinal acceleration). Maximum speed is typically in the range from 50 km/h to 80 km/h.

Stops/Stations

4.2.1.8 Station size depends on train length, but is similar to those for Heavy Rail or Light Metro with paid and unpaid areas at the concourse and boarding platforms. Station spacing also varies depending on the context. APMs used as circulators have much denser station spacing than those used as urban feeders or trunk lines. For instance, the Miami Metromover (a downtown circulator) has a station spacing of 350 m, Singapore's Bukit Panjang LRT has a spacing of 550 m, while Tokyo's Yurikamome has a spacing of 900 m.

Vehicles

4.2.1.9 APM vehicles can consist of individual vehicles (normally 12-13 m long) or multiple units. Size of each vehicle varies by system. For instance, airport APMs (such as Hong Kong's Airport People Mover) have a car capacity of about 150 passengers/car compared to systems such as the Yurikamome, or the Santiago or Montreal Metros (up to 300 passengers/car). Vehicles are self-propelled and powered by on-board electric motors that source power from power rails which are placed either in the middle or at the side of the guideway. Operation of the trains may be manual or driverless, when operating on the main line. Various APM technologies are proprietary, which means it is difficult to change supplier at system expansion or renewal.

Capital Costs

4.2.1.10 The following table provides a summary of capital costs for APM systems:

Table 4.2.1: Equivalent FY2015 Capital Costs for Various APM Systems

System	Length (km)	Year Opened	Cost (HK$)	Cost (HK$) / km
Dallas International Airport APM, Dallas, United States	7.9	2005	9,855 million	1,247 million
Zhujiang New Town APM System, Guangzhou, China	8	2010	7,439 million	930 million
Yurikamome, Tokyo, Japan	14.7	1995	12,788 million	876 million

Source: Arup Database (cost in 2015 Price Level)

4.2.2 APM - Operating Characteristics

Service and Passenger Capacity

4.2.2.1 Average operating speed is up to 35 km/h. Headways of 90-120 seconds are not unusual for APM systems. Urban circulator and airport systems will typically provide more frequent service than those in business parks or outer areas. The Miami Metromover arrives every 90 seconds in the peak. Singapore's Sengkang system operates 3.5 minute peak headways. Tokyo's Yurikamome is as an urban feeder and operates 3.0 minute peak headways.

4.2.2.2 The table below compares operating characteristics of several APM systems:

Table 4.2.2: Service Profiles for Various APM Systems

System	Route Length (km)	# of Stations	Average Speed (km/h)	Headway (min)	Capacity (pphpd)
Bukit Panjang LRT, Singapore	7.8	14	33	2.5	4,500
Hong Kong Airport People Mover, Hong Kong SAR, China	2.8	5	N/A	2.0	7,800
Macau LRT Phase 1, Macau SAR, China	20.2	21	N/A	3.0	9,000
Metromover, Miami, United States	7.1	21	14	1.5	4,800
Punggol LRT, Singapore	9.5	8	25	2.0	1,800

System	Route Length (km)	# of Stations	Average Speed (km/h)	Headway (min)	Capacity (pphpd)
Sengkang LRT, Singapore	10.7	12	25	3.5	1,800
Yurikamome, Tokyo, Japan	14.7	16	30	3.0	6,000-7,000

Sources:

Hong Kong: https://www.hongkongairport.com/eng/passenger/arrival/t1/airport-services-facilities/in-terminal-transport.html
Macau: Arup Database
Miami Metromover: Jane's Urban Transport System 2015-2016
Singapore Bukit Panjang: ARUP database; Jane's Urban Transport System 2015-2016; and http://www.urbanrail.net/as/sing/singapore.htm
Tokyo Yurikamome: Jane's Urban Transport System 2015-2016;
http://www.kobelco.co.jp/english/engineering/products/traffic/agt/vehicle.html

4.2.3 APM - Other Key Characteristics

Reliability

4.2.3.1 APM can provide a high degree of reliability as it operates in its own right-of-way, grade separated and unobstructed by street level traffic. Technology is well proven and an APM system currently operates at Hong Kong International Airport and many other overseas countries both as an airport circulator and as an urban trunk line in cities such as Tokyo (Japan), Santiago (Chile) and Montreal (Canada).

Impacts on Other Road Users

4.2.3.2 APM is grade separated from road traffic and would have minimal to no impact on road users, except for column placement in the middle of a road, which would require some road width for a protected median.

Land Requirements

4.2.3.3 APM systems require the track right-of-way, stations, and a depot. The design carrying capacity of the system dedicates the fleet size, which then governs the size of the depot and the length of the station. Depending on the design of the system, an APM system generally shares similar characteristics as heavy rail with paid and unpaid areas at the concourse and boarding platforms at stations. Land provisions should be allowed during the design stage to reserve for the construction, operation and maintenance of the system.

Transit Oriented Development (TOD) Implications

4.2.3.4 Overall, APM, as a rail-based mode operating in its own fixed guideway, provides a sense of "permanence" along the fixed alignment. Depending on the context, APM can also encourage TOD and densification. In Montreal and Santiago where APM plays the primary role in the public transport system, APM can facilitate TOD.

Safety and Evacuation Requirements

4.2.3.5 Normally, a failed train should be moved to the nearest station to detrain passengers. If the failed train has lost traction power, it can be pushed by another train. If this cannot be done, passengers have to be evacuated to dedicated evacuation walkways. Detrainment could either be via side doors or via the front/back of the lead/last vehicle. APM suppliers could design vehicles with fronts/ends in addition to or as an alternative to side detrainment, depending on the requirement of the local authorities.

Environmental Implications

4.2.3.6 APM vehicles are powered by electric motors, which minimises environmental impact. Noise emissions are low due to the electric motors and rubber tires depending on the system design operating speed and frequency (subject to environmental assessment).

4.2.4 APM – Case Study

4.2.4.1 Two case studies are presented: (i) Tokyo, Japan – Yurikamome Line; and (ii) Singapore – Sengkang and Punggol Light Rail Lines.

APM Case Study 1: Tokyo, Japan – Yurikamome Line

Reference image

System Description:
The Yurikamome Line is an elevated driverless APM system, also referred to as Automated Guideway Transit, operating between Shimbashi Station in Tokyo and the reclaimed island of Odaiba. The Yurikamome Line is 14.7 km long with 16 stops and crosses Tokyo Bay to reach Odaiba via the double-deck suspension Rainbow Bridge. The total end-to-end journey time takes 31 minutes. The Yurikamome Line operates at 3 minute peak headways and 4-10 minute off-peak headways. Trains consist of six cars and can accommodate up to 352 passengers. This equates to a peak capacity of 6,000-7,000 pphpd.

The Yurikamome Line functions as a moderate capacity line linking directly to the Heavy Rail Japan Railways Yamanote Line among others. The Yurikamome functions as both a primary circulator on Odaiba and a major connector linking Tokyo proper and various urban/suburban rail lines to Odaiba. Capacity, however, is much lower than any of the Heavy Rail JR or private subway lines in Tokyo.

Construction costs for the line were US$1.65 billion, or US$350 million per mi. Of the US$1.65 billion, US$1.1 billion was paid by the Tokyo Municipal Government, while US$550 million was paid by the private sector through a consortium of 17 different banks. The high costs are attributed to the large footings required for portions of the guideway built above water or above mud flats in Tokyo Bay.

Planning Background:
As part of a plan to decentralize Tokyo into urban sub-centres in 1985, the Tokyo Metropolitan Government (TMG) started to reclaim a large island east of Tokyo on 448 ha of reclaimed land, 6 km from the city centre. Known as Odaiba, the planned workforce was to number 110,000, with a night-time population of 60,000. Odaiba would be connected by the now famous Rainbow Bridge to the mainland and Tokyo proper.

Several modes were considered and ultimately, the choice was AGT (manufactured by Mitsubishi). AGT was selected for three specific reasons: (i) Odaiba was built on reclaimed land, which offers large open areas making an elevated guideway a lower-cost option than a subway (or Heavy Rail)

APM Case Study 1: Tokyo, Japan – Yurikamome Line

system; (ii) the compact and lightweight AGT vehicle would be more suitable for crossing the Rainbow Bridge suspension bridge; and (iii) an automated, driverless system matches the vision for a Odaiba as a round-the-clock sub-centre.

System & Service Characteristics:

Reference image

- Total Number of Lines: 1 line
- Network Length: 14.7 km
- # of Stations: 16
- Vehicle Type/Size: 6-car trains (accommodating up to 352 passengers; most recent models can hold 306 passengers)
- Average Speed: 30 km/h
- Service Hours: 5:00AM-12:00AM
- Headway: 3 minutes in the peak; 4-10 minutes in the off-peak
- Peak Capacity: 6,000-7,000 passengers per hour per direction (based on car size)
- Capital Cost (FY2015): HK$12.8 billion (US$1.65 billion)

Performance Characteristics:

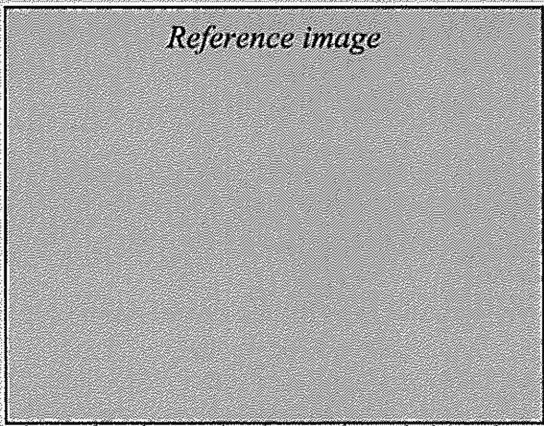
- Ridership: 107,000 daily riders
- Operating Costs: US$60.0 million (FY1997)
- Fare Revenues: US$68.0 million (FY1997)
- Farebox Recovery: 113% (FY1997)

References:

- http://www.jrtr.net/jrtr16/pdf/f15_iwata.pdf
- http://www.kobelco.co.jp/english/engineering/products/traffic/agt/vehicle.html
- http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rrd_42.pdf
- http://www.yurikamome.tokyo/aboutus/overview/
- http://www.yurikamome.tokyo/file/pc/en/pdf/info/timetable/u-01.pdf
- http://www.yurikamome.tokyo/qa/qa_category/qa-vehicle/

APM Case Study 2: Singapore – Sengkang and Punggol LRT Lines

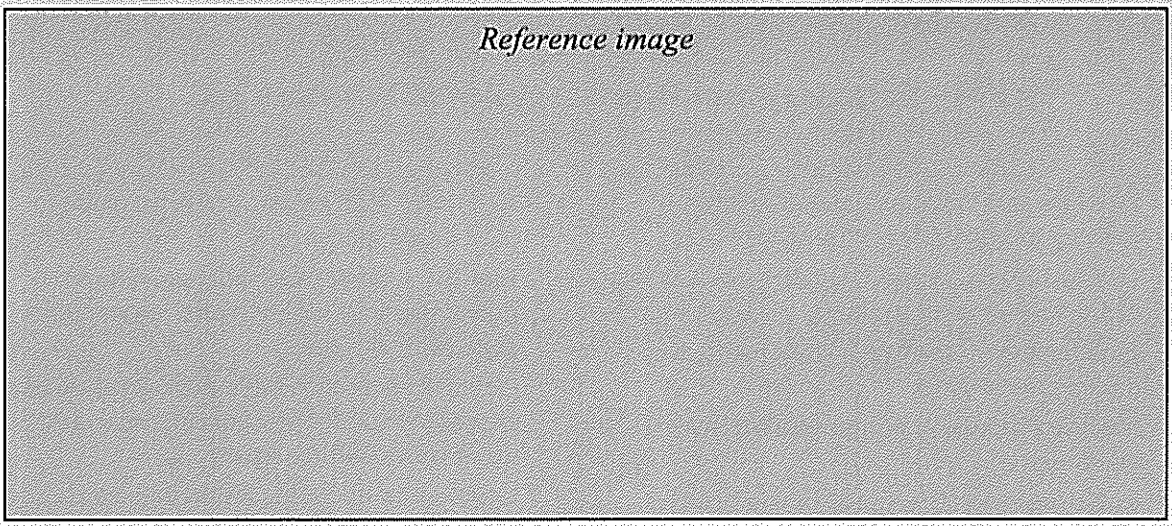
System Description:



Singapore operates three elevated driverless APM systems: (i) the Bukit Panjang Line (opened in 1999); (ii) the Sengkang Line (opened in 2003); and (iii) the Punggol Line (opened in 2005). These three APM systems operate on an exclusive guideway with rubber-tire trains. The focus of this case study is on the Sengkang and Punggol Lines which are the newer APM systems operating in Singapore.

Both the Sengkang Line and the Punggol Line consist of two east and west loop lines which converge at a MRT interchange station. The Sengkang Line is 10.69 km long with 14 stations, and operates at 3.5 minute headways in the peak and 6.0 minute headways in the off-peak. The Punggol Line is 9.47 km long with 15 stations (only 8 are in operation today) and operates at similar headways. Both lines use Mitsubishi Crystal Mover vehicles that can hold up to 105 passengers (with 18 seats). Design capacity of the two lines is approximately 1,800 passengers per hour per direction. Plans are in the works to operate 2-car trains, which is expected to increase capacity by between 40-50%.

Although they are described as a separate technology (LRT vs. the Heavy Rail MRT), these systems are fully integrated into the urban rail network of Singapore, as free transfers can be made to/from the LRT and MRT. Each of the three systems are centred around a MRT Heavy Rail station, thus the APM plays a role as a feeder line, as well as a circulator line within these suburban developments.



Planning Background:

The background of the LRT network was the desire to provide better door-to-door service in outlying areas that were soon to be connected to the MRT, Singapore's urban rail system. The Singapore Government's 1996 White Paper, titled "A World Class Land Transport System" specifically identified the future LRT lines as feeders to the MRT network, suitable for lighter corridors (i.e., lower demand than would sustain a Heavy Rail system) and in areas where there is sufficient demand. Bus would then continue to serve the less heavy (in terms of demand) corridors to complement the MRT-LRT network. Thus, the LRT lines would not only link to the regional MRT network, but also provide local circulation within these developments.

APM Case Study 2: Singapore – Sengkang and Punggol LRT Lines

Subsequently, LRT was developed in three outlying areas, centred on an MRT station. The Sengkang LRT was opened in 2003 and connects residential districts and suburbs of the Sengkang Town Centre as well as the North-East Line and the Sengkang Bus Interchange. Also, the Punggol LRT was opened in 2005 to serve residents in Punggol Township and link to the North-East Line and Punggol Bus Interchange. Similarly,

System & Service Characteristics (Sengkang and Punggol Lines only):
- Total Number of Lines: 2 lines
- Network Length: 20.2 km
- # of Stations: 20
- Vehicle Type/Size: Crystal Mover (holding up to 105 passengers)
- Average Speed: 25 km/h
- Service Hours: 5:30AM-12:45AM
- Headway: 3.5 minutes in the peak and 6.0 minutes in the off-peak
- Peak Capacity: 1,800 passengers per hour per direction

Performance Characteristics:
- Ridership: 15.1 million daily trips (FY2009, including all three LRT lines)

References:

- https://www.lta.gov.sg/content/dam/ltaweb/corp/PublicationsResearch/files/ReportNewsletter/White-Paper.pdf
- http://www.lta.gov.sg/content/ltaweb/en/public-transport/projects/punggol-lrt.html
- http://www.lta.gov.sg/content/ltaweb/en/public-transport/projects/sengkang-lrt.html
- http://www.sbstransit.com.sg/transport/trpt_lrt_overview.aspx
- Jane's Urban Transport Systems 2015-2016.

4.2.5 APM - Summary and Broad Applicability within KE

Pros	Cons
• Provides fast, high quality and reliable journey in segregated right-of-way • Can be fully automated and driverless, which can reduce operating costs • Less impact on roadways since mode does not operate at-grade • Electric propulsion minimises harmful emissions • Lower noise profile due to rubber tires • Can run at small horizontal radii (18-30 m) • Creates sense of permanence and has been shown to facilitate TOD	• Relatively high capital costs compared to road-based modes • Limited number of suppliers may limit procurement of new vehicles / systems for expansion or repair • Generally less accessible than street-running, at-grade mode for passengers, especially those with mobility issues • Requires an operational control centre and a maintenance depot for the system, which has land implications

Key Findings and Broad Applicability within KE

- An APM system within KE would offer a fully segregated rail system, which can be fully automated (driverless). APMs play a variety of roles from circulator to feeder to trunk system and their capacity can vary significantly. APMs in some instances have been implemented instead of Heavy Rail (as seen in Montreal and Santiago) to cater for a system with a moderate passenger demand at a lower cost. APM operate quieter than steel rail systems, which may be an advantage when travelling through heavily populated areas.
- As the case studies showed, APM is a flexible mode that can be used as both a moderate capacity

connector (such as the Yurikamome), but also as a feeder and local circulator (as Singapore uses its LRT). The Yurikamome is a moderate capacity system that links a key leisure and employment hub to Tokyo and its dense Heavy Rail network. The Singapore LRTs operate as a feeder service to the MRT Heavy Rail network, but also are quiet enough to operate through dense residential developments.

- Within the context of Kowloon East, APM could be well suited to the unique operating environment as well as system spacing and capacity required for the EFLS. APM would operate quieter than steel rail systems and may be appropriate in built-up areas in Kwun Tong and Kowloon Bay. APM could operate similar to a downtown circulator (like Miami) as well as a circulator line similar to the Singapore LRT lines that link to the MRT. The relatively simple mechanism for switches is a benefit if switches are to be retrofitted to the system.

4.3 Cable Drawn Shuttles

4.3.1 Cable-Drawn Shuttles - System Characteristics

Background and System Technology

4.3.1.1 As discussed in **Section 3.2.1**, cable propelled transit includes both ground-based and aerial-based systems. This section covers ground-based cable systems (referred to as cable-drawn shuttles). Cable-drawn shuttles are propelled by cables that are winched by motors placed on the infrastructure. There are no traction motors on the vehicles, which enables them to be lighter and consequently, the viaducts for the guideway can be made slimmer. Given that there are no on-board motors, there is less noise from the trains compared with other systems. Due to the cable hauling, both acceleration and maximum speed is relatively low compared to other self-propelled rail-based systems.

4.3.1.2 Cable-drawn shuttles are either permanently attached to the cable or can attach/release the cable. Both types of cable-drawn shuttles exist today:

- **Shuttles That Are Permanently Attached to Cable** - Funicular railways (such as Peak Tram and the railway at Ocean Park in Hong Kong) are examples of cable-drawn shuttles permanently attached to the cable.
- **Shuttles That Can Grip and Release Cable** - "Heritage" cable cars such as San Francisco and Lisbon are examples of cable-drawn shuttles that are not permanently attached to the cable. More modern versions of cable-drawn shuttles include so-called cable liners and include the new Oakland Airport Connector, Toronto Pearson International Airport's LINK as well as Zurich Airport's Skymetro. The Cabletren Bolivariano in Caracas, Venezuela, is one of the only examples of a cable-drawn system operated in an urban (non-airport) context.

Role in Transport Hierarchy

Shuttles That Are Permanently Attached to Cable

4.3.1.3 Such cable-drawn systems have low capacity and are typically used to as tourist attractions or to scale severe grades. Systems where vehicles are permanently attached to the cables can only have two vehicles on any given cable and have severe capacity constraints. The operation of only two vehicles at any given time is severely limits capacity.

Shuttles That Can Grip and Release Cable

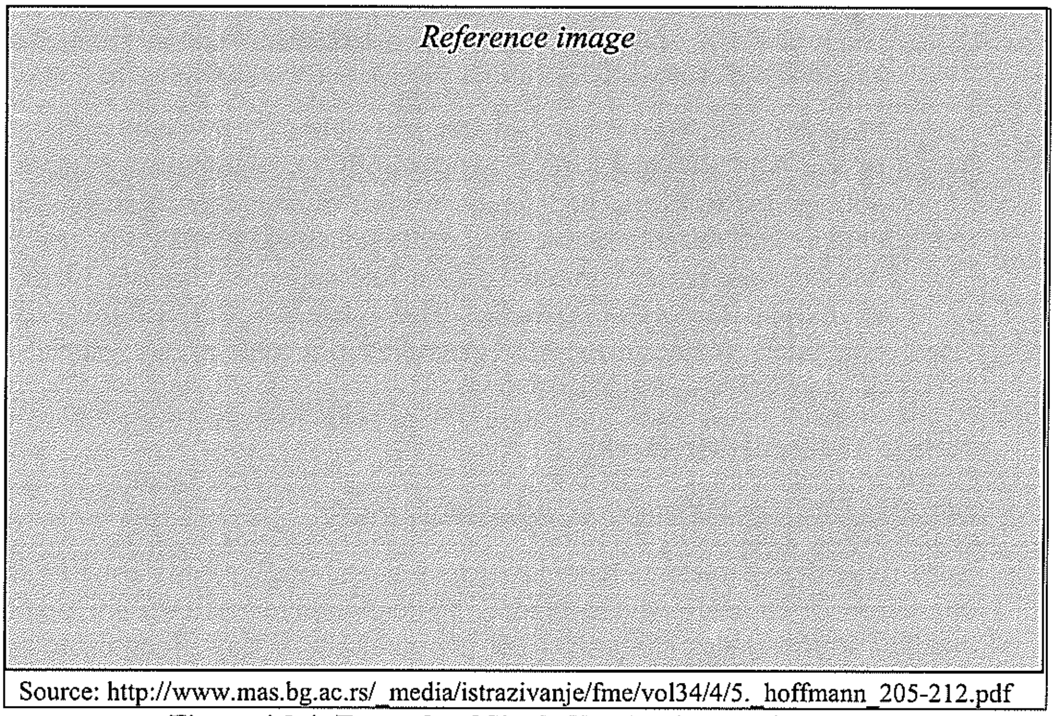
4.3.1.4 Cable-drawn systems that can grip and release cables can have multiple vehicles operating along a multi-station corridor – thus they could theoretically achieve much higher capacity than systems permanently attached to the rail. They can thus play a more varied role in the transport network – often as feeder systems from higher capacity rail or bus systems, providing last-mile connectivity and localized access. Recent applicable of cable-drawn systems has been at airports, providing connectivity to/from nearby rail lines.

Key Infrastructure Elements and Vehicles

4.3.1.5 The major infrastructure elements include the guideway track, hauling cable, the wheelhouse, stations, and depots (for some systems). The hauling cables restrict the alignment of the system, in particular the vertical alignment which requires a large radii (4000-6000 m). Horizontal curvature is also restricted to radii ranging from 38-200 m.

Guideway Track and Hauling Cable

4.3.1.6 A major limitation of systems with vehicles permanently attached to the cable is that there can only be two trains on the line. The guideway can either be continuous double track, or a single track with a passing loop in the middle of the line (the Hong Kong Peak Tram is an example of the latter system, which has only two trains on a single track - when one train ascends Victoria Peak, another descends down it – passing each other at the mid-way point). The cable is stationary when the trains are at stations and then accelerates with the same acceleration rate as the vehicles. Since the trains will travel at the same speed at any time, the line should be symmetric. The distances between stations (if any intermediate stations) should also be symmetric along the line so that when trains stop, both are stopping at stations.



Source: http://www.mas.bg.ac.rs/_media/istrazivanje/fme/vol34/4/5._hoffmann_205-212.pdf

Figure 4.3.4: Example of Single Track with Passing Loop (Similar to Hong Kong Peak Tram)

4.3.1.7 Cable-drawn systems with vehicles that are detachable from the cable have significantly differing characteristics. These systems have a main cable that runs at constant speed, and so a separate conveyer mechanism must accelerate the train when it is leaving a station. Thus, a gripper on the vehicle catches the cable and holds it to enable the vehicle to be drawn to the next station, where the gripper is released and the vehicle can start to decelerate to a stopping position at the platform.

4.3.1.8 Thus, depending on the system (noted below), there may be issues to handle local speed restrictions (small radius curve) since it is designed to pull the trains at the same constant speed as the cable. If a local speed restriction is applied, it will be necessary to disconnect the trains from the first cable and connect it to second cable system, running at a lower constant speed, and finally connect it to a third cable system running at the higher speed. Multiple cables, conveyer mechanisms, and fixed traction motors will be necessary. The alternative is to apply the local speed restriction the whole way between two stations. The gripper technology results in wear and the system is not really suitable for an alignment with many intermediate stations. Furthermore, the mechanism to haul the trains through turnouts (necessary at terminus stations and stations with turnback tracks for local shuttles) is complicated.

Types of Shuttle Systems

4.3.1.9 There are four types of such systems in operation today:

Shuttles That Are Permanently Attached to Cable

- **Single Shuttle System** – This system has one train operating both ways on a single guideway. It is most appropriate for 3km system with 2-5 stations. It is the lowest cost option, however has low capacity and the system must be shut down completely for maintenance. There is potential to place a station in the middle of the line, but distances must be equidistant from each station.
- **Double Shuttle System** - Double system has two independently operated trains on dual guideways. Each system has its own haul rope and drive machinery. Such a system is also appropriate for 3km system with 2-5 stations. The double shuttle system effectively doubles capacity compared to a single system and can remain operational even if one line is closed for maintenance. Costs are typically higher for a double shuttle system compared to a single one.
- **Bypass System** – This is similar to a single shuttle system. Two trains operate on a single shared guideway, except vehicle may pass one another at designated bypass locations. This provides similar capacity as a double shuttle system, but lacks the redundancy during maintenance – therefore if the line is closed for maintenance outside of bypass areas – the entire system must be closed.

Shuttles That Can Grip and Release Cable

- **Pinched Loop System** – This system operates with multiple vehicles in each direction with a series of pinched cable loops. This allows for higher capacity and more trains than the other three types of systems, allowing for a longer system with more stations and higher frequencies. Vehicles can operate independent of one another. Loops adjoin and overlap one another at stations. Vehicles can use pinched loops around curves so that faster straight-away speeds can be achieved (i.e., vehicles can operate at different design speeds along the straight-away and curves).

System Length and Stations

4.3.1.10 Longer systems require large and more powerful pullhouses to propel the vehicles. In addition, longer systems have more vehicles on the line at one time, which would also require additional and more powerful pullhouses. In addition, estimated maximum system length is around 5.0 km due to passenger load, loading/unloading time, and desirable time between successive vehicles (as vehicles operate at uniform speeds between stations – thus a minimum separation distance/time must be maintained to allow for station loading/unloading without bringing vehicles into potential conflict).

4.3.1.11 As noted, attached cable-drawn systems have must have stations at equidistant distances from one another. For detached cable liner systems, independent systems separately decelerate and accelerate vehicles into and out of stations. As each station would require its own acceleration and deceleration system, thus corresponding system costs would increase with each additional station. This also increases the complexity of the system and the possibility for breakdowns. The maximum number of stations currently served on existing cable liner systems is 5.

4.3.1.12 Due to these station and system length limitations, maximum achievable capacity is estimated at around 8,000 pphpd, but systems implemented elsewhere have only achieved up to 4,500 pphpd and are mainly used for specialised feeder purposes and not for urban use (for instance between a rail station and airport terminal, or within an airport).[32] Doppelmayr notes that effective capacity is typically up to 6,000 pphpd.[33]

Capital Costs

4.3.1.13 Capital costs for a range of cable-drawn systems are presented below.

Table 4.3.3: Equivalent FY2015 Capital Costs for Various Cable-Drawn Shuttle Systems

System	Length (km)	Year Opened	Cost (HK$)	Cost (HK$) / km
Oakland Airport Connector, Oakland, United States	5.1	2014	5,286 million	1,036 million
Toronto Pearson LINK, Toronto, Canada	1.5	2006	1,666 million	1,111 million
Zurich Airport Skymetro, Zurich, Switzerland	1.1	2003	1,410 million	1,282 million

Source: Arup Database (cost in 2015 prices). Escalation for the Zurich system is based on historical exchange rates from the OFX Group Website (http://www.ofx.com) for Year 2003 between Swiss Franc (CHF) and Hong Kong Dollar (HKD) as well as the change in Hong Kong's Consumer Price Index. Escalation is based on the following: (ii) CHF to HKD in 2003 (as of end of 2003) is HK$5.798 = 1.0 CHF; (ii) escalation in HK$ from 2003 to 2015 is 1.382; and (iii) original construction cost is estimated at CHF176.0 million.

[32] http://www.mas.bg.ac.rs/_media/istrazivanje/fme/vol34/4/5._hoffmann_205-212.pdf
[33] Discussions with Doppelmayr staff, November 29, 2016.

4.3.2 Cable-Drawn Shuttles - Operating Characteristics

Service and Passenger Capacity

4.3.2.1 Cable-drawn shuttles can achieve average speeds up to 35-40 km/h. Headways as low as 4-6 minutes have been achieved. For instance, the LINK at Toronto's Pearson International Airport operates has 4 minute headways, while the Oakland Airport Connector has 6 minute headways.

4.3.2.2 Passenger capacity differs based on headway, size of the vehicle, and whether the vehicle is permanently attached to the cable. Passenger capacity (pphpd) is relatively low for cable-drawn shuttles permanently attached to the cable as only two trains operate on the line.

4.3.2.3 **Table 4.3.4** shows capacity per direction for various cable-drawn shuttle systems whose vehicles are not permanently attached to the cable. The highest capacity system is at the Zurich Airport Skymetro, which has a capacity of over 4,500 pphpd, while the Oakland Airport Connector represents the lower end of such a system at 1,400 pphpd. Based on discussions with Doppelmayr, the maximum capacity of cable-drawn systems is about 5,000 pphpd and 5.0 km in length due to the length of cables and the number of independent cables required for each vehicle.[34]

Table 4.3.4: Service Profiles for Various Cable-Drawn Systems with Vehicles Not Permanently Attached to Cable

System	Route Length (km)	# of Stations	Average Speed (km/h)	Headway (mins)	Capacity (pphpd)	Daily Ridership
AirRail Link, Birmingham Airport, Birmingham, UK	0.6	2	N/A	2.0	1,600	N/A
Cabletren Bolivariano, Caracas, Venezuela	2.1	5	19	4.5	3,000	N/A
Pearson Link Train, Toronto, Canada	1.5	3	25	2.5	2,500	17,000
Mandalay Bay Tram, Las Vegas, United States	0.8	4	N/A	4.0	1,900	N/A
Mexico City Airport Aerotren, Mexico City, Mexico	3.0	2	N/A	5.0	550	N/A
Oakland Airport Connector, Oakland, United States	5.1	2	38	4.5	1,400	3,000
Venicle Tronchetto Piazzale Roma Shuttle, Venice, Italy	0.9	3	N/A	3	3,000	N/A
Zurich Airport Skymetro, Zurich, Switzerland	1.1	2	36	1.5	4,500	N/A

[34] Discussions with Doppelmayr staff, November 29, 2016.

Sources
Caracas: http://www.metrodecaracas.com.ve/obrasyproy/proy_cabletren.html
Toronto:
https://www.thestar.com/news/city_hall/2012/05/21/pearsons_cablepropelled_transit_link_is_ttc_riders_dream.html
Zurich: https://www.leitner-ropeways.com/fileadmin/user_upload/pages/MiniMetro-en.pdf
Others: Doppelmayr – http://www.dcc.at/references

4.3.3 Cable-Drawn Shuttles - Other Key Characteristics

Reliability

4.3.3.1 Cable-drawn systems can provide a high degree of reliability as it operates in its own right-of-way, unobstructed by street level traffic. However, for cable-drawn systems permanently attached to the cable, maintenance or replacement of the cables requires the whole system to be closed for up to several months unless a duplicate / standby system is readily available. For systems that can grip and release the cable, it is theoretically possible to single track around construction / maintenance so long as switches are provided. However, overall capacity through the pinchpoint would be reduced.

Impacts on Other Road Users

4.3.3.2 Cable-drawn shuttles are grade separated from road traffic and would have minimal to no impact on road users, except for column placement in the middle of a road, which would require some road width for a protected median.

Land Requirements

4.3.3.3 Cable-drawn systems require land for the track right-of-way (typically ranging in width from 4.5m, subject to supplier and the local context), the stations, wheelhouse (sizing depends on system/machinery spatial requirements) and depots (for some systems). Since trains are relatively short or of moderate length, land requirements for stations are moderate depending on the length of the shuttle line and the carrying capacity. Subject to the design, the wheel house should be located in a separate location, thus spatial requirement for the wheel house should be taking into consideration. Typical ROW width including station width would be about 20-24 m (depending on whether island platform or side platforms are used).

Transit Oriented Development (TOD) Implications

4.3.3.4 Although cable-drawn shuttles are a rail-based mode, their relatively low capacity and inability to operate in certain environments (as maximum capacity is about 5,000 pphpd and length is about 5.0 km) does not lend itself to support TOD by itself. Most cable-drawn shuttles are used to link to an airport or within an airport.

Safety and Evacuation Requirements

4.3.3.5 Normally, a failed train should be moved to the nearest station for detrainment of passengers. If the system has lost its traction performance, passengers have to be evacuated via the track or dedicated evacuation walkways.

Environmental Implications

4.3.3.6 Cable-drawn shuttles are powered by electric motors fixed installed at certain locations along the line, which minimises the environmental impact with regards to harmful emissions.

4.3.4 Cable-drawn Shuttles – Case Studies

4.3.4.1 The case study of the Oakland, United States – Oakland Airport Connector (OAC) is presented below.

Cable-Drawn Shuttles Case Study 1: Oakland, United States – Oakland Airport Connector (OAC)

System Description:

Reference image

The two station, 5.2 km Oakland Airport Connector (OAC) is an elevated, driverless cable-drawn shuttle linking Oakland International Airport with the nearby Coliseum BART Station (BART is the San Francisco Bay Area's Heavy Rail system). The OAC system operates on an elevated steel guideway and trains can detach from the cable.

Beginning operations in November 2014, trains depart every 4.5 minutes in the peak and take 8 minutes (an average of 40 km/h). The train is intended to provide a convenient and fast linkage between the BART system, which also links to San Francisco International Airport, and Oakland Airport. A new platform was built above the existing Coliseum Station for passenger transfers.

The OAC has a line capacity of 1,400 pphpd (with potential for up to 1,900 pphpd). [redacted]

Planning Background:

Reference image

Prior to OAC, Oakland Airport passengers would need to transfer at Coliseum Station and use AirBART buses to the airport. Buses were often slowed by traffic as well as passing commuter and freight trains. Furthermore, the Coliseum Complex houses an arena and stadium, creating crowded station conditions at the street level as well as significant congestion on local roads when events begin or ended.

Traditional Heavy Rail BART technology was not considered from the start due to higher construction cost as well as longer construction timeframe. BART noted that modifications to the track at Coliseum Station would be needed, which would cause service delays and require single tracking. The system was meant to only carry a few thousand passengers per day, not hundreds of thousands like the BART system. Automated Guideway Transit (or AGT) was selected as the desired mode over an enhanced bus scenario based on numerous factors including travel time, reliability, ambient traffic impact, and costs.

Cable-Drawn Shuttles Case Study 1: Oakland, United States – Oakland Airport Connector (OAC)

System & Service Characteristics:

- Total Number of Lines: 1 lines
- Network Length: 5.1 km
- # of Stations: 2
- Vehicle Type/Size: Three-car train (carrying 114 passengers)
- Average Speed: 38 km/h
- Service Hours: 4:00AM-1:00AM
- Headway: 4.5 minutes in the peak
- Peak Capacity: 1,400 passengers per hour per direction
- Construction Timeframe: 4 years (2010-2014)
- Capital Cost (FY2015): HK$5.286 million or (FY2009 HK$3,750 million (US$484.0 million))

[redacted]

References:

- Email with Andrew Tang, Principal Planner, BART, 4 February 2016.
- FAQ for BART to OAK Service, 13 November 2014.
- http://www.dcc.at/files/sites/default/data/DCC/References/Oakland_airport_connector_reference_sheet.pdf

4.3.5 Cable-Drawn Shuttle - Summary and Broad Applicability within KE

Pros	Cons
• Provides fast, high quality and reliable journey in segregated right-of-way • Can be fully automated and driverless, which can reduce operating costs • Less impact on roadways since mode does not operate at-grade • Electric propulsion minimises harmful emissions	• Not well suited for urban environments due to vertical and horizontal alignment constraints • Low capacity for system with vehicles permanently attached to the cable • Generally less accessible than street-running, at-grade mode for passengers, especially those with mobility issues • Lower capacity compared to other rail modes • Complicated mechanisms for system with vehicles that are detached from the cable when stopping at stations • Switch mechanisms complicated for systems with more than two trainsets • Although on a fixed alignment, does not facilitate TOD due to low capacity

Key Findings and Broad Applicability within KE
• Cable-drawn systems have for the most part been implemented for specific situations where demand is relatively low with a limited number of stations. Systems that are permanently attached to the cable have low capacity and little flexibility. Systems that can grip and release the cable can accommodate higher capacities and multiple stations, although have a ceiling on capacity (of about 5,000 pphpd) and length (5.0 km). Cable-drawn systems can achieve relatively high operating

speeds as it operates in fully-grade separated tracks, however, the technology has vertical and horizontal alignment constraints due to the capabilities of the pulling cable. Therefore, cable-drawn shuttles are not able to take very tight turns or quick grade changes. Cable-drawn systems are mainly implemented as feeder or circulator systems to/from airports due to the fixed nature of demand and the limited number of stations as shown by the Oakland Airport Connector example.

- In the context of Kowloon East, a cable-drawn shuttle would offer a fully segregated rail system, which can be fully automated (driverless). The capacity of cable-drawn shuttles may be an issue for Kowloon East. Furthermore, there are technical limitations in Kowloon East for instance the dense built-up areas that may constrain potential of a cable-drawn system. Furthermore, the complicated mechanisms at switches would be complex if the EFLS is to be provided with bifurcations, branch lines to adjacent districts, additional turnback tracks, etc.

4.4 Heavy Rail

4.4.1 Heavy Rail - System Characteristics

Background and System Technology

4.4.1.1 Heavy Rail is a rail-based public transport system that can accommodate the highest passenger capacities of all modes example. Heavy Rail, also known as metro, subway in the United States, or underground in the United Kingdom, are fully grade separated either on viaduct, at-grade, or in tunnels. Heavy Rail is powered by a wayside third rail or overhead catenary. Station spacing is typically the longest of all urban rail systems, with the longest trains and platforms.

4.4.1.2 Heavy rail serves as the principal trunk route or backbone of the urban transport network, with all other modes playing supporting, supplemental roles. Heavy Rail systems have a long history starting including systems over 100 years old in London, Paris, New York, and Chicago, etc. Hong Kong's MTR and Singapore's MRT are considered modern day Heavy Rail systems and are today's standard bearers.

Role in Transport Hierarchy

4.4.1.3 Heavy Rail provides the highest capacity of all urban rail modes – but it is the most expensive. For this reason, Heavy Rail is only operated as the primary backbone of the public transport network – typically along heavily travelled and dense corridors that support all-day ridership. Heavy Rail systems are completed by feeder systems that consist of other light rail and bus systems (for instance, Berlin's U-Bahn has complementary modern tram and bus lines).

Key Infrastructure Elements and Vehicles

4.4.1.4 The main infrastructure elements for Heavy Rail include the guideway, the station, the vehicles, operation control centre and depot.

Runningway & Track

4.4.1.5 Heavy Rail operates in fully segregated rights-of-way with electrified third rail or catenary. Some Heavy Rail systems operate express or limited stop service and have four or more operating tracks along the same corridor. According to international standards, lower limit for horizontal radius is typically 140-150 m, even though such radii are rarely used outside depots. On main lines, a normal lower limit is about 300 m, which would allow a train speed of about 80 km/h.

Maximum gradient is typically in the range 3-4%. Maximum speed of the trains for heavy urban and suburban lines is in the range of 100-160 km/hr.

Stops/Stations

4.4.1.6 Stations can accommodate maximum train length (up to 12 cars long) or more depending on design. Newer stations are equipped with platform screen doors – this helps to improve safety for riders but also increase effective platform area for queuing (as passengers will not wait close to the platform edge without doors). Station spacing is normally 1,000 m or more.

Vehicles

4.4.1.7 Heavy Rail vehicles (based on Hong Kong's MTR) can carry between 250-320 passengers, based on 4-6 standing passengers per square metre. Trainsets may be linked or separated – for instance the Hong Kong MTR has a linked trainset in which passenger compartments are linked and not separated by doors – this allows better ventilation and passenger movement. Systems such as San Francisco's BART operate separate cars in that adjacent cars are separated by doors – which may or may not open (in Chicago and New York's cases, the doors cannot be opened and passengers cannot move from one car to the next). Separated systems are more flexible as trainsets can be shortened or increased depending on peak or off-peak service. Train length depends on the time of day and demand – Hong Kong's MTR for instance runs 8 to 10-car trains depending on the line. The length of trainsets and the speeds that Heavy Rail can reach means that longer following distances are required between trains – depending on the sophistication of the signalling and control systems.

Capital Costs

4.4.1.8 Capital costs for a range of Heavy Rail systems are presented below.

Table 4.4.5: Equivalent FY2015 Capital Costs for Various Heavy Rail Systems

System	Length (km)	Year Opened	Cost (HK$)	Cost (HK$) / km
Kaohsiung Mass Rapid Transit	42.7	2008	184,349 million	4,317 million
Klang Valley Mass Rapid Transit	51	2017 (Planned)	152,206 million	2,984 million
Taichung Metro Green Line	16.5	2018 (Planned)	52,600 million	3,188 million

Source: Arup database (cost in 2015 Price Level)

4.4.2 Heavy Rail - Operating Characteristics

Service and Passenger Capacity

4.4.2.1 As noted, Heavy Rail can achieve speeds of up to 160 km/h in some stretches. Headways for Heavy Rail can be as low as 2 minutes during peak periods – depending on signalling systems, maximum speed on the line and track configuration at the terminus stations. While MTR operates all-stop service calling at all stations along the line, some systems use express or limited stop service to reduce travel times during peak periods. This may be achieved by scheduling and/or the use of a passing track, siding, or multiple platforms. Various lines in Tokyo and London operate such services.

4.4.2.2 The table below compares operating characteristics of several MTR lines in Hong Kong based on car size, train length, and assumed passenger capacity. Year 2015 design line capacity ranges from 32,000 on the relatively short Ma On Shan Line to over 101,000 on the East Rail Line (assuming 6 ppsm (persons per square metre), based on the Legislative Council Panel on Transport Subcommittee on Matters Relating to Railways, Capacity and Loading of Trains in the MTR Network – LC Paper No. CB(4)854/15-16(07)).

4.4.2.3 **Table 4.4.6: Service Profiles for Various Heavy Rail Lines in Hong Kong (based on 2015)**

System	Route Length (km)	Average Speed (km/h)	Morning Peak Headway (s)	Design Capacity (pphpd) [A]
East Rail Line	41.1	50	164 s	101,000
Island Line	16.0	33	112 s	85,000
Kwun Tong Line	11.2	33	126 s	85,000
Tsuen Wan Line	16.0	33	120 s	85,000
Tseung Kwan O Line	11.9	33	153-400 s [B]	85,000
Tung Chung Line	31.1	80	240-480 s [C]	66,000
West Rail Line	35.4	56	171 s	64,000
Ma On Shan Line	11.4	38	180 s	32,000

Source: (i) http://www.legco.gov.hk/yr15-16/english/panels/tp/tp_rdp/papers/tp_rdp20160419cb4-854-7-e.pdf, Legislative Council Panel on Transport Subcommittee on Matters Relating to Railways, Capacity and Loading of Trains in the MTR Network – LC Paper No. CB(4)854/15-16(07); and (ii) MTRC Business Overview, October 2015 - https://www.mtr.com.hk/archive/corporate/en/publications/images/business_overview_e.pdf

Notes:

[A] Capacity based on 6 ppsm (persons per square meter).

[B] The Tseung Kwan O Line has variable headways by section as follows: (i) 240-480 s between Tung Chung and Tsing Yi; and (ii) 240 s between Tsing Yi and Hong Kong.

[C] The Tung Chung Line has variable headways by section as follows: (i) 153-246 s between Po Lam and North Point; and (ii) 400 s between LOHAS Park and North Point.

4.4.3 Heavy Rail - Other Key Characteristics

Reliability

4.4.3.1 Heavy Rail can provide a high degree of reliability as it operates in its own right-of-way, unobstructed by street level traffic.

Impacts on Other Road Users

4.4.3.2 Heavy Rail is grade separated from road traffic and would have minimal to no impact on road users, except for column placement in the middle of a road, which would require some road width for a protected median.

Land Requirements

4.4.3.3 Heavy Rail systems require land for the track right-of-way, the stations, depots, substations, etc. Since trains can be of long length, land requirements for stations and depots can be sizeable. An example of right-of-way width at a station would be about 27 m wide including platform and tracks (intermediate station with island platform on West Rail Line).

Transit Oriented Development (TOD) Implications

4.4.3.4 Heavy Rail creates a fixed corridor and alignment. With its premium service and high capacity, Heavy Rail provides a high sense of "permanence" and encourages investment and development around its stations. As an example, TOD atop Hong Kong MTR stations is a staple of development throughout the SAR.

Safety and Evacuation Requirements

4.4.3.5 For safety and evacuation concerns, the best practice is to detrain at station platform where all train doors can be opened to allow direct and prompt evacuation of large volumes of passengers. Any failed train should be moved to the nearest station for detrainment of passengers. If the failed train has lost its traction performance, it can be pushed by another train into the station for evacuation (which is the strategy adopted by MTRC).

4.4.3.6 For passengers with disabilities, the best location to evacuate from a train is at the station platform, where evacuation can be conducted in a spacious environment without a vertical step difference. Furthermore, station staff and passengers would be available to help facilitate efficient evacuation. This is also a practiced strategy of the MTRC on the existing railway network.

4.4.3.7 In case an incident train, for whatever reason, cannot reach a station platform, passengers with disabilities would need to evacuate to the evacuation walkway next to the track with possible assistance from other passengers and proceed to the nearest station. The evacuation walkway should be 850mm wide and at the same level as the train compartment. According to Appendix 10.A2, Section 10 of the MTRC Design Standards Manual, the minimum space required for users of self-propelled and electrically propelled wheelchairs is 800mm wide – thus providing an 850mm wide evacuation walkway would be sufficient for the evacuation of disabled passengers using wheelchair. The 800mm wide space requirement for wheelchair users in controlled passage is also specified in Clause 35, Division 9 in Chapter 4 of the Design Manual for Barrier Free Access 2008 published by the Buildings Department.

Environmental Implications

4.4.3.8 Heavy Rail vehicles are powered by electric motors, which minimises the environmental impact with regards to carbon emissions. Noise and vibrations from the contact between steel wheels and steel rails can be an issue. Furthermore, discharge of heavy metal particles generated from the rail and wheel may contaminate the drainage system that requires special attention to meet the statutory requirements.

4.4.4 Heavy Rail – Case Study

4.4.4.1 No Heavy Rail case studies are provided. It is assumed that Hong Kong's MTR is a well- known example of the technology, utility, and capability of such a system.

4.4.5 Heavy Rail - Summary and Broad Applicability within KE

Pros	Cons
• Highest capacity mode of all green transport modes investigated • Provides fast, high quality and reliable journey in segregated right-of-way • Less impact on roadways since mode does not operate at-grade • Can be fully automated and driverless, which can reduce operating costs • Minimises carbon emissions due to electric propulsion • High degree of standardisation of subsystems and components ensure many suppliers also at renewals and extensions • Creates sense of permanence and has been shown to facilitate TOD	• Most expensive rail mode to build/ operate • Relatively high capital costs compared to road-based modes • Largest footprint required due to station size and train turning radii • Generally less accessible than street-running, at-grade mode for passengers, especially those with mobility issues • Noise and vibrations from interface of steel wheels and rails may be an issue • Requires depot along the route
Key Findings and Broad Applicability within KE	
• Heavy Metro has been operated in Hong Kong for nearly four decades. It offers the highest capacity and the most reliable service of all green transport modes, but is the most costly to build and operate compared to other green transport modes. • In the context of KE, several Heavy Metro lines already provide regional access to the area including Kwun Tong, Ngau Tau Kok, Kowloon Bay, as well as the future Shatin-Central Link's Kai Tak Station. Internal flows in Kowloon East appear to be moderate and well below the capacity provided in other rail lines in Hong Kong. Therefore, given the high investment cost of Heavy Rail and the relatively modest demand forecast in Kowloon East, Heavy Rail would likely be inappropriate for the internal circulation needs of Kowloon East.	

4.5 Light Metro

4.5.1 Light Metro - System Characteristics

Background and System Technology

4.5.1.1 Light Metro is a form of rail-based transit that is generally smaller in size with lighter vehicles and infrastructure than traditional Heavy Rail. Light Metro systems are typically driverless and have a moderate to high capacity. Light Metro systems are fully grade separated either on viaduct, at-grade, or in tunnels. Light Metro typically operates along major corridors with higher density land uses and major trip generators and attractors.

4.5.1.2 The key distinction between Light Metro and Modern Tram is that the former operates solely within a segregated right-of-way, while the latter can operate in both on-street situations (with cross traffic) and within a segregated right-of-way. Light Metro and Automated People Mover (APM) systems are often mistaken for one another – the key different is that Light Metro uses steel wheel vehicles, while APM uses rubber tire vehicles.

4.5.1.3 For Light Metro, the standards for Heavy Rail have been found to be too conservative. For Light Metro systems there exist no common standard, but local specifications are fairly similar to the UIC and CEN standards for traditional railways, but have less restrictive limits for certain parameters (such as horizontal radius, vertical radius, gradient).

4.5.1.4 Notable examples include the Copenhagen Metro, the Docklands Light Railway (DLR) in London, and the Vancouver SkyTrain, Light Metro plays the role of trunk system in Copenhagen and Vancouver, while serving as a circulator/feeder service in London.

Role in Transport Hierarchy

4.5.1.5 Light Metro typically operates as the trunk line, where no Heavy Rail line is present – this is the case for Vancouver's SkyTrain or Copenhagen's Metro. If Heavy Rail is present, Light Metro typically serves the role as a feeder and local circulator. The Docklands Light Railway (DLR) in London is a Light Metro system operating in the Docklands area and provides internal circulation and connection to the London Underground, which is a Heavy Rail system

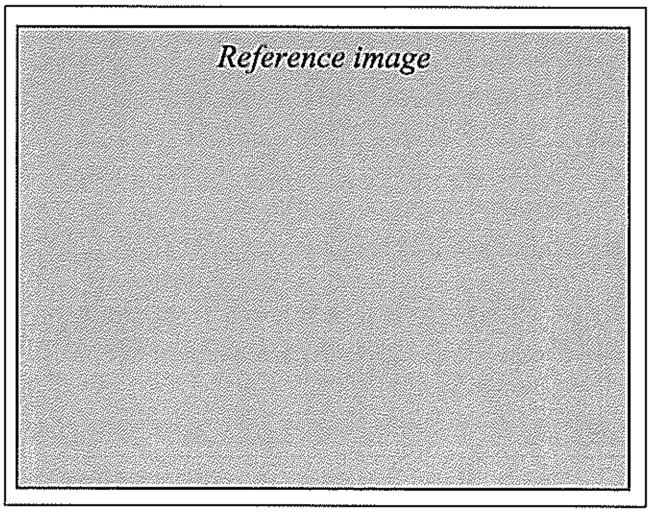


Figure 4.5.1: Small Horizontal Radii on Elevated Portion of Docklands Light Railway (DLR)

4.5.1.6 Light Metro can typically serves medium- to long-distance trips and operates within and through the urbanised core.

Key Infrastructure Elements and Vehicles

4.5.1.7 The main infrastructure elements for Light Metro include the guideway, the station and the vehicles.

<u>Runningway & Track</u>

4.5.1.8 Light Metro operates in fully segregated rights-of-way with electrified third rail or catenary. Light Metro and Heavy Rail share many characteristics. For example, many types of track components are similar. The system can have variable switch and crossing designs allowing alignment design flexibility. Infrastructure may be "lighter" than Heavy Rail due to lighter and shorter trains (discussed below)

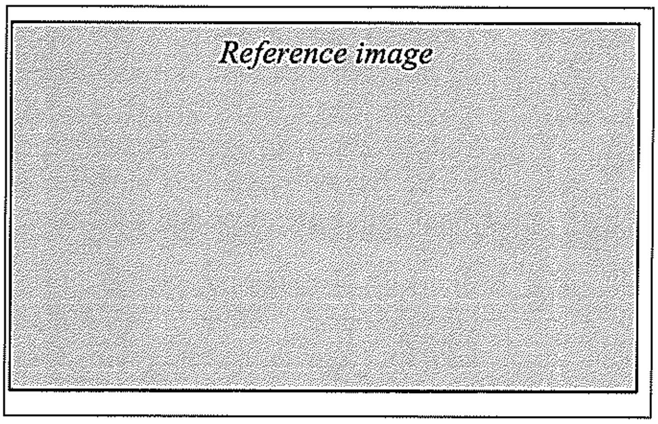


Figure 4.5.2: Island Platform with Platform Screen Doors on Copenhagen Light Metro (Kobenhavns Lufthavn, Kastrup)

4.5.1.9 The lower limit for horizontal radius can be as low as 40 m, even though such radii are rarely used outside depots. Maximum speed of the trains is typically in the range of 80-100 km/h (for example see Docklands Light Railway – Engineering Standard ES-401). Typical widths for Light Metro include the following (subject to supplier and local context): (i) corridor – 9.0m; (ii) rollingstock – 2.6-3.2m; and (iii) gauge – 1,422-1,435mm.

Stops/Stations

4.5.1.10 Stations can look similar as well with platform screen doors and faregates for off-board fare collection. Light Metro stations are typically smaller than Heavy Rail ones as trainsets are shorter (typically up to a maximum of 4 cars), and spaced typically 800-1,000 m apart.

Vehicles

4.5.1.11 Vehicles themselves are smaller in size and lighter than Heavy Rail vehicles. Trains are also shorter – between 1-4 cars – which limits capacity per train and overall line capacity, both of which are lower than those for Heavy Rail.

Capital Costs

4.5.1.12 Capital costs for a range of Light Metro systems are presented below.

4.5.1.13 **Table 4.5.7: Equivalent FY2015 Capital Costs for Various Light Metro Systems (for Single Line)**

System	Length (km)	Year Opened	Cost (HK$)	Cost (HK$) / km
Al Mashaaer Al Mugaddassah Metro Southern Line, Mecca, Saudi Arabia	18.1	2010	HK$17.4 billion	HK$959 million/km
Canning Town-Stratford International Line, Docklands Light Rail, London, United Kingdom	4.5	2010	HK$2.6 billion	HK$578 million/km
Canada Line, Vancouver, Canada (Canada Line)	19.2	2009	HK$12.08 billion	HK$630 million/km
Metro Line 4, Milan, Italy	15	Not Built (Planned 2022)	HK$18.9 billion	HK$1.3 billion/km
Rapid Metrorail, Gurgaon, India	5.1	2013	HK$6.1 billion	HK$1.2 billion/km

Source: Arup database (cost in 2015 Price Level)
Canning Town-Stratford International Line: http://www.railway-technology.com/projects/docklands/
Canada Line: http://www.partnershipsbc.ca/projects/operational-complete/canada-line/

4.5.2 Light Metro - Operating Characteristics

Service and Passenger Capacity

4.5.2.1 Light Metro can typically achieve speeds in the range of 80-100 km/h. Headways for Light Metro systems can be as low as 2 minutes during peak periods (depending on configuration at terminus stations). Train lengths are typically 1-4 cars. As an example, London Docklands Light Railway (DLR) trains have a capacity of 200 passengers/car. Assuming peak 2 minute headways, and 3-car trainsets, the capacity of the DLR is about 18,000 passengers per direction per hour.

4.5.2.2 The table below compares operating characteristics of several Light Metro systems:

Table 4.5.8: Service Profiles for Various Light Metro Systems

System	Route Length (km)	Total Number of Lines	Average Speed (km/h)	Peak Headway (min)	Capacity (pphpd)	Daily Ridership
Copenhagen Metro, Copenhagen, Denmark	20	2	40	2-4	12,000	160,000
Docklands Light Rail, London, United Kingdom	38	7	N/A (see Case Study 1)	2.0	18,000	350,000
SkyTrain, Vancouver, Canada	69	3	45	2.0-5.0	17,500	400,000

Source:

Copenhagen Metro: Proceedings of the Copenhagen Metro Inauguration Seminar/Copenhagen/Denmark/21-22 Nov 2002; Jane's Urban Transport System 2015-2016; and http://m.dk/#!/om+metroen/facts+om+metroen/statistik/passagertal.

London DLR: Email from Transport for London (TfL) – March 14, 2016.

Vancouver SkyTrain: Jane's Urban Transport System 2015-2016; http://www.translink.ca/; and http://www.apta.com/resources/statistics/Documents/Ridership/2014-q4-ridership-APTA.pdf.

4.5.3 Light Metro - Other Key Characteristics

Reliability

4.5.3.1 Light Metro can provide a high degree of reliability as it operates in its own right-of-way, unobstructed by street level traffic.

Impacts on Other Road Users

4.5.3.2 Light Metro is grade separated from road traffic and would have minimal to no impact on road users, except for column placement in the middle of a road, which would require some road width for a protected median.

Land Requirements

4.5.3.3 Light Metro systems require land for the track right-of-way (typically a 9m width subject to the specific project and suppliers), the stations, depots, substations, etc. Since trains are of moderate length, land requirements for Light Metro, with its shorter stations and smaller depots, are less extensive than for Heavy Rail. Right-of-way width requirements at a station are about 20-24 m (depending on whether island platform or side platforms are used).

Transit Oriented Development (TOD) Implications

4.5.3.4 Light Metro, as a moderate to high capacity rail mode operating in its own fixed guideway, provides a sense of "permanence" and encourages investment and development around its stations. The existence of the Docklands Light Railway helped to spur redevelopment and further intensification of the Docklands, which was previously a derelict wharf and warehouse area southeast of London's core.

Safety and Evacuation Requirements

4.5.3.5 Normally, a failed train should be moved to the nearest station for detrainment of passengers. If the failed train has lost its traction performance, it can be pushed by another train into station to evacuate to platform. If this cannot be done, passengers have to be evacuated via the track or dedicated evacuation walkways (typically about 850 mm above the track level), which can also accommodate wheelchair users.

Environmental Implications

4.5.3.6 Similar to Heavy Rail, Light Metro vehicles are powered by electric motors, which minimise the environmental impact from carbon emissions. Noise and vibration from the contact between steel wheels and steel rails cause environmental impacts, but are not insurmountable.

4.5.4 Light Metro – Case Study

4.5.4.1 Two case studies are presented: (i) London, United Kingdom – Docklands Light Railway (DLR); and (ii) Copenhagen, Denmark - Copenhagen Metro.

4.5.4.2

Light Metro Case Study 1: London, United Kingdom – Docklands Light Railway (DLR)

System Description:

The Docklands Light Railway (DLR) has been operating since 1987 as a driverless, computerised system that operates fully grade separated with an electrified third rail. The DLR is a Light Metro system operating in the Docklands Area, which is immediately east of Central London. The initial segment of the DLR opened in 1987 was 13 km and had 15 stations and was designed for one-car operations. The system has subsequently been expanded considerably with 7 lines, 38 km of track and 45 stations. Stations are now designed and handle three-car trains, which can hold up to 600 passengers. Peak headway is 2 minutes, equating to a peak capacity of about 20,000 pphpd. [redacted] Due to the constrained geometry of the system and the short intra-station distances, average speeds are relatively low, which is specific to the DLR and no average speed was provided.

Reference image

The DLR is owned by the Docklands Light Railway Ltd., which is a part of Transport for London (TfL). The DLR is part of the comprehensive urban public transport system in London including the Underground trains, double-deck buses, etc. The DLR specifically plays a role as a connector system to/from the Underground, as well as a circulator within the Docklands Area. As shown in the DLR system map below, three are numerous connections to various Underground Lines including the Central, Jubilee, and Northern Lines.

Reference image

Planning Background:

The planning for the DLR started in the 1980s when plans were made to redevelop the Docklands area, an industrial and dockland area, into an employment and mixed use hub. The Thatcher Government sought to implement a modern transportation system to complement the nearby Underground Lines and provide circulation within the Docklands.

The Docklands has several important geographic and topographic constraints including the need to connect numerous small islands and cross multiple bodies of water. Heavy Rail and Light Metro technologies were considered, but Light Metro was eventually selected for the following reasons: (i) flexibility in design to cross bodies of water and take tight curves; (ii) lower costs to build; and (iii) need to minimise impacts on some existing structures as some docks were to be kept open. System planners also focused on developing an innovative modern design, thus a driverless system similar to Vancouver's Skytrain was selected, but with a staff member on-board each train.

The initial system was composed of one-car trains with a capacity of 1,500 pphpd. Structures and stations were designed for one car operations. It cost GBP77.0 million. The first segment was

Light Metro Case Study 1: London, United Kingdom – Docklands Light Railway (DLR)

opened in 1987 and has since been expanded to consist of 7 lines and 45 stations. To cope with higher than expected demand, trains now consist of three cars, resulting in the need to retrofit bridges and stations to accommodate the larger and heavier trains. Newer extensions are designed for three-car trains from the outset. TfL notes that initial structures were built out of steel which resulted in noise issues once residential buildings arose alongside the railway. The last true extension was opened in 2010 and was procured using via Private Finance Initiatives (PFI) (this combined the construction and maintenance into a single contractor), which TfL oversaw. This is one of many PFIs deployed for transport infrastructure funding to minimise public borrowing. PFI projects typically have long lived and rigid contractual forms.

DLR has served as a catalyst for more intense development and TOD at stations and alongside the rail network, helping to transform the Docklands into a vibrant business, living and recreational attraction.

System & Service Characteristics:

- Total Number of Lines: 7 lines
- Network Length: 38 km
- # of Stations: 45 (890 m spacing)
- Vehicle Type/Size: Three-car trains (accommodating 600 passengers); initially system was designed for one-car trains
- Service Hours: 5:30AM-12:30AM
- Headway: 2 minute peak headway
- Peak Capacity: 18,000 passengers per hour per direction

Performance Characteristics:

[redacted]

References:

- Discussions with Richard de Cani, MD Planning, Transport for London (TfL), 25 February, 2016.
- Email from Lee Hill, FOI Case Officer, FOI Case Management Team, Transport for London, March 14, 2016.
- http://canarywharf.com/getting-here/docklands-light-railway/
- http://developments.dlr.co.uk/faq/#What is DLR's operating hours?
- https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/433286/light-rail-and-tram-statistics-2014-15.pdf
- https://www.gov.uk/government/statistical-data-sets/lrt01-ocupancy-journeys-and-passenger-miles
- https://tfl.gov.uk/modes/dlr/
- Private Finance Initiative: Seventeenth Report of Session, 2010-12, Volume 1.

Light Metro Case Study 2: Copenhagen, Denmark – Copenhagen Metro

System Description:

Reference image

Operating since 2002, the Copenhagen Metro is a driverless Light Metro system consisting of two lines (M1 and M2) and 22 km, which connects Copenhagen with several nearby cities. The system is fully grade separated and operates using an electrified third rail. Furthermore, the system features a number of key elements including: (i) fully automatic, driverless trains; (ii) level access to trains with a 55 mm gap between the train and platform; (iii) platform doors in underground stations; and (iv) unique ticket purchased system using text messaging. The Copenhagen Metro is part of a multimodal public transport network comprised of the S-train (or S-Tog), which is similar to a regional rail service, trams and buses. The Copenhagen Metro acts more like an urban trunk line, but also connects to the Airport.

Reference image

The system operates with three-car trains that can hold up to 300 passengers. Trains operate every 2-4 minutes in the peak and every 3-6 minutes in the off-peak. The Metro operates 24 hours a day, 7 days a week. Metro operates late night service with 20 minute headways from Sunday-Thursday and 7-15 minute headways on Fridays and Saturday. In 2014, some 56 million passengers rode the Metro, amounting to a daily average of about 160,000 passengers. A new Circle Line (Cityringen) that is 15 km of underground railway with 17 stations is being built for completion by 2019.

Planning Background:

Over the last century, ideas for Metro projects in Copenhagen have been discussed and dismissed. In the 1960s, a law for a Metro line was passed through the Danish Parliament, but was cancelled prior to implementation. In the 1980s, there was also a proposal for an underground link for S-trains between Vanløse and Copenhagen Airport, but cost estimates were too high.

Planning of the Copenhagen Metro was spurred by the development of the Ørestad area of Copenhagen, which lies to the south of the traditional city centre and north of the Airport. The main idea of this project was to develop a new town area – Ørestad – located in the centre of the new Øresund Region and connected to the Øresund fixed link. The new town area would be spurred by development of a new infrastructure – the Metro being the most important part of this – which was expected to increase the land value in Ørestad. The higher land value would then be used to pay for part of the infrastructure.

Forecasts showed that the expected number of residents and jobs would grow to about 20,000 and 80,000 respectively. However, Ørestad was not covered by the existing S-Tog train network. The Government decided to build a transit system running as a connection between Ørestad and Downtown Copenhagen. Light Metro was chosen due to its combination of highest average speed, highest passenger capacity, lowest visual and noise impact, and best accident record.

Light Metro Case Study 2: Copenhagen, Denmark – Copenhagen Metro

System & Service Characteristics:

- Total Number of Lines: 2 lines
- Network Length: 20 km
- # of Stations: 22 (900 m station spacing)
- Vehicle Type/Size: Trains carry 300 passengers (96 seated and 204 standing)
- Average Speed: 40 km/h
- Service Hours: 24 hours per day
- Headway: 2-4 minutes in the peak; 3-6 minutes in the off-peak; 7-20 minutes during late nights
- Peak Capacity: 12,000 passengers per hour per direction

Performance Characteristics:

- Ridership: 160,000 daily passenger or 56.0 million passengers per year (2014)

References:

- http://intl.m.dk/#!/about+the+metro/travel+information/timetable
- http://m.dk/#!/om+metroen/facts+om+metroen/statistik/passagertal
- http://www.railjournal.com/index.php/metros/ramboll-and-arup-to-design-copenhagen-metro-extension.html
- Proceedings of the Copenhagen Metro Inauguration Seminar/Copenhagen/Denmark/21-22 Nov 2002

4.5.5 Light Metro - Summary and Broad Applicability within KE

Pros	Cons
• Provides fast, high quality and reliable journey in segregated right-of-way • Can be fully automated and driverless, which can reduce operating costs • Minimises carbon emissions due to electric propulsion • Allows for tighter turning radii compared to Heavy Rail • High degree of standardisation of subsystems and components ensure many suppliers also at renewals and extensions • Creates sense of permanence and has been shown to facilitate TOD	• Relatively high capital costs compared to road-based modes • Generally less accessible than street-running, at-grade mode for passengers, especially those with mobility issues

Key Findings and Broad Applicability within KE

- Light Metro plays a role as both a trunk and feeder/circulator service in various contexts around the world. Light Metro is typically less expensive than Heavy Rail and more flexible in terms of turning radius. Stations are shorter and infrastructure typically "lighter" than Heavy Rail.
- The DLR example is instructive and very similar to KE in that a new transportation system was required to provide circulation within a fixed area alongside the waterfront. Light Metro was selected due to ability to handle tight curves and cross multiple water bodies for a moderate level of demand. The need to build in capacity to handle future demand was an important lesson for DLR as stations and structures required subsequent upgrade to handle heavier and longer trains than initially envisioned. The Copenhagen example also demonstrates a successful example of a system that can still achieve required capacity with smaller vehicles, while serving a new redevelopment area. Both systems are driverless and fully segregated, which allow for on-time and

reliable service, while lowering overall operating costs compared to systems with drivers.

- In the context of KE, a Light Metro system would offer a fully segregated rail system, which can be fully automated (driverless). Light Metro would likely offer a more reliable and on-time service compared to at-grade modes, while being cheaper to operate due to driverless operations. Capacity would be sufficient to serve as the EFLS. Alignment design criteria would most likely allow the system to be used for the EFLS alignment.

4.6 Modern Tram

4.6.1 Modern Tram – System Characteristics

Background and System Technology

4.6.1.1 Modern trams are rail vehicles of varying lengths that run on tracks which are typically integrated into public areas such as streets and parks. They are powered by electricity that the vehicles source from either overhead catenary or in-ground contact and contactless systems.

4.6.1.2 Modern trams can operate in:

- Fully segregated corridors with no grade crossings for vehicles or pedestrians (i.e., crossings are grade-separated);
- Dedicated corridors with at-grade crossings for road traffic and pedestrians;
- Shared corridors with other vehicles; or
- Shared corridors with pedestrians.

4.6.1.3 It is common for a modern tram system to operate in all fashions along a route, although segregated and dedicated corridors can allow for better speed and reliability than shared lanes, with most new modern tram systems operating in dedicated corridors instead of shared lanes. Although modern trams typically run along streets at-grade, sections of track can also be elevated or run underground, if available land area proves to be a prohibitive constraint. This flexibility allows for modern trams to be used to overcome various space constraints. When operating along at-grade streets, signal priority is typically provided to reduce intersection delay.

4.6.1.4 Modern tram, unlike other rail based systems operating in completely segregated corridors, requires a driver due to the potential interaction with vehicles and pedestrians along the corridor and at intersections.

4.6.1.5 Modern tram systems today can be divided into two types. The first type are those that evolved from historic tram and trolley lines – principally seen in Western and Central Europe. Cities such as Amsterdam (Netherlands), Leipzig (Germany), and Zurich (Switzerland) upgraded historic lines to handle modern trams in order to maintain continuity and utilise infrastructure and systems already in-place. In many of these locations, modern tram operates in shared lanes with other traffic.

4.6.1.6 Newer systems such as those in French cities such as Bordeaux and Nantes, as well as Dublin (Ireland), Barcelona (Spain), Sydney (Australia), and Dallas, Houston, and Phoenix (United States) have implemented modern tram in new corridors – often with the goal of remaking the street and urban feel, as well as using abandoned freight rail corridors. In these newer locations, most modern tram systems operate in dedicated corridors, with at-grade crossings at intersections. In Hong Kong, the Tuen Mun Light Rail is an example of a modern tram system that operates in segregated right-of-way as well as shared street environments with motor vehicles at intersections.

Role in Transport Hierarchy

4.6.1.7 Modern tram can serve as both a trunk and complementary system within the overall urban public transport hierarchy – although the role of modern tram typically depends on the historic development of the urban transport system. Those cities with established Heavy Rail (Metro) networks have adopted modern trams as a complementary, feeder mode operating on suburban or lower density corridors. Barcelona is an example of this with two new modern tram routes operating on the western periphery of the city, providing connectivity to/from the dense Heavy Rail network and urban bus system. Sydney's planned modern tram system will complement the existing suburban commuter line and planned Heavy Rail lines through Downtown.

4.6.1.8 Modern tram may also function as the trunk/core system for a city – carrying the highest volume of passengers and penetrating the urban core. Medium-sized French cities including Nantes and Bordeaux have adopted modern tram as the trunk route. Modern tram also serves as the core system for cities such as Dublin (Ireland), Manchester (United Kingdom), as well as Dallas, Houston, and Phoenix (United States) as its ability to operate at-grade on the street level provide an opportunity to remake and regenerate streets and urban areas.

Key Infrastructure Elements and Vehicles

4.6.1.9 The key components of modern tram systems include the runningway, tracks, stations, power systems, depot and vehicles.

Runningway

4.6.1.10 Modern tram can operate in four different environments: (i) shared corridor with pedestrians where trams operate through pedestrian malls or pedestrian-only areas; (ii) shared corridor with other vehicles, where private vehicles, taxis, and/or public transport vehicles share the same lane with modern tram; (iii) dedicated corridors where interaction with other road users is limited to signalised intersections only; and (iv) segregated corridors where modern tram has no interaction with other vehicles or pedestrians (sometimes in abandoned rail corridors).

4.6.1.11 **Table 4.6.9** shows an example of the four operating types, the level of segregation, as well as operating implications.

Table 4.6.9: Modern Tram Runningway Type and Implications

	Shared (Pedestrian Mall)	**Shared (Shared Lane)**	**Dedicated**	**Segregated**
Photo	*Reference image* Amsterdam Tram	*Reference image* Sacramento LRT	*Reference image* Barcelona Tram	*Reference image* Sydney Light Rail
Level of Segregation	Low - Modern trams operate through pedestrian-only zones, where pedestrians can freely cross the tracks	Low - Vehicles use the same track as modern tram such as private vehicles, taxis, and/or buses	Moderate - Interaction with pedestrians / vehicles occurs at signalised intersections (sometimes with safety barriers)	High -No interaction with other vehicles or pedestrians as rail corridor is completely grade-separated (with safety barriers at all grade crossings)
Operational Implications	High: Tram must operate slowly through pedestrian areas	High - Tram impacted by road and junction traffic and congestion, and turning vehicles	Moderate - Trams impacted by junction traffic and turning vehicles	Low - Tram can operate at maximum speed

Sources:

Amsterdam Tram - https://austinrailnow.files.wordpress.com/2013/10/arn0_ams-lrt-leidsestraat_roeland-koning.jpg

Barcelona Tram - http://www.subways.net/spain/barcelona.html

Sacramento Light Rail - https://austinrailnow.files.wordpress.com/2013/04/sac-lrt-12th-str-mixed-trf-15347-20010428x_eric-haas.jpg

Sydney Light Rail - http://www.gmpoles.com.au/wp-content/uploads/SydneyLightRail.jpg

4.6.1.12 Tram systems operating in three of four or all four environments are not uncommon – the Sydney Light Rail, various systems in North America (including San Jose) and systems in Europe (including Berlin) are examples. Most modern tram systems implemented in new corridors (i.e., not historic tram or trolley corridors) strive to provide a high degree of segregation with dedicated or segregated operations. A 2003 study on modern tram systems in the United Kingdom and France found the following:[35]

- 15 of 22 modern tram lines reviewed operate in either segregated or dedicated corridors for 100% of their journey;
- Of the 7 lines that operate with some segment of shared operations, most operate for 10% or less of the entire alignment, while only one line (Sheffield) operates for more than 20% of its alignment in a shared corridor (60%);
- All French systems operate in segregated or dedicated corridors for capacity, speed and reliability reasons, except for lines in Nantes and Paris

[35] Comparative Performance Data from French Tramway Systems – Final Report, South Yorkshire Passenger Transport Executive, December 2003.

(these two system have short shared segments due to the narrow cross-sections of existing roadways that did not allow for dedicated corridors); and

- Shared corridors are typically adopted only where: (i) train frequency is relatively low; (ii) spare capacity exists on the road to "reduce" capacity left for vehicles so modern tram is not significantly delayed by congestion; and (iii) few road vehicles are affected by stopping tram vehicles.

4.6.1.13 Thus, the key finding is that all systems operate in portions of dedicated corridors for most, if not all, of the rail corridor. No systems operate completely with shared corridors – as the shared corridor portion of the alignment makes up very little of the total alignment.

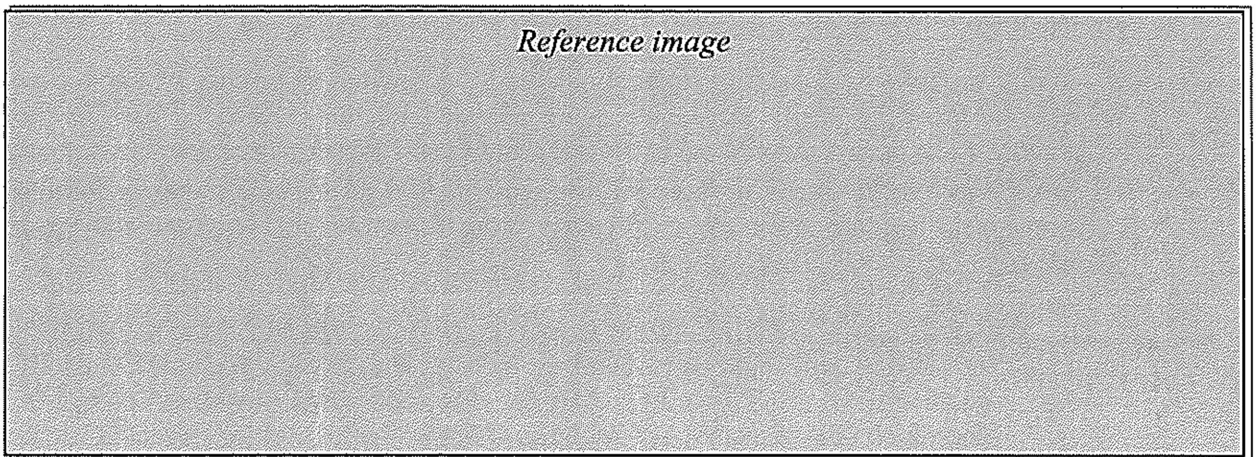
4.6.1.14 While modern tram largely operates at-grade, dedicated segments of track may also be provided partly in tunnels or on elevated viaducts. Systems such as the Dublin Luas Cherrywood Line and the Seattle Link Light Rail operate on viaducts (with the Seattle system also operating in tunnels). Although there is nothing preventing modern tram from operating on a fully elevated viaduct, there are several reasons why this is not done:

- **Cost** - The cost for elevated MT is also significantly more than that associated with at grade systems – with costs approaching higher capacity modes. MT is typically used for lower-medium capacity corridors, therefore fully elevated MT would not be cost-effective for expected levels of ridership.
- **Alignment with Urban Transport Policy** - At-grade MT systems require "taking back" lanes and giving priority to public transport and pedestrians over motor vehicles – this aligns with policy and strategic desires of cities to encourage public transport and reduce reliance on driving;
- **Catalyst for Regeneration** – At-grade modern tram is often viewed as a catalyst for urban renewal and enhancing the urban design of a corridor and open space environment.
- **Access and Land Use** – An elevated system would require access facilities to the MT. This means elevated stations and additional land take for vertical circulation, lifts, as well as loading/unloading facilities compared to at-grade facilities.
- **Need for Special Vehicles Eliminated** – MT vehicles are designed for street operations, thus low floors to allow quick boarding and alighting from the sidewalk. If MT is fully elevated and segregated, it can be provided with platforms at all tram-stops, and the need for low-floor trams is eliminated. Thus, the vehicles would be no different than those for other segregated rail modes. Such MT systems that fully elevated and segregated would thus be classified as Light Metro.

Track

4.6.1.15 As noted, modern trams can mix with external traffic or run within right-of-ways and tracks. Varying rail profiles can be utilized to suit the different operating environments and tracks can either be embedded into concrete for on-street operation, or use conventional ballasted track in sections of tramway that run out of public reach. Increasingly, for segregated tram lanes, tracks are being laid in concrete foundations which are then covered and surrounded by grass.

4.6.1.16 Standard tram gauge is 1,435 mm and this allows trams to run within standard vehicle lanes. Tracks are similar to those of Light Metro however, when integrated into streets or public spaces, the space between tracks is usually filled to create a flush surface. Shared lanes with road traffic or shallow crossings with road lanes create some risks of bicycles becoming stuck in the grooved rail. Typical right-of-way width can be as narrow as 8.5m including barriers on both sides, accommodating two tracks for 2.65m width trains.[36] This is depicted in the figure below.



Source: General Guidelines for the Design of Light Rail Transit Facilities in Edmonton (http://www.trolleycoalition.org/pdf/lrtreport.pdf).

Figure 4.6.3: Minimum Width of Bi-Directional Modern Tram Corridor without Station for Edmonton LRT

4.6.1.17 Limit for horizontal radius can be as low as 20 m or less, even though such radii are preferred since they impose considerable speed restrictions.

4.6.1.18 When operate at-grade, Modern Tram systems typically install signal priority at crossings to reduce intersection delay (similar to that discussed in the BRT Section).

Power System

Overhead Wires

4.6.1.19 The majority of modern tram systems are powered by overhead electrical wires (catenary) where electricity (typically 600 or 750 Volt DC) transferred from the wire to the vehicles by pantograph. Alternate power systems include: (i) Ground-Level Power Supply (GLPS); and (ii) induction charging with supercapacitors.

Ground-Level Power Supply (GLPS)

4.6.1.20 Trams may run on Ground-Level Power Supply (GLPS), in which power is supplied to conductive segments laid beneath the track as the vehicle passes over. Vehicles have "pickups" to contact with the power source. Radio beacons signal

[36] General Guidelines for the Design of Light Rail Transit Facilities in Edmonton (http://www.trolleycoalition.org/pdf/lrtreport.pdf).

the oncoming tram and powers the specific conductive segment. In Bordeaux, France, conductive segments are 11 m long, with 8 m powered sections and 1.5 m buffer sections on each end – only one segment is powered at a time for safety reasons.[37] GLPS may be used as a stand-alone system or as a complement to catenary or battery systems.

4.6.1.21 This technology has been implemented in several French cities include Bordeaux, Reims, Orleans, Angers and Tours, and in Dubai (which is the first system operated completely with GLPS) using Alstom's GLPS.[38] The technology has been in revenue use for over 12 years (starting in the early 2000s). For the Bordeaux case, the power rail stands 12 mm above the road surface and GLPS has not been installed in mixed traffic lanes (i.e., for shared lanes).[39] Issues with water logging (when water does not flow away quickly enough) and automatic switch off of power have been identified. Furthermore, battery life may be lower in high humidity areas in which trains constantly run the air conditioning (which decreases the range of the vehicle). Trams also still have batteries in case of breakdowns. Ansaldo's TramWave is a similar technology that has been implemented in Zhuhai's Line 1 and Beijing's Xijiao Line.

4.6.1.22 For relevant examples within Asia with similar climates as Hong Kong, Ansaldo's TramWave technology has been or is planned for implementation as follows:

Table 4.6.10: East Asia Examples of Ground-Level Power Systems for Modern Tram

#	Location	Line	Date of First Operation	Details
1	Zhuhai, China	Line 1	August 2015	• 8.7 km; 14 stations • System uses Ansaldo's TramWave with charged segments being 3-5m long embedded between the running rails • Retractable copper and graphite shoe on the tram bogie uses hybrid permanent magnets to lift contact plates and complete circuit • Specifically note that four workers can replace a damaged Tramwave module in 30 minutes (due to incidents of typhoons) • CNR Dalian said early trials provided technology could work in heavy rain
2	Beijing, China	Xijiao Line	Under Construction	• 4.4 km segment without catenary (total line is 9.4 km) • System uses Ansaldo's TramWave with charged segments

Source:
http://www.railjournal.com/index.php/light-rail/catenary-free-technology-for-chinese-light-rail-project.html
http://www.railjournal.com/index.php/light-rail/cnr-to-supply-catenary-free-lrvs-to-beijing.html
http://www.railwaygazette.com/news/news/asia/single-view/view/huaian-tram-opens.html
http://www.railwaygazette.com/news/single-view/view/zhuhai-tramway-starts-trial-operation.html

[37] http://citytransport.info/Bod.htm
[38] http://www.alstom.com/products-services/product-catalogue/rail-systems/Infrastructures/products/aps-ground-level-power-supply/
[39] http://www.apta.com/resources/standards/Documents/APTA-RT-ST-GL-001-13.pdf

4.6.1.23 One key concern with GLPS has been whether the system is reliable during heavy rains and flooding conditions. Alstom provided the responses for its GLPS:[40]

4.6.1.24 The power box embedded into the track can be immersed in up to 1.0m of water for several days without any water ingress. Trackform and drainage must be designed to avoid pooling of water, which can cause leakage if the water becomes too deep. The systems have undergone water pooling tests that indicate the step voltage around the tram is always significantly below standards.

4.6.1.25 Furthermore, the control boards of the power box are protected against humidity and tropical conditions.

4.6.1.26 In areas subject to pooling (due to municipal drainage systems, not the tracks), the power boxes are remotely shut off to prevent short circuits and the trams can run through unpowered sections automatically using power from emergency batteries mounted on the roof.

Supercapacitors

4.6.1.27 The power box embedded into the track can be immersed in up to 1.0m of water for several days without any water ingress. Trackform and drainage must be designed to avoid pooling of water, which can cause leakage if the water becomes too deep. Another more recent technology is the use of supercapacitors, which charge vehicles during stops and layover and in locations where vehicles are accelerating. This charge can then power the vehicles short distances between stops, where the process is repeated. Nanjing's system uses a hybrid battery/catenary system in which 90% of the alignment is catenary-free, with catenary provided at stops and in areas where vehicles accelerate. A system fully powered by induction charging has yet to be implemented, although induction charging has been tested on Line 3 of the Augsburg (Germany) system. Supercapacitor systems seem to do well in areas without heavy rain as ponding and extreme temperatures resulted in poor performance. Furthermore, supercapacitors are relatively large and take up space within the vehicle and can increase the envelope of the vehicle. Both systems are based on Bombardier's PRIMOVE technology.[41]

4.6.1.28 Siemens has also developed a similar system. Supercapacitor systems have been implemented in Guangzhou for the Haizhu's Circular Route and the Huai'an Tram in Jiangsu Province. Similar systems are being implemented for the Wuhan Tram and Kaoshiung's Circular Line. Systems in East Asia with comparable weather and climate as Hong Kong are identified below.

[40] Email Correspondence: Alstom, December 16, 2016.
[41] http://www.railway-technology.com/projects/bombardier-primove-light-rail-trams-germany/

Table 4.6.11: East Asia Examples of Supercapacitor Systems for Modern Tram

#	Location	Line	Start of Operations (or Planned Start Date)	Details
1	Nanjing, China	Hexi Line	September 2014	• 8.0 km with 13 stations • Trams run on Primove lithium-ion traction batteries that are recharged through the pantograph at stops • 90% of the route is catenary free.
2	Guangzhou, China	Circular Route in Haizhou	Late 2014	• 7.7 km with 10 stations • Siemens supercapacitor technology adopted, with on-board supercapacitors automatically charged by a ground-level power system at stops • Charging typically takes between 10-30 second • Trams are able to run up to 4 km between charges • Mobile charging vehicles are to be used in case of faults at charging points
3	Huai'an, Jiangsu, China	Huai'an Tram	December 2015	• 20.1 km with 23 stops • Recharging is similar to the Nanjing system with charging at each stop through the pantograph • System represents the world's longest catenary-free LRT line • Flash charging is completed within 30s at the tram stops • Trams are able to run at least 4 km after one charging • 85% of brake energy is converted and stored as electric energy to reuse
4	Wuhan, China	Wuhan Tram	End 2016	• 20.0 km and 29 stations • Recharging is similar to the Nanjing system with charging at each stop through the pantograph • Charging will be finished within 30 seconds • Brake energy converted to electric energy
5	Kaoshiung, Taiwan	Circular Line	End 2016	• 22.1 km with 36 stations • On-board energy storage system is recharged at intervals along the line through the pantograph

Source:
http://www.crrcgc.cc/zjen/g1733/s4283/t264108.aspx
http://www.railwaygazette.com/news/urban/single-view/view/battery-trams-running-in-nanjing.html
http://www.railwaygazette.com/news/urban/single-view/view/guangzhou-supercapacitor-tram-unveiled.html
http://www.railwaygazette.com/news/urban/single-view/view/guangzhou-tram-line-opens.html
http://www.railwaygazette.com/news/urban/single-view/view/kaohsiung-picks-caf-to-build-catenary-free-trams.html
http://w1.siemens.com.cn/news_en/news_articles_en/2951.aspx

4.6.1.29 The table below compares the various propulsion systems.

Table 4.6.12: Modern Tram Propulsion Systems

	Overhead Catenary	**Ground-Linked Propulsion System**	**Induction Charging**	**Hybrid Battery & Catenary**
Photo	*Reference image*	*Reference image*	*Reference image*	*Reference image*
Description	Vehicle powered by overhead wires via a pantograph	Vehicle powered by embedded third rail beneath the tracks; power switched only when vehicle is above	Vehicle powered by contactless induction coils at stops, terminals, and areas where vehicle is accelerating	Vehicle powered by catenary at stops and sections where vehicle accelerates; vehicle operates on battery power rest of the way
Pros	Traditional means of powering tram	No overhead wires required; fairly well tested in a variety of cities	No overhead wires required	Overhead wires only at stops and acceleration sections
Cons	Visual implications of catenary	More complex construction, proprietary issues, has yet to be implemented in shared lanes, and potential issues with waterlogging and automatic power switchoff	More complex construction, proprietary issues, issues with ponding and extreme temperatures, capacitors increase the size of the vehicles, and not yet widely implemented as emerging technology	More complex construction, proprietary issues, not yet widely implemented and still requires catenary
Examples	Hong Kong, Barcelona, Dublin	Various French cities (Bordeaux, Orleans, Reams), Dubai, Zhuhai (Line 1) , Beijing (Xijiao Line)	Augsburg (Germany)	Nanjing Hexi Line, Guangzhou (Haizhu Circular Line), Huai'an (Huai'an Tram), Wuhan (not operational yet), Kaoshiung (not operational yet)

Source:

Photos for catenary, GLPS and induction charging - http://www.alstom.com/products-services/product-catalogue/rail-systems/Infrastructures/products/aps-ground-level-power-supply/

Photo for hybrid battery and catenary - http://primove.bombardier.com/fileadmin/primove/content/GENERAL/PUBLICATIONS/English/PT_PRIMOVE_Datasheet_2015_Nanjing_EN_print_110dpi.pdf

Stops/Stations

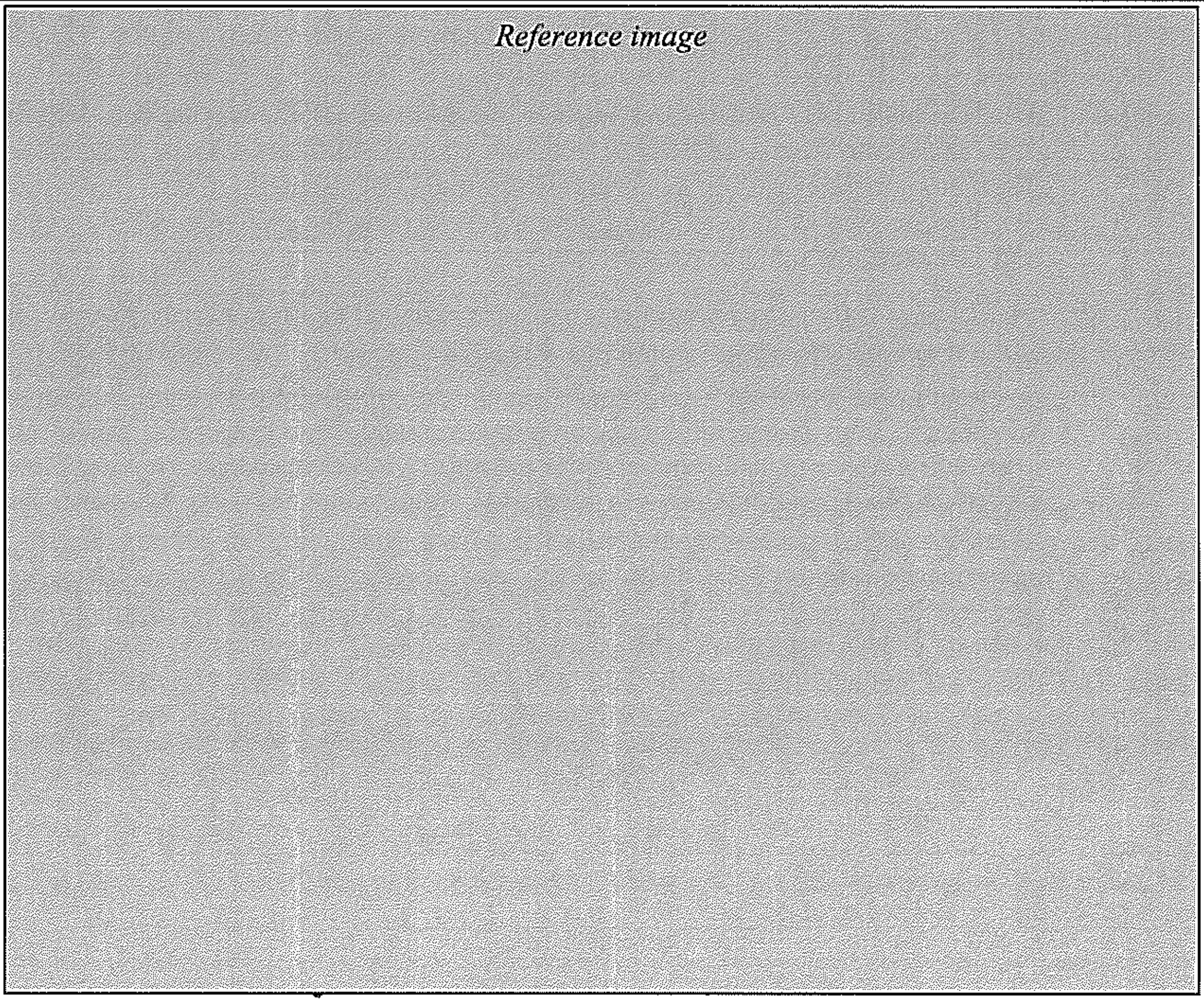
4.6.1.30 The design of stops/stations depends on the level of boarding and alighting. More basic tram stops are more akin to elaborate bus stops and do not require extensive platform or other facility construction (unless stations are elevated). Other systems may have wider and more elaborate stations to accommodate passenger waiting, as well as boarding/alighting and ticketing areas as well as to meet wheelchair or mobility disadvantaged requirements. The Tuen Mun LRT for instance typically has 3.0m wide side platforms.

4.6.1.31 The Edmonton LRT designs call for side platforms of 3.65m and central platforms of 7.3m width. Where traffic is directional, central platforms may be 5.5m wide. Edmonton operates with three car trains (up to 74.0m in length), thus it has station platform lengths up to 80m. The figure below depicts the typical width for centre and side platform stations, respectively.[42]

4.6.1.32 Connecting Abu Dhabi 2030, Abu Dhabi's Surface Transport Master Plan calls for 3.0m side platforms and 6.0m centre platforms up to 90m long.[43] This document also notes that: (i) the Office of Rail Regulations (United Kingdom) specifies a 3.0m minimum for island platforms and clear space of 1.5m to any obstruction (other than shelter canopies or roofs) for side platforms; (ii) the Dublin LUAS (Ireland) tram specifies a minimum 3.0m width for side platforms and 4.0m for island platforms; and (iii) the Metro North Line in Dublin (Ireland) specifies a minimum 3.5m width for side platforms and 7.0m for island platforms. The width of stations though depends on demand and the existing physical constraints at each location, and may vary in a system.

[42] Source: General Guidelines for the Design of Light Rail Transit Facilities in Edmonton (http://www.trolleycoalition.org/pdf/lrtreport.pdf).

[43] Source: Platform Preferences for Tramways and the Metro, Connecting Abu Dhabi 2030, Department of Transport, Technical Note No. 10.



Source: General Guidelines for the Design of Light Rail Transit Facilities in Edmonton (http://www.trolleycoalition.org/pdf/lrtreport.pdf).

Figure 4.6.4: Typical Station Width Dimensions for Centre and Side Platform Stations

4.6.1.33 Given that trams typically run through public areas, dedicated stops can range from a simple cross-roads stop with no infrastructure to an off-road station complete with platform, shelter and other amenities. Stop spacing is typically on the order of 400-600 m, although this can be much shorter in dense urban environments – for instance a pedestrian mall or major commercial street.

4.6.1.34 Floor level of a modern tram is typically 300mm above rail level, which may limit access for those with disabilities. Ideally, the platform level should also be 300mm above the track (and road level), even though some systems use lower platforms or have tram stops on shared lanes with no platform at all.

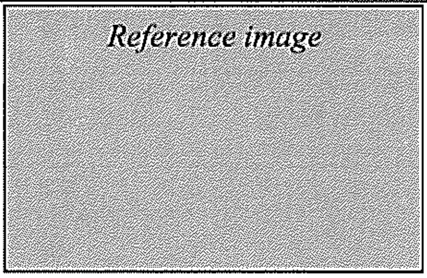
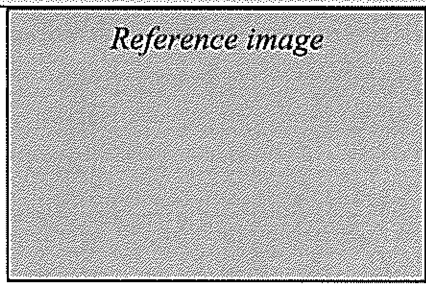
4.6.1.35 Where the tram line runs on shared road lanes or dedicated lanes, it is normally preferred to have the tram track in the middle of the road. This maintains vehicular access to the kerb without interfering with the tram (for loading and unloading of passengers and goods). With tram lanes in the centre of the road, the tram stop will not be adjacent to the sidewalk. Several tram stop configurations can be considered:[44]

Table 4.6.13: Modern Tram On-Street Platform Configurations (Dedicated Platforms)

	Island Platform (Widened Street)	Island Platform (Merged Road Lanes)	Flare-Out Platform
Photo	*Reference image* Paris (http://reconnectingamerica.org/assets/Uploads/The-Modern-Tram-in-Europe.pdf)	*Reference image* Hong Kong	*Reference image* Melbourne (http://www.historyworks.com.au/LightRailExtensions.pdf)
Description [A]	• Island platform arranged between road lane and tram track • Applicable when road can be widened • Platforms around 60m long and 4m wide	• Road lanes merged to create space for island platform • Applicable where road cannot be widened • Platforms around 20-25m long and 1.5-2.0m wide	• Platform flares into road • Road lane merged with track so tram shares road with vehicles • About 10m long and 3m wide
Pros	• Dedicated platform for passengers • Road capacity maintained	• Dedicated platform for passengers • No street widening	• Dedicated platform for passengers • Direct access to sidewalk for riders • No street widening
Cons	• Tram passengers must cross street to sidewalk • Reallocation of parking and sidewalk	• Tram passengers must cross street to sidewalk • Reduced road capacity due to lane loss	• Reduced road capacity • Trams stop in travel lane and block (also, traffic may block trams from stop) • Cyclists may get wheels caught in rail where cycle paths cross tram tracks

[44] Tony Prescott: A practical scheme for Light Rail extensions in inner Sydney, Transit Australia, Vol. 63-64, (Nov 2008-Jan 2009)

Table 4.6.14: Modern Tram On-Street Platform Configurations (Other Types of Platforms)

	Drive Over Platform	No Platform
Photo	 Melbourne (http://www.historyworks.com.au/LightRailExtensions.pdf)	 Hong Kong
Description [A]	• 30m x 4.25m drive-over platform can be built atop the road (creating a speed bump) • Tram passengers must wait on sidewalk and access tram when stopped	• No platform provided, as passengers wait on the sidewalk and access the tram when stopped • The demarcated boarding area on the street is about 12m long.
Pros	• Direct access to sidewalk • Reduced travel speeds due to speed bump	• Direct access to sidewalk
Cons	• Tram passengers need to wait on sidewalk • Increased risk to passengers alighting directly onto the road • Vehicles stop behind tram during loading and unloading • Speed bump may be undesired for road users when there no tram is present	• Tram passengers need to wait on sidewalk • Floor level of tram is 300mm above street level, thus limiting access for those with disabilities • Increased risk to passengers alighting directly onto the road • Vehicles stop behind tram during loading and unloading

[A] Width and length of station is on a case-by-case basis; stations are sized according to boarding/alighting activity and passenger accumulation. Also, the age of the system is a factor in the width as later stations provide access for wheelchair and other mobility disadvantaged passengers.

Vehicles

4.6.1.36 Tram vehicles are highly customizable and can range in length from around 20 to 70 m, the longest of which can carry up to 500-600 passengers. Trams are typically around 40 m in length and can carry approximately 300 passengers. Tram width ranges from 2.3 to 2.65 m wide. Modern tram vehicles typically have low-floors that are easily accessible from street level or designed to be flush with platforms. The trend towards low floor vehicles begin several decades ago to provide stair-free passenger cabins. This is made possible by complex axle systems where each wheel is individually powered.

4.6.1.37 In some systems, vehicles are 100% low-floor, meaning all units of the vehicle are low-floor, while other systems have partial low floor vehicles with both low- and high-floor sections on the vehicle. A 100% low-floor vehicle allows for minimal dwell times and low-floor doors along the entire vehicle, as well as no steps inside the vehicles. However, the interior spacing as wheel wells must be accounted for. In order to achieve the low floor level, the tram needs special running gear, which may increase maintenance costs.

4.6.1.38 A partial low floor vehicle provides more room for the wheels, and conventional running gear can be used. However, steps will be required inside the vehicle and fewer doors will be on the low-floor section of the tram. Most European systems use 100% low-floor vehicles, while systems in the US and Canada also use partial low-floor vehicles.[45]

Capital Costs

4.6.1.39 The following table provides a summary of capital costs for Modern Tram projects that have been built or under planning.

Table 4.6.15: Equivalent FY2015 Capital Costs for Various Modern Tram Systems

System	Length (km)	Year Opened	Cost (HK$)	Cost (HK$) / km
G:Link, Gold Coast, Australia	13.0	2014	10,127 million	779 million
Nottingham Phase Two Tram Extension, Nottingham, United Kingdom	17.5	2015	8,239 million	471 million
Shenyang Tram Network, Shenyang, China	60.0	2013	15,759 million	263 million

Source: Arup Database (cost in 2015 Price Level)

4.6.2 Modern Tram - Operating Characteristics

Service and Passenger Capacity

4.6.2.1 The major operating restriction of modern trams is when they share road space with external traffic. In these situations, tram service may be delayed by congestion. Also, the risk of accidents increases. Drivers must run on their line-of-sight, which can lead to a slower service compared to automated signalling systems as well as lower service frequency and thus capacity (due to longer following distances). Typical operate speeds of up to 25 km/h can be achieved over the route.

4.6.2.2 Tram vehicle length can be limited for systems that share road space with external traffic. Given that these trams mix with various types of traffic, tram lengths have to be restricted to ensure appropriate levels of road safety are achieved.

4.6.2.3 Passenger capacity differs based on frequency, size of the vehicle, and likelihood of external traffic induced delay. Frequency is usually a result of demand and can typically be adjusted to suit the application situation. As an example, a tram line with a train capacity of 250 passengers and a headway of 5 minutes could carry 3,000 passengers per hour per direction.

4.6.2.4 The table below compares operating characteristics of several modern tram systems:

[45] For a system which is completely segregated, high platforms can be arranged, and there will be no need to compromise between performance of running gear, steps inside the vehicle and the number of doors which perfectly matches the platform level.

Table 4.6.16: Service Profiles for Various Modern Tram Systems

System	Route Length (km)	Total Number of Lines	Average Speed (km/h)	Headway (min)	Capacity (pphpd)
LUAS, Dublin, Ireland	38.0	2	22-27	3	4,900
Barcelona Tram, Barcelona, Spain	29.1	6	18	4	3,000
Sydney Light Rail, Sydney, Australia	12.8	1	25	5	2,400 [A]

Source:
Dublin: Letter from Bonneagar Iompeir Eireann (Transport Infrastructure Ireland), from Mr. Raymond Foley, Regulatory & Administrative Unit, March 3, 2016.
Barcelona: Email with Eduard Cabrera, Responsible d'Operacio Sistemes, Barcelona Tram, 17 February, 2016
Sydney: Various sources (see Modern Tram Case Study 4 references)

Note:
[A] Sydney's CBD and South East Lines will operate trains with capacity of 466 passengers, operating at 2 minute headways. This is equivalent to about 13,500 pphpd.

4.6.3 Modern Tram – Other Key Characteristics

Reliability

4.6.3.1 Reliability of trams is highly dependent on the level of segregation from external traffic. Trams that mix with external traffic are obviously more susceptible to delays however, the higher the level of segregation and prioritisation of trams, the higher the level of trip duration reliability.

4.6.3.2 This prioritisation can be achieved by allowing trams to run along dedicated right-of-ways, as well as providing signal prioritisation at signalised junctions. If a high level of segregation can be achieved then tram systems can be extremely reliable. However, such segregation will affect road traffic negatively.

4.6.3.3 GLPS or in-ground traction systems have proven themselves as a reliable technology in all weather conditions (Dubai with extreme heat, France with humid, rainy conditions as well as snow, as well as in Zhuhai with similar climate as Hong Kong) for the past decade. The power box embedded in the ground is built to withstand pooling of up to 1.0m of water and various power box components are built to resist humidity. Thus in typical rainy conditions, where pooling around the track does not exceed 1.0m, manufacturers have tested and are confident the system is reliable and resilient. In locations where frequent pooling occurs, the power box can be shut off and the tram can operate under battery power through this section. Therefore, there is some built-in resilience into the system and the system appears reliable under typical rainy weather conditions.

4.6.3.4 It is noted in the case of severe pooling over 2.0m (and likely heavy street flooding), it is also unlikely that trams would run in these conditions in the first place, although maintenance checks would need to be performed on all power boxes after such severe rains and flooding.[46]

[46] Email Correspondence: Alstom, December 16, 2016.

Impacts on Other Road Users

4.6.3.5 As discussed in the land requirements section, when provided with a dedicated track, tram would typically require at least one lane of traffic for the track in each direction. This would reduce the number of general purpose lanes for traffic and could have implications on traffic. Furthermore, where stations are provided, additional road width would be required, which could further reduce capacity. Cross traffic at junctions would also be impacted.

Land Requirements

4.6.3.6 If trams use segregated runningways, typical width is 6-7 m excluding tram stops. This corresponds approximately to two road lanes. Total width for tram stops depends on platform configuration, number of passengers using the tram stop, and network configuration. If several tram lines are sharing the same tram stop, some waiting passengers will not take the first arriving tram, but wait for a tram with another destination. It is possible to use staggered platform arrangements to minimise the total width of the tram stop. Assuming 4-5m platform width, the width for a tram stop width dedicated platforms would be 14-17m if platforms are placed opposite each other and 10-12m with staggered platforms.

4.6.3.7 Land is also required for catenary poles as well as sub-stations. In addition, utilities are typically relocated outside of the tracks to facilitate easy maintenance access and to minimise disruption to operations during servicing (as well as to allow the installation of ground-linked power systems).

Transit Oriented Development (TOD) Implications

4.6.3.8 Modern tram with the fixed guideway and alignment create a sense of "permanence". This is important in that developers and retailers know that a fixed urban public transport line will provide reliable service all day and could potentially facilitate greater densification of land uses. In Europe and North America, modern tram is considered a catalyst for urban redevelopment and regeneration, and is often integrated within parks and pedestrian malls. The Portland Tram is one example of a modern tram that helped to revitalise and enliven downtown streets and encourage development and return of businesses.

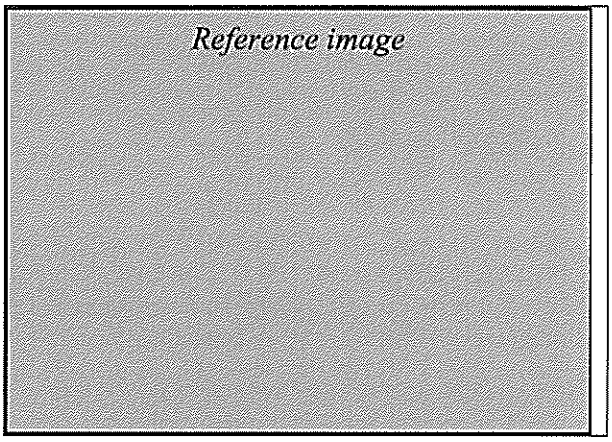


Figure 4.6.5: Tram Stop with Platform (along Wu Chui Road – Tuen Mun Light Rail)

Safety and Evacuation Requirements

4.6.3.9 As with the other operational aspects of trams, safety is highly dependent on their level of integration with external transport modes. However, with such a complete segregation, the system should be classified as Light Metro. If trams are completely segregated from external traffic, the likelihood of incidents involving other road traffic is low given that trams are confined to tracks and external vehicles and pedestrians can be prohibited.

4.6.3.10 Where trams are mixed with other transport modes, they are still confined to tracks and therefore cannot deviate course. It is more likely for other vehicles to cause incidents as they can freely turn in-front of trams.

4.6.3.11 Situations where trams travel through pedestrianized spaces such as parks, squares and plazas also pose a safety risk to both external pedestrians and internal passengers. In these situations, tram speeds should be kept to a minimum and should not exceed 30 km/h. If possible, barriers should be constructed to alert pedestrians to the presence of trams.

4.6.3.12 Detrainment from a low-floor tram at street level is easy and does not require any elevated evacuation walkways.

Environmental Implications

4.6.3.13 Tram vehicles are powered by electric motors, which minimises the environmental impact with regards to carbon emissions. Noise and vibrations from the contact between steel wheels and steel rails may have environmental impact, but are not insurmountable. Catenary may be visually unappealing, although some new systems run on ground-linked propulsion systems.

4.6.4 Modern Tram – Case Studies

4.6.4.1 Four case studies are presented: (i) Hong Kong SAR – MTR Light Rail; (ii) Barcelona, Spain – Barcelona Tram; (iii) Dublin, Ireland – Dublin Luas; and (iv) Sydney, Australia – Sydney Light Rail.

Modern Tram Case Study 1: Hong Kong, SAR – MTR Light Rail

System Description:
The Light Rail (also known as Light Rail Transit or LRT) is an at-grade railway with at-grade crossing of streets and segments of shared right-of-way with vehicular traffic. This has resulted in delays to LRT service due to mixed flow traffic impacts. The LRT network connects various new towns in the Northwest New Territories including Tuen Mun, Yuen Long, and Tin Shui Wai. A total of 12 routes operate in the 36 km network, including 68 stops. Vehicles operate at 3 minute peak multiple headways at speeds ranging from 13-21 km/hour. Vehicles use overhead catenary and can hold about 250 passengers. Vehicles are powered by overhead catenary. [redacted] Platform width is about 3.0m on average.

Planning Background:
Around 1977, the Government designated areas of the Northwest New Territories for development as new tons, which were to be self-sufficient so that residents would not need to commute to the urban area. It was planned that railways would eventually be built in those new towns as the population in those districts grew. While public demand for such rail linkages was strong, the actual demand to use the system was deemed inadequate from a commercial point of view for potential operators.

In planning the new towns, rail reserves had been allocated, although an operator had yet to be found. The purpose of the LRT was to provide internal transport for Tuen Mun residents to travel within the town and to nearby Yuen Long and Tin Shui Wai. It was hoped that by 1986, populations in these areas would be high enough to sustain and warrant rail service. After putting the project out

Modern Tram Case Study 1: Hong Kong, SAR – MTR Light Rail

Reference image

to bid, the Kowloon Canton Railway Corporation (KCRC) was invited to bid on the project and ultimately agreed to the project as long as competing operating feeder bus routes were removed from the area. The system has subsequently expanded to include the southern and eastern parts of Tuen Mun.

System & Service Characteristics:

- Total Number of Lines: 12 lines
- Network Length: 36 km
- # of Stations: 68
- Vehicle Type/Size: 20.2 m trams (up to 250 passengers)
- Average Speed: 13-21 km/h
- Service Hours: 5:30AM-1:00AM
- Headway: up to 3 minute peak multiple headway
- Peak Capacity: 3,750 passengers per hour per direction

Performance Characteristics:

[redacted]

References:

- Letter from Sammy Wong, Head of Operating – West Region, MTR Corporation Limited, April 7, 2016.
- http://www.mtr.com.hk/archive/corporate/en/investor/images/E119.pdf
- https://www.mtr.com.hk/archive/corporate/en/publications/images/business_overview_e.pdf
- http://www.mtr.com.hk/en/customer/services/train_service_index.html
- http://www.scmp.com/news/hong-kong/article/1457047/mtr-track-carry-20000-more-passengers-day
- Yeung Au, Lai Kit, Rikkie, "The governance of government-owned railway organisations in Hong Kong: integration and autonomy in changing times", 2005. http://hub.hku.hk/bitstream/10722/32220/15/FullText.pdf?accept=1

Modern Tram Case Study 2: Barcelona, Spain – Barcelona Tram

Reference image

System Description:

Since 2004, Barcelona has operated two separate modern tram networks using overhead catenary. The two modern tram networks, operating since 2004, are known as Trambaix and Trambesòs, with a combined total of 6 lines, 29.2 km of track and 56 stops. They are not physically connected. Trambaix consists of three routes (T1, T2, and T3), extending out from the western part of Barcelona. Trambesòs also consist of three routs (T4, T5 and T6) that run to the northeast of the city. These trams operate at average speeds of 18 km/h, with headways between 4-8 minutes. [redacted]

Both modern tram networks operate within an at-grade semi-dedicated right-of-way (with at-grade intersection crossings). Train preemption signals have also been installed at crossings. The reserve is also level with sidewalks and is grass covered in some areas or with concrete or asphalt concrete

Modern Tram Case Study 2: Barcelona, Spain – Barcelona Tram

when running alongside a road. Trains are 32 m long with 12 doors and capacity for 200 passengers. Stations are in the centre median and allow access from both directions, with station length extending the entire block. Station width varies from 2.5m-3.0m for side platforms. Center platform stations have similar dimensions, but a much larger informal waiting area as they occupy the entire width of the median (with a walking path in between the station shelter and boarding/alighting area).

The two tram networks are not connected physically. The trams play a secondary role to the underground Metro and bus systems. These routes operate on diagonal routes radiating from the city centre and connect outer areas to the periphery of the city.

Planning Background:
As noted, Barcelona has an extensive Metro network of 8 lines, in addition to an extensive bus system. Up until the 1970s, Barcelona had an extensive tram network which was eventually replaced with diesel bus routes. Growing demand for connections from the suburbs spurred consideration of new tram lines. The Government deemed tram appropriate for these corridors given the level of expected demand.

System & Service Characteristics:
- Total Number of Lines: 6 lines
- Network Length: 29.1 – 15.1 km in one network (lines T1-T2-T3) + 14.0 in other (lines T4-T5-T6)
- # of Stations: 56 (29+27)
- Vehicle Type/Size: 32 m train (carrying 200 passengers)
- Average Speed: 18 km/h
- Service Hours: 5:00AM-12:00AM
- Headway: 4-8 minutes in the peak (combined headway on common segments)
- Peak Capacity: 3,000 passengers per hour per direction
- Construction Timeframe: 34 months (from June 2001 to April 2004)

[redacted]

References:

- Email with Eduard Cabrera, Responsible d'Operacio Sistemes, Barcelona Tram, 17 February, 2016.
- http://public-transport.net/bim/Bcn/Bcn_hist.htm
- http://www.tram.cat/en/
- http://www.tram.cat/en/the-tram/advantages/
- http://www.tram.cat/en/the-tram/stop-tram/

Modern Tram Case Study 3: Dublin, Ireland – Dublin Luas

System Description:

Dublin, Ireland's largest city, is served by two modern tram lines known as Luas or "speed" in Gaelic as part of a multimodal system including buses and commuter rail. The tram lines serve as the primary urban transport circulator – although two metro lines are being built. The Red Line and Green Lines both opened in 2004. Construction of a third line, the Luas Cross City (indicated in Purple), will connect the Green and Red lines and extend to areas in the north. The Cross City Line will be completed and operational by 2017.

Reference image

In total, the Red and Green Lines comprise a network of 38 km and 58 stations, [redacted] Annual ridership amounted to 32.6 million in 2014 on both lines. [redacted] As they are configured today, the Red and Green Lines operate completely separately without an interchange. Both lines operate principally in segregated track, with short segments in pedestrian malls. The system operates on 750 VDC overhead power, using a standard rail gauge of 1,435mm. The system originally operated with 30m carriages carrying up to 235 passengers – these have now been upgraded to 43m carriages carrying up to 280 passengers. Luas has 3.0m wide side platforms and 4.0m centre island platforms.

Planning Background

The implementation of Dublin's Luas system stems from the Dublin Transportation Initiative (DTI) published in August 1995, which recommended an integrated transport strategy for Greater Dublin consisting of Quality Bus Corridors (dedicated bus lanes on major arterials leading into the city), a three line modern tram system, with a metro system for the busiest routes. DTI recognised that while the car has its role in the transport system, it should not be allowed to dominate it. Therefore a goal of the DTI was to reduce private car use to 1991 congestion levels by improving the reliability, availability, and quality of public transport. Road improvements would be limited and would focus on enhancing public transport capacity.

Reference image

The selection of modern tram for the two lines that eventually were built (the Red and Green Lines) is based on the moderate level of demand on these corridors (ranging from 3,000 to 9,000 pphpd, which was considered to be more appropriate for modern tram than other modes), as well as socio-economic and financial costs and benefits. Business cases assessing the eventual Red and Green Line corridors and other possible modes were undertaken and found modern tram to perform the best. Related reports concluded that a surface running system would be most appropriate and cost effective in meeting transport needs of the city and providing capacity to meet long-term passenger demand.

The planning of the new 5.6 km Cross City Line also considered a surface running BRT system.

Modern Tram Case Study 3: Dublin, Ireland – Dublin Luas

However, modern tram was selected as the preferred mode due to the following issues: (i) doubt over BRT's ability to provide sufficient carrying capacity to meet existing demand and reserve capacity for future demand (with a maximum assumed capacity of 3,600 pphpd in the Dublin context); and (ii) alignment with the strategic policy to provide an integrated urban transport system and effectively link the Green and Red Lines together. The total cost of the Cross City Line is estimated at 368 million Euro (at 2012 prices without VAT), with a projected benefit-cost ratio of 2.28:1. The experience of the Green and Red Lines has identified predictability in terms of frequency and journey time, as well as reliability and consistent performance are critical to achieving required capacities. Therefore, priority at traffic lights and a high level of physical segregation has been provided for the Cross City Line. Along the 5.6 km route, about 4.5 km will be in segregated operations, with about 1.1 km in shared lanes with other vehicles.

System & Service Characteristics:

- Total Number of Lines: 2 (Red / Green)
- Network Length: 38 km (21 km for Red Line / 17 km for Green Line)
- # of Stations: 58 (36 for Red Line / 22 for Green Line)
- Vehicle Type/Size: 43m trains (carrying up to 280 passengers per train)

[redacted]

- Service Hours: 6:00AM-11:00PM
- Headway: 3-5 minutes in the peak; 5-6.5 minutes in the off-peak

[redacted]

- Capital Cost (FY2015): HK$7.7 billion (or FY2004 HK$7.4 billion or €775.0 million)

Performance Characteristics:

- Annual Ridership (2014): 32.6 million

[redacted]

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Modern Tram Case Study 4: Sydney, Australia – Sydney Light Rail

System Description:

Sydney's urban public transport system consists of commuter rail, buses and light rail. The Sydney Light Rail system currently consists of a single line, operating in both shared and dedicated track for a distance of 12.8 km (including 1.5 km of on-street operations). This line, known as the Inner West Light Rail or L1 Dulwich Hill Line, connects the southern edge of the CBD, with Darling Harbour, and areas to the west of Sydney, serving as a radial route. It has 23 stations overall, with trains operating at 5 minute peak headways and 15 minute off-peak headways and an average speed of 25 km/hour. Annual ridership is about 6.1 million (as of 2015), which has increased significantly after the extension of the Inner West Light Rail was completed in 2014 and the introduction of the Opal integrated fare card in 2015. The current system has a fleet of 12 33m vehicles that hold up to 200 passengers. The minimum curve radius is 20 m, with a maximum gradient of 8.5%. Vehicles are powered by overhead catenary.

Reference image

The current system is being expanded with the CBD and South East Light Rail line – an AUD$1.4 billion extension (now AUD$2.2 billion). The CBD and South East Light Rail lines will operate at-grade in median dedicated lanes with grade crossings at junctions – following areas where the original Sydney tram used to operate. Key components of this line include the following:

- Within the CBD, the lines will operate in a north-south alignment and complement Sydney's first Metro line (opening in 2019), providing local circulation within the CBD and to areas in the southeast.
- The expansion includes 23 new stations and 15 km track, tying into the Inner West Line at Central.
- The system will operate with 67m vehicles (two attached trains), with capacity of 466 passengers. Platforms will have a minimum width of 3.0m, although this may vary by location. For instance, the UNSW High Street stop has a 4.5m width for the north platform/footpath, while the south platform would be 6.0m wide subject to detailed design.
- The system will operate in at-grade, median dedicated lanes as well as a 1.0 km pedestrianized zone on George Street. Within this zone, only emergency vehicles, property owners, and small delivery trucks will retain access to the pedestrianized zone 24 hours a day. Beyond the pedestrianized zone on George Street, one lane in each direction would be maintained on both sides of the track.
- The new lines will run on overhead catenary on the majority of the route, however, on the stretch of the pedestrianized section of George Street north to Circular Quay, the vehicles will be powered by a ground-level power supply system without catenary.
- The loss of traffic lanes and capacity on certain corridors (from the median running dedicated tracks) has been handled with an integrated strategy that focuses on: (i) removing on-street parking and encouraging greater use of spare off-street capacity and maintaining access to off-

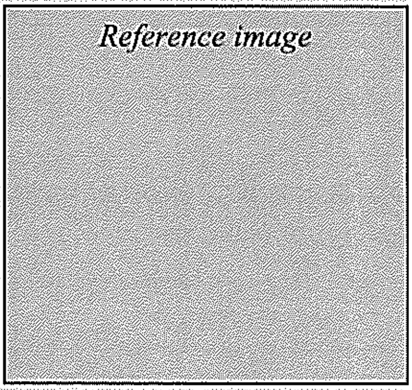
Modern Tram Case Study 4: Sydney, Australia – Sydney Light Rail

street facilities; (ii) identifying alternate traffic routes for private vehicles and providing priority for private vehicles with traffic management and specific street designs;

Planning Background:

The history and development of the Sydney Light Rail system can be divided into three distinct stages: (i) the privately built Sydney Light Rail system built in 1997; (ii) Government purchase of the Light Rail System and integration into the urban public transport network in 2012; and (iii) expansion of the Sydney Light Rail system.

Stage 1 – Privately Built Sydney Light Rail Line

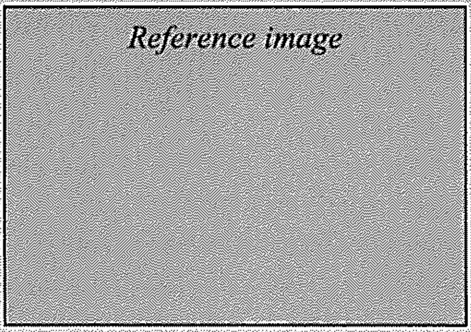


The original street tram network for Sydney has its origins in the 1860s and grew to be an extensive network. Private car ownership led to the demise of the tram network, with the last line closing in 1961, being replaced by diesel buses. In 1994, the Sydney Light Rail Company, a private entity, was awarded a 30-year concession to bring back street running rail services and operate a light rail system. This line would connect the south edge of the CBD with Chinatown, the western edge of Darling Harbour, and Sydney's first legal casino – a distance of 3.6 km and 10 lines. A subsequent expansion in 2000 extended the line by 3.6 km and 4 stops. The original terms of the concession agreement gave the existing Light Rail owner the first right to tender for the construction, operation and maintenance and repair of any extension to the Sydney Light Rail system. The system was originally operated by TNT Transit Systems, also the owner of the Sydney Monorail. The Sydney Light Rail Line and the Sydney Monorail had overlapping alignments along a portion of the western edge of Darling Harbour for about a quarter of the Monorail's one-way loop route. Although operating on a similar alignment, the services served different purposes (co-existing for more than 15 years), with the light rail linking into the Central Station and its commuter rail lines, while the Monorail provided a one-way service that was more geared for tourists. As Sydney Light Rail was privately operated, tickets were not integrated with other public transport services.

Stage 2 – Government Purchase of Light Rail Operators

In 2012, the Government of New South Wales purchased the company owning the Light Rail and Monorail in order to: (i) eliminate the need to negotiate with the owners over potential light rail expansion (as noted the original contract stipulated the owners had say over future expansions); (ii) spur further re-development of Darling Harbour including the Convention Centre; and (iii) remove the Monorail to make room for new developments. As covered in the Sydney Monorail case study, the Monorail ceased operations in 2013 and was removed in 2014. The Monorail was removed (and the Light Rail retained) due to the following reasons: (i) the Monorail occupied areas intended for further redevelopment of Darling Harbour; (ii) the Monorail was configured as a single, one-way loop which made for long journey times (with a complete loop taking up to 15 minutes); (iii) the Monorail did not link major trip generators in the area and was not well integrated with other public transport modes (furthermore the ticketing system was different than that used by other public transport systems in Sydney); and (iv) the Monorail was poorly used by local residents and workers and became more of a tourist attraction. Following the purchase of the Light Rail, the NSW Government put out its vision to prioritise Light Rail through its Light Rail Future document described below.

Modern Tram Case Study 4: Sydney, Australia – Sydney Light Rail



Stage 3 – Expansion of the Light Rail System

Sydney's Light Rail Future (from December 2012), is a visionary document from the Government of New South Wales that establishes plans and the vision for light rail and its role in Sydney's urban public transport system. It outlines a four step process to expand and prioritise light rail as a vital cog in the overall network. Key steps were as follows:

- Service Integration and Improvements – Integrate the Light Rail into the existing fare systems and introduce the Opal card, Sydney's integrated ticketing system.
- Modernise and Extend the Existing System – Construct the Inner West Light Rail Extension (a 5.6 km extension to Dulwich Hill), which was started in 2012 and completed in 2014. This extension operates in an upgraded former rail corridor to the west of the city, within a largely segregated corridor with limited grade crossings.
- Deliver a New CBD and South East Service – Construct the noted CBD and South East Line, using light rail as a tool to revitalise and re-vision urban streets including the pedestrian of 40% of George Street.
- Longer Term Investigations – Investigate other corridors for light rail or other high capacity public transport.

The selection of Light Rail for the CBD and South East Line was rooted in the current problems faced by Sydney in the peak commute periods and the dense street grid in the CBD. About three-quarters of all commute trips are on public transport, with a quarter of these on the bus system. This resulted in significant bus flows coming into the city on a select number of corridors. It was noted that between 350-400 buses per hour would operate on George Street in the morning peak. This resulted in severe consequences including: (i) heavy congestion and long travel times including 30 minutes to traverse the 2.5km section from Central Station to Circular Quay; (ii) buses travel along the entire CBD corridor, even after most passengers have alighted; (iii) significant space is occupied by bus stops and bus layover areas.

Light Rail was favoured over various bus and BRT in this corridor for several reasons:

- Forecast Demand – BRT demand was estimated to be half that for the Light Rail along the same corridor.
- Capacity – The proposed Light Rail vehicle could hold up to 300 people at a time (since upgraded to 466) at 2 minute headways – the equivalent of 9,000 pphpd. On the other hand, articulated BRT vehicles could only hold up to 180 passengers at a time, meaning to achieve the same 9,000 pphpd, 50 trips per hour would be required (or a bus every 1.2 minutes). Potential to increase BRT service to expand capacity was also limited compared to Light Rail.
- Congestion – Light Rail would reduce the number of buses entering the CBD by up to 220 vehicles (including bus restructuring measures), helping to lower congestion.
- Reliability – Light rail, operating in a dedicated corridor with at-grade crossings, is estimated to operate at 97% on-time performance. Only 19-35% of buses achieve this in the CBD and Anzac Parade corridors.
- Urban Renewal Potential – Taking lessons from Europe and elsewhere, Light Rail has potential to revitalise and promote urban renewal in key areas, with urban renewal having been witnessed along the Inner West Rail Line in Darling Harbour.
- Pedestrianisation – The Light Rail line would allow the pedestrianisation of key CBD corridors, where walking is pre-dominant.

Modern Tram Case Study 4: Sydney, Australia – Sydney Light Rail

System & Service Characteristics (Current L1 Dulwich Hill Line Only):

- Total Number of Lines: 1
- Network Length: 12.8 km
- # of Stations: 23
- Vehicle Type/Size: 33m trains (carrying up to 200 passengers) (total fleet of 12)
- Average Speed: 25km/h
- Service Hours: 6:00AM-11:00PM
- Headway: 5 minute peak / 15 minute off-peak headways
- Peak Capacity: 2,400 pphpd (up to 13,500 pphpd for the CBD and South East Line)
- Capital Cost (FY2015): HK$1.0 billion (or FY2014 HK$1.3 billion or AUD$176.0 million – note the AUD-HKD currency has fluctuated significantly between FY2014 and FY2016)

[redacted]

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4.6.5 Modern Tram - Summary and Broad Applicability within KE

Pros	Cons
• Short stop/station spacing can be arranged if preferred • May operate on partly segregated infrastructure and in shared lanes to reduce street impacts • More accessible than grade separated modes, especially for passengers with mobility issues • Perceived as a catalyst for urban regeneration and revitalisation • Creates sense of permanence and has been shown to facilitate TOD • Electric propulsion minimises harmful emissions • High degree of standardisation of subsystems and components ensure many suppliers also at renewals and extensions	• Operates fully or partially in on-street mixed flow conditions, which can reduce speed, reliability, and safety • Requires reallocation of general purpose travel lanes for tramway and stations, thus permanently occupies traffic lanes in developed areas and thus has land implications • Need to divert all underground utilities along the corridor to allow utility access without disruption to tram service • Extensive modification to traffic signals and junction layouts required to accommodate tram • Tram corridor along kerb or within median would impact vehicle access to/from adjacent buildings • Requires driver, which can increase operating costs compared to other rail modes that are automated • Limited speed and capacity compared to other automated rail lines due to operation by driver line of sight • Lower capacity compared to Light Metro, APM and Monorail • Visual impact of catenary wire (although this can be minimised through urban design such as green tracks or with vehicles using ground-linked propulsion systems) • Potential flooding issues for underground propulsion systems, while induction charging systems have yet to be implemented widely • Prohibited vehicles may enter tracks and impact service, therefore enforcement/monitoring required

Key Findings and Broad Applicability within KE
• Modern tram can play the role as a complementary piece of the urban transport system. Modern tram can operate in shared lanes or pedestrian malls, dedicated corridors with grade crossings, or fully segregated corridors. Modern tram can operate on overhead catenary, underground propulsion, or even battery power. Modern tram blends in well with the street environment and has been shown to facilitate development along a corridor and is viewed as a regeneration catalyst. Interaction with road users has significant operating implications, thus newer modern tram systems have tried to maximise the level of segregation and operation in dedicated lanes, with shared track only in highly constrained urban corridors with no other alternative alignments. Most modern tram systems operate at-grade, with minimal elevated or underground sections due to cost. Modern tram operating at-grade requires the reallocation of road space for tracks and stations. As shown in the Sydney case, stretches can also be fully pedestrianized, in which traffic lanes are eliminated. This is handled by re-routing vehicles along other parallel roads and by allowing emergency vehicle access at all times. Modern tram requires drivers and cannot be automated, and thus have higher operating costs relative to other rail modes that can be automated. • As shown with the LRT in Hong Kong, shared use of roads can significantly impact reliability and travel speed of the system. Other systems place the tram in semi-segregated operations whereby intersections are the only locations where traffic and the tram mix – this can improve reliability and reduce the chances of incidents. This is the case with Barcelona, which has built a network of 6 tram lines since 2004 that offer regional linkage services to complement the Metro network. Barcelona has also integrated these lines into the urban realm with grassy medians. Dublin's Luas was implemented as a moderate capacity system that would complement the eventual metro system and serves as an urban circulator/connector. These lines operate at-grade, with small shared

portions of track with vehicles. A new third Luas Line is under construction and was selected over BRT for capacity reasons. Emphasis on segregated corridors and signal priority has been integrated into the design to ensure higher speeds and consistency of service. Sydney's new CBD and South East Line provides a dedicated track of 12 km leading into the city, consisting of 1 km of shared pedestrianized zones. The goal is to reduce the number of buses coming into the city and thereby facilitate urban renewal, improve reliability of public transport services, and reduce congestion on key corridors.

- In the context of Kowloon East, a modern tram system operating at-grade would not offer a fully segregated rail system, which would have implications on travel speed, reliability, safety and other road users. To operate efficiently, dedicated tram lines should be arranged, which may be very difficult along the EFLS route and require reallocation of lanes to the tracks. Headway of the tram system must be synchronized with the road signals at all crossings. This would have significant and negative impact for other road users. The propulsion system must also align with the urban design of the corridor, while potentially requiring significant utility relocation and diversion works. Overhead catenary within KE would not only cause visual impact, locating the overhead wiring on carriageway and junction would restrict the use of the air space along the corridor. Potential flooding issues for underground propulsion systems, while induction charging systems have yet to be implemented widely

4.7 Monorail

4.7.1 Monorail - System Characteristics

Background and System Technology

4.7.1.1 A monorail system consists of self-propelled vehicles that run on a fully-segregated singular track or rail. In most cases, the track is elevated as this is the most economical way of implementing such a system in an already developed environment. This being said, monorails can also run in tunnels if required. For example, Tokyo Monorail (from Haneda Airport to Shinagawa Station) has dedicated tracks connecting to the depot at grade, and the main lines in tunnel at the airport.

4.7.1.2 Vehicles can either be supported (straddle type) or suspended from the track (underslung type). Straddle type monorail have thinner guideways than those for other rail systems and are able to handle moderate volumes of demand.

4.7.1.3 Monorail systems have been operating for over 100 years. The Wuppertal Suspension Railway in Wuppertal, Germany is considered the first monorail, which was opened in 1901. The H-Bahn (also called Sky-Train) in Dusseldorf Airport is also a suspended monorail system, which commenced service 2002 between the regional rail station and the terminal building. Straddle type systems are more prevalent and include monorail lines that are used as urban trunk lines, as well as for specialised tourism purposes.

4.7.1.4 Straddle-type monorail systems used as core lines for daily urban commuters include the Tokyo Monorail (which serves Haneda Airport to the southeast of Tokyo proper, but also has numerous stops along the way for residential and commercial developments) built in 1964, the Osaka Monorail, the Kuala Lumpur Monorail, the Okinawa Monorail, and the world's most comprehensive and well used system in Chongqing, China, built in 2005.

4.7.1.5 Recently, several new urban monorail lines have been opened or are being planned to complement existing Heavy Rail networks including: (i) Line 3 in Daegu, South Korea (opened in 2015); (ii) Line 15 in Sao Paulo, Brazil (opened in 2015, with Lines 17 and 18, both urban monorail lines, currently under construction); (iii) Line 1 in Mumbai, India (opened in 2014); and (iv) the Riyadh Monorail to serve the planned King Abdullah Financial District (being constructed).

4.7.1.6 As discussed in the case studies in the next section, monorail was selected over heavy rail or a road-based system such as BRT in these dense urban corridors for the following reasons: (i) monorail would deliver more reliable and consistent service as existing urban road networks were highly congested and BRT alternatives would have occupied land and experience lower operating speeds; (ii) monorail would be cheaper and faster to build than a comparable heavy rail system (operating above or below ground); and (iii) the moderate level of demand justified a moderate capacity system rather than a high capacity one (such as heavy rail).

Role in Transport Hierarchy

4.7.1.7 Monorail plays different roles throughout the world. The Chongqing Monorail system is the primary rail trunk line in the city and carries the highest number of passengers of any monorail systems in the world. In cities such as Tokyo, Osaka, Daegu, and Sao Paulo, monorail plays a key role as a reliable, moderate capacity trunk system that ties into and complements the heavy rail system. In these monorail corridors, demand is insufficient to justify heavy rail costs. In other cities, monorail systems provide localised circulation for both urban and tourism nodes.

4.7.1.8 Monorail can thus play various roles as a longer-distance trunk line, but also as a localised circulator for shorter-distance trips.

Key Infrastructure Elements and Vehicles

Runningway & Track

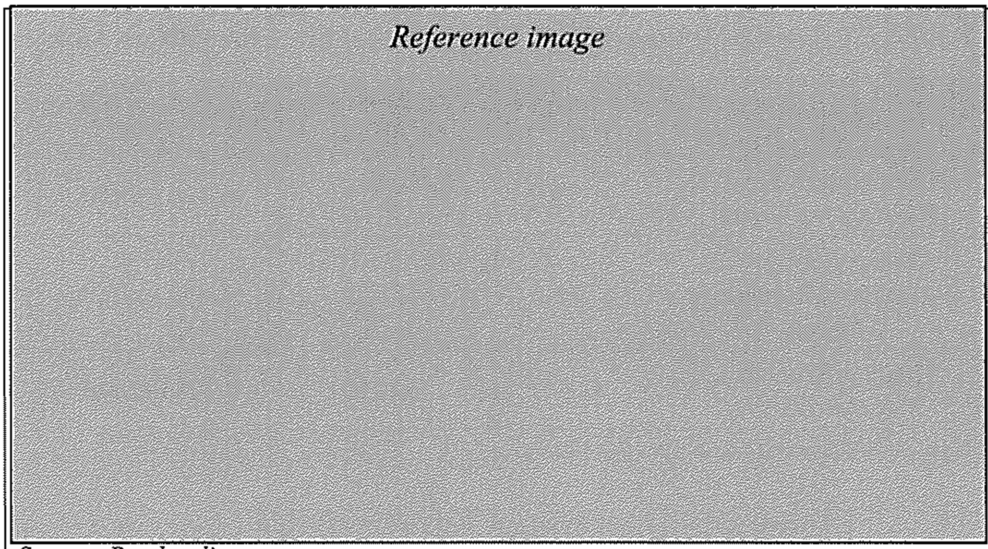
4.7.1.9 Monorail systems operate in fully grade separated corridors without pedestrian or vehicular crossing, thus all crossings must be grade separated. Thus, monorail is similar to Heavy Rail, Light Metro, cable-drawn systems, and APMs in that they operate fully grade separated in their own right-of-way. Monorail vehicles are wider than the guideway that supports them, which is typically about 0.8 m wide.

4.7.1.10 The lower limit for horizontal radius varies and can be as low as 15 m (Intamin Peoplemover) to 100 m (large type of Hitachi Monorails). Monorail can handle maximum gradients ranging from 6% to 10%, although grades in this range may cause passenger discomfort due to high longitudinal acceleration. Maximum speed ranges from 40 km/h to 80 km/h.

4.7.1.11 Monorail is known for its "slim" guideway or beam, which is often described as the advantage with monorail systems. The beam is significantly narrower than comparable track/guideway for other elevated rail based modes. This allows the infrastructure to appear less bulky and obstructive, while also allowing more sunlight to reach the street level. At the same time though, as vehicles are wider and overhang the beam, loose components may fall to the ground from the train.

4.7.1.12 The guideway needs to have mounted power rails on the side of the major beam. The guideway has a reputation of requiring less maintenance than conventional railway.

4.7.1.13 Switch mechanisms are relatively complicated for monorails, since the whole supporting beam must shift laterally. The viaduct sections for switches are fundamentally different from viaduct sections for plain track, as the monorail beams moves so the diverging route between the two through tracks can be created when necessary. However, beams belonging to parts of the through route must be shifted sideways to create clearance to the diverging route. Hence, the infrastructure of the switch section needs to be wider and may appear more bulky at the crossovers. It also appears that evacuation walkways at crossover locations should be designed to cater for the beam movement.



Source: *Bombardier*

Figure 4.7.6: Monorail Crossover in Jacksonville

Stops/Stations

4.7.1.14 Stations are similar to other rail-based modes such as Heavy Rail and Light Metro and vary based on the maximum length of the trains. Tokyo Monorail stations can handle four car trains that are up to 60m in length. Daegu's Line 3 operates 46m long trains with 3 cars. Station spacing varies by system, but may range from 300-1000 m.[47]

Vehicles

4.7.1.15 Monorail vehicles can consist of individual vehicles or multiple units which can run on rubber tires. The vehicles are self-propelled and powered by on-board electric motors that source power from third rails or contact systems that run along the monorail. Trains can either be controlled by a driver or be fully-automated. Vehicle capacity varies by system. Daegu Line 3 uses 46m trains holding between 265-400 passengers per train. Tokyo Monorail trains can hold up to 600 passengers in the four car trains.

4.7.1.16 The various monorail technologies are proprietary, which means it may be difficult to change supplier at system expansion or renewal. For instance, Japanese monorails are supplied by Hitachi (straddled) and Mitsubishi (suspended). The Kuala Lumpur Monorail, built by a Malaysian company (Scomi), is based on the Alweg monorail in Seattle. Bombardier built and operates and maintains a monorail in Las Vegas, built the Sao Paulo Monorail, and is building one in Riyadh, Saudi Arabia.

Capital Costs

4.7.1.17 Capital costs for a range of monorail systems are presented below.

[47] Akira Nehashi, New Types of Guided Transport, Japan Railway & Transport Review 26, February 2001

4.7.1.18 **Table 4.7.17: Equivalent FY2015 Capital Costs for Various Monorail Systems**

System	Length (km)	Year Opened	Cost (HK$)	Cost (HK$) / km
Chongqing Line 3, Chongqing, China	39.0	2011	46,976 million	1,204 million
Chongqing Line 3 Extension, Chongqing, China	16.5	2013	18,482 million	1,120 million
Moscow Monorail, Moscow, Russia	4.7	2010	5,208 million	1,108 million

Source: Arup Database (cost in 2015 Price Level)

4.7.2 Monorail - Operating Characteristics

Service and Passenger Capacity

4.7.2.1 Average speed for monorail systems can reach more than 50 km/h (provided that station spacing is not too close). Service headways of about 2-3 minutes are not uncommon for monorail systems (with Chongqing's Line 2 operating at the lowest headway of 2.5 minutes). Peak capacity of over 40,000 pphpd can be achieved as demonstrated by Chongqing's Line 2 and Sao Paulo's Line 15. **Table 4.7.18** compares operating characteristics of several monorail systems:

Table 4.7.18: Service Profiles for Various Monorail Systems

System	Route Length (km)	# of Stations	Average Speed (km/h)	Headway (min)	Capacity (pphpd)
Chongqing Monorail (Line 2), Chongqing, China	37	28	30	2.5	43,200
Daegu Metro Line 3, Daegu, South Korea	24	30	30	5	4,700
Kuala Lumpur Monorail, Kuala Lumpur, Malaysia	8.6	11	30	4	3,600
Okinawa Monorail, Naha, Japan	12.8	15	28	5	2,000
Osaka Monorail, Osaka, Japan	28	18	35 - 37	6.67	4,000
Sao Paulo Monorail (Line 15), Sao Paulo, Brazil [A]	24.5	17	30	1.5	40,000
Tokyo Monorail, Tokyo, Japan	17.8	11	44 – 56	3.33	10,000

Note:

[A] Only a short two-station segment is currently open. The information included above is for the ultimate 17 station line.

4.7.3 Monorail – Other Key Characteristics

Reliability

4.7.3.1 Monorails can provide a high degree of reliability as it operates in its own right-of-way, unobstructed by street level traffic.

Impacts on Other Road Users

4.7.3.2 Monorail is grade separated from road traffic and would have minimal to no impact on road users, except for column placement in the middle of a road, which would require some road width for a protected median.

Land Requirements

4.7.3.3 Monorail systems require right-of-way for tracks, stations, and depots. The systems land requirements depend on the size of the fleet and level of demand. The smaller the vehicles and train consists, the smaller the stations and depots are. The monorail tracks themselves typically consist of two guide beams that are each about 0.8m wide. This is thinner than the typical guideway for other elevated rail systems. Typical width required for a monorail station (including a platform and two tracks) is about 20-24 m.

Transit Oriented Development (TOD) Implications

4.7.3.4 Monorail, as a rail mode operating in its own fixed guideway, provides a sense of "permanence" along the fixed alignment and can encourage development and densification.

Safety and Evacuation Requirements

4.7.3.5 While potentially being lighter and more aesthetically pleasing, monorail's single beam makes evacuation complicated from stranded trains. Normally, a failed train should be pushed / pulled to the nearest station for detrainment of passengers at the station. If the failed train has lost its traction performance, it can be pushed by another train. If this cannot be done, passengers have to be evacuated by other means. Means to evacuate could include the following:

- **Side Evacuation** - If evacuation is to a train on the adjacent track, the spacing between the two tracks must be narrow. This will require the use of side platforms on elevated stations. However, gaps between the two trains may still be sizeable along horizontal curves (track spacing needs to be wider on curves, since the vehicles forms a chord on the curved track). An additional concern during evacuations to the adjacent track is smoke and heat implications on the evacuation train.
- **Front and Rear Evacuation** - If doors exist at the front and rear of the train, it is possible to evacuate passengers to another train on the same track. However, if there is a fire in the middle of the train, it may be necessary to evacuate passengers both through the front vehicle and the rear vehicle. That means that two rescue trains would be needed.
- **Road-based Evacuation** - Road-based cherry pickers for evacuation require road access to all parts along the line. The evacuation of passengers will be slow, and it is important that the rescue vehicles can be moved

quickly to an incident train (hence, that there is no congestion on the road network).

4.7.3.6 The above issue can be overcome by providing evacuation walkways. Other cities have installed evacuation walkways along the tracks, which are connected to platforms at the stations or to dedicated Emergency Access Points (EAP). The evacuation walkways should ideally be on the same level as the vehicle floor (or slightly lower), and therefore, potential falling distance from the walkway to a protective mesh (which must be clear from the lowest part of the Monorail vehicle) would be about 2.5 m. The trend is that newer systems provide evacuation walkways, which can also serve as access for maintenance crews. The Kuala Lumpur and Dubai Monorails are examples of systems installing a centre-running evacuation walkway. Furthermore, it is notable that Chongqing Monorail Line 2 has no evacuation walkways, but the newer Monorail Line 3 is provided with an evacuation walkway between the two tracks.

4.7.3.7 Due to the switch technology for monorails, where the whole supporting structure is shifted laterally, the design of the evacuation walkways at the switches and crossover sections may need special attention.

Environmental Implications

4.7.3.8 Monorail vehicles are powered by electric motors, which minimises the environmental impact with regards to carbon emissions. Noise emissions are low due to the electric motors and the rubber tires.

4.7.4 Monorail – Case Study

4.7.4.1 Several monorail case studies are presented in Section 5 in the detailed urban monorail comparison.

4.7.5 Monorail - Summary and Broad Applicability within KE

Pros	Cons
• Provides fast, high quality and reliable journey in segregated right-of-way • Can be fully automated and driverless, which can reduce operating costs • Can serve as urban trunk line as well as local circulator • Electric propulsion minimises carbon emissions • Less impact on roadways since mode does not operate at-grade • Slim beam for plain track segments of the alignment with less visual impact and better daylighting for the street level • Viewed as futuristic and is attractive to tourists and visitors • Creates sense of permanence and has been shown to facilitate TOD	• Relatively high capital costs compared to road-based modes • Generally less accessible than street-running, at-grade mode for passengers, especially those with mobility issues • Limited number of suppliers may limit procurement of new vehicles / systems for expansion or repair • Vertical distance from the evacuation walkway to a protective mesh on the trackside of the walkway is about 2.5m, which is higher than that for other elevated rail modes. • Crossover locations may require wider clearance to swing out • More difficult to expand than other elevated rail systems due to complex switch mechanisms to add additional track bifurcations

Key Findings and Broad Applicability within KE
• Monorails operate in various contexts including as circulators, feeders and trunk lines. Monorail guideways are considerably slimmer than other rail-based modes, making the system more visually appealing. Monorail capacity can rival moderate-capacity heavy rail systems with upwards of 40,000 pphpd as seen in Chongqing and planned in Sao Paulo, although most systems are of low-moderate capacity (under 10,000 pphpd). Urban monorail lines have recently opened in 2015 in both Daegu, South Korea and in Sao Paulo, Brazil – these lines serve as urban trunk lines and complement existing heavy rail systems. Monorail offers a moderate capacity rail alternative that is more reliable and is grade-separated compared to road-based modes, but can be built cheaper and quicker than a comparable heavy rail option. • In the Kowloon East context, monorail would offer a fully segregated system, which can be driverless. The system would need to operate within the existing built-up area, with tight turns, narrow corridors, and numerous buildings. System capacity and station spacing correspond well to the planned EFLS. The main running track sections of the alignment can be slim (two parallel beams, each about 0.8 m wide). However, viaduct elements for switches, with movable supporting beams, are less aesthetically pleasing. The evacuation strategy may require additional walkways, emergency access points and emergency egress points for the elevated tracks / viaducts (these would need to be attached to the elevated structures, which may be particularly difficult along switches). During retrofitting, the complex switch mechanisms and supporting infrastructure may require long closure of the system if additional switches are added (for instance for bifurcations, additional of branch lines, and additional turnback tracks).

4.8 Personal Rapid Transit (PRT)

4.8.1 PRT - System Characteristics

Background and System Technology

4.8.1.1 Personal Rapid Transit, PRT, (also known as Urban Light Transit, or Automated Transit Network, ATN) is a public transport mode featuring small automated electric vehicles (sometimes called "pods") operating on a network of specially built guideways. Vehicles operate on rubber tires within the guideways. PRT is intended to provide an on-demand, highly personalised point-to-point journey. Passengers can select their destination and be taken non-stop without stopping at intermediate stations.

4.8.1.2 PRT vehicles are sized for individual or small group travel, typically carrying no more than 2 to 6 passengers per vehicle. Although vehicles depart frequently, PRT capacity is limited. Guideways are arranged in a network with stations located on sidings and with frequent merge/diverge points.

4.8.1.3 Technology is still evolving and four systems are operational in the world. The first PRT was built in 1975 in Morgantown, West Virginia in the United States at West Virginia University. More recent examples include: ULTra at London Heathrow Airport, 2getThere in Masdar City (Abu Dhabi, United Arab Emirates), and SkyCube in Suncheon, South Korea.

Role in Transport Hierarchy

4.8.1.4 PRT is intended to provide on-demand, direct origin to destination service for individuals or groups of individuals travelling to the same destination. This high level of service however has a cost, capacity is relatively low. PRT is best suited for intra-campus or intra-district travel or for use at an airport (such as London's Heathrow Airport). It is considered a last-kilometre type system to provide connectivity from a major hub or trunk line where there are multiple dispersed destinations rather than larger concentrated trip generators and attractions.

Key Infrastructure Elements and Vehicles

4.8.1.5 Major infrastructure elements for PRT include the guideway and track, stations and vehicles.

Runningway

4.8.1.6 PRT operates in dedicated guideway, which can be located above ground, at or near ground level, or underground.

Stops/Stations

4.8.1.7 Stations have multiple boarding bays to reduce waiting time and increase throughput. The ULTra at London Heathrow can handle between 100-120 vehicles per hour per bay. Intermediate stations typically require at least four parallel guideways - two main lines to bypass the station and two side lines to serve the station. Side lanes to serve the station platform must be of sufficient length to accommodate several vehicles at the same time. Sufficient side lane length should also be established to cater for the deceleration and acceleration of

PRT vehicles. This will be necessary to allow the stopping vehicles to leave and enter the main line without reducing the speed of non-stopping vehicles on the main through-lines.

Vehicles

4.8.1.8 Vehicles are similar to small pods, carrying between 2-6 passengers at a time. Pods may also be used by an individual or small groups travelling together by choice. Vehicles are fully driverless and automated. Vehicles run on batteries that are charged at stations or en-route. Vehicles are able to steer themselves as on-board control systems are now installed into the vehicles themselves. Vehicles use rubber tires and operate exclusively within the guideway.

Capital Costs

4.8.1.9 The table below presents a summary of capital costs for recent PRT projects.

Table 4.8.19: Equivalent FY2015 Capital Costs for Various PRT Systems

System	Length (km)	Year Opened	Cost (HK$)	Cost (HK$) / km
2getThere, Masdar City, Abu Dhabi, United Arab Emirates	1.5	2010	[redacted]	[redacted]
ULTra, Heathrow Airport, London, United Kingdom	4.8	2011	[redacted]	[redacted]
SkyCube, Suncheon, South Korea	4.6	2014	[redacted]	[redacted]

Source: Arup Database (cost in 2015 prices)

4.8.2 PRT - Operating Characteristics

Service and Passenger Capacity

4.8.2.1 PRT is intended to allow users to select from a variety of destinations and be taken non-stop to this destination – bypassing intermediate stations. Logic and control issues are still being resolved in order to provide a large selection of destinations to choose from.

4.8.2.2 PRT operates at speeds of up to 50 km/h (for instance Suncheon SkyCube). The capacity of a PRT system is highly dependent on the specific system design and network layout, as well as the number of dispatch bays per station. In the ULTra example, a single dispatch bay can handle a departure every 30 seconds. Thus a station with multiple dispatch bays can have a very short "combined" headway. Assuming a 2-second headway and four persons per vehicle, a PRT line can achieve a theoretical maximum capacity of 7,200 passengers per hour. However, most estimates assume that vehicles will not generally be filled to capacity, due to the point-to-point nature of PRT.

4.8.2.3 **Table 4.8.20** presents the line and system capacity for the three most recent systems – ULTra in London, 2getThere in Masdar City, and SkyCube in Suncheon. Line capacity ranges from about 2,400 to 5,400, although system capacity is currently constrained by station size.

4.8.2.4 **Table 4.8.20: Maximum Line Capacity vs. System Capacity and Actual Daily Ridership for Various PRT Systems**

System	Maximum Line Capacity (pphpd)	Maximum System Capacity (pphpd)	Average Daily Passengers
ULTra, Heathrow Airport, London, United Kingdom	2,400 (7,200 projected)	650	800
2getThere, Masdar City, Abu Dhabi, United Arab Emirates	2,880 (7,200 projected)	300	700-1000
SkyCube, Suncheon, South Korea	5,400 (7,200 projected)	1,500	N/A

Source: *Advanced Transit Association (quoted in* Felix Tihlmann Vahle: Quo vadis PRT? Review, Update and Outlook of Personal Rapid Transit in the Context of a Changing Urban Mobility Paradigm. IIIEE Thesis 2014:30)

4.8.3 PRT - Other Key Characteristics

Reliability

4.8.3.1 Given that PRT vehicles travel on their own dedicated track network, any congestion is limited to PRT vehicle traffic only. This ensures unknown traffic situations caused by external vehicles will not affect PRT systems.

Impacts on Other Road Users

4.8.3.2 PRT is grade separated from road traffic and would have minimal to no impact on road users, except for column placement in the middle of a road, which would require some road width for a protected median.

Land Requirements

4.8.3.3 PRT systems require land for the guideway, stations, depots, etc. Guideway are relatively narrow due to the small size of the vehicle.

Transit Oriented Development (TOD) Implications

4.8.3.4 PRT is still evolving and existing cases have yet to show increased development and property values around PRT stations. Given the low capacity of the system, it is likely that PRT would not in itself facilitate significant development at stations or alongside the system. So far, PRT has been applied to new urban developments as a means of providing a premium personalised level of service.

Safety and Evacuation Requirements

4.8.3.5 Because PRT systems operate on their own segregated infrastructure, vehicle conflict can be highly controlled and consequently, the systems are safe. System programming and on-board vehicle sensors ensure that vehicles easily avoid collision, creating a safe means of travel from point to point.

Environmental Implications

4.8.3.6 PRT vehicles are powered by electric motors, which minimises the environmental impact with regards to harmful emissions. Noise emissions are low due to the electric motors and the rubber tires.

4.8.4 PRT – Case Studies

4.8.4.1 The case studies for the London Heathrow Airport's ULTra PRT and Suncheon (South Korea)'s SkyCube systems are presented below.

PRT Case Study 1: London, United Kingdom – ULTra at London Heathrow

Reference image

Reference image

System Description:

In operation since May 2011, ULTra (short for Urban Light Transit) has operated at London's Heathrow Airport. ULTra is an automatically controlled personal rapid transit (PRT) system with small vehicles (4-6 seats) that run on their own segregated guideway network. Each vehicle operates on battery power and each vehicle runs on rubber tires. If a vehicle is not available, passengers can call for a vehicle. Once inside, passengers can select their destination once in the vehicle and be taken to their destination non-stop at speeds up to 40 km/h.

The three stations, 4.8 km track links Heathrow's Terminal 5 and outer parking areas. Stations have multiple boarding berths. The Terminal 5 station has 4 berths, while the two perimeter parking stations each have 2 berths. Some 18 vehicles are required for service. At present, the peak vehicles / hour / direction is about 70, although the guideway is equipped to handle up to 280 vehicles / hour / direction. [redacted]

Planning Background

Heathrow Airport faces many issues that other airports have including environmental responsibility, local area congestion, space limitations, capacity constraints, passenger service targets, and multimodal connectivity. Previously, Terminal 5 was connected to the remote parking lots with a shuttle bus service. ULTra won an Innovative Transport funding contract that went towards the development of a 1km test track in Cardiff. Once approved for public use by the UK Regulatory Authority (HM Rail Inspectorate). ULTra was then selected to build a pod system at Heathrow Airport, with goals to improve passenger experience and reduce environmental impact. The shuttle bus service was cancelled several months after ULTra opened.

System & Service Characteristics:

- Total Number of Lines: 1 line
- Network Length: 4.8 km
- # of Stations: 3
- Vehicle Type/Size: ULTra Vehicle (3.7m long, carrying 4-6 passengers)
- Average Speed: 40 km/h
- Service Hours: 22 hours (matching Heathrow Airport's operations)
- Headway: 12 seconds
- Peak Capacity: 650 passengers per hour per direction (capacity limited by stations currently)

[redacted]

PRT Case Study 1: London, United Kingdom – ULTra at London Heathrow

References:

- http://www.heathrow.com/transport-and-directions/heathrow-parking/heathrow-pod-parking-terminal-5
- http://www.ultraglobalprt.com/how-it-works/vehicle-features-customisation/
- http://www.ultraglobalprt.com/wheres-it-used/heathrow-t5/
- http://www.ultraglobalprt.com/wp-content/uploads/2012/01/History-of-Ultra.pdf
- ULTra Global PRT – Heathrow POD Summary
- ULTra Global PRT – ULTra PRT Overview

PRT Case Study 2: Suncheon, South Korea – Suncheon SkyCube

System Description:

Reference image

The Suncheon SkyCube is one of the first PRT systems in the world, opening in April 2014. The system is 4.6 km long, running from Suncheon's Dream Bridge to Suncheon's Literature Center serving two stations. The vehicles, called cubes, operate at average speeds of 35-45 km/hour, with maximum speeds of 50 km/hour. The system is designed for on-demand service with vehicle departures every 3-4 seconds. The vehicles peak capacity of the system is 1,500 pphpd and operate with a fleet of 40 cubes, each holding up to 9 passengers. The system provides level access with access for mobility impaired. The system operates exclusively on electricity with linear induction motors (LIM) contained within each car. The guideway is made of concrete, with typical spans of 30m between columns (with a 50m span over a river). The SkyCube can climb grades of between 3.5% and 10.0%. Vehicles run on polyurethane coated wheels instead of steel wheels to reduce noise.

Planning Background:

The SkyCube was specifically implemented by POSCO, a Korean conglomerate, to serve as a demonstration project of its PRT technology, which had first been trialled on a test track in Sweden. Besides the fact that PRT was implemented to demonstrate its wider commercial application, PRT was chosen for its eco-friendliness and its energy-efficiency. Suncheon Bay is one of the world's foremost coastal wetlands and the green transport system would need to preserve and maintain the Bay. [redacted]

System & Service Characteristics:

Reference image

- Total Number of Lines: 1
- Network Length: 4.6 km
- # of Stations: 2
- Vehicle Type/Size: Cubes can hold up to 9 passengers (40 cubes)
- Average Speed: 35-40 km/hour
- Service Hours: 8:30AM-6:00PM
- Headway: Departures every 3-4 seconds
- Peak Capacity: 1,500 pphpd

PRT Case Study 2: Suncheon, South Korea – Suncheon SkyCube

[redacted]

References:

- Email from Chun Hee Kim, POSCO, 2:10PM March 2, 2016.
- http://english.visitkorea.or.kr/enu/AKR/FU_EN_15.jsp?cid=1917408
- http://globalblog.posco.com/koreas-first-personal-rapid-transit-prt-skycube/
- http://www.podcarcity.org/PodCityVirtualConf/ConferencesFolder/9__siliconvalley/Documents/After%20-%20Ingmar%20Andreasson/Suncheon%20PRT%20edited_Podcar%20City%209th.pdf

4.8.5 PRT – Summary and Broad Applicability within KE

Pros	Cons
• Offers personalised, non-stop point-to-point travel journey that other public transport modes cannot meet • Ideally, passengers able to choose from a variety of destinations and be taken directly there • Provides journey in segregated right-of-way which provides high level of reliability • Less impact on roadways since mode does not operate at-grade • Narrower guideways due to smaller and lighter vehicles • Viewed as futuristic and is attractive to visitors • Fully automated and driverless • Electric propulsion minimises harmful emissions	• Low capacity system with small pods • Generally less accessible than street-running, at-grade mode for passengers, especially those with mobility issues • Non-stop service requires passing lanes at stations, hence stations will require additional width • Technology has not been widely applied and is still evolving • Unclear if this technology is applicable to handle larger passenger volumes

Key Findings and Broad Applicability within KE

- PRT offers a highly personalised, on-demand journey on a dedicated guideway that bypasses intermediate stations for a point-to-point experience. This allows for a relatively fast and reliable service. PRT has been implemented in four locations around the world, although other systems are being planned and related systems/technologies are evolving. It is most applicable to areas with dispersed destinations. PRT vehicles are small in order to offer this personalised travel experience, however, this reduces the overall capacity of the system. The relatively light vehicles allow for longer spans and lighter spans.
- As the Heathrow ULTra case study shows, PRT can play a role as a specialised feeder system and provide a high level of passenger service. However, capacity is limited by the stations and the guideway and ULTra is a low-capacity system. Suncheon's SkyCube also provides tourist service within an environmentally sensitive wetland area, which can climb relatively steep grades. The SkyCube was opened as a demonstration project and the financial viability is unclear. Similar to ULTra, SkyCube handles relatively low capacity.
- Therefore within the context of Kowloon East, adoption of PRT would be limited by the required capacity for the EFLS in addition to the width of stations that require passing lanes. Although PRT can provide a unique non-stop experience from origin to destination, PRT would likely play a more specialised role as a local circulator within a discrete area and/or feeder to the EFLS and the existing MTR rail network.

5 Detailed Urban Monorail Comparison

5.1 List of Monorail Systems

5.1.1 An overview of monorail systems and related technology has already been included in **Section 4.7**. This section contains detailed monorail case studies focusing on those applications in an urban context. The section, as requested in the brief, provides more in-depth information on the planning, operations, and performance of each system. The following urban monorail systems are described (in order of implementation year).

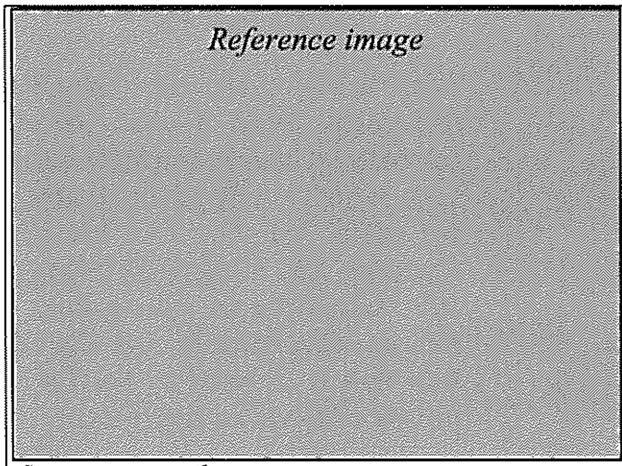
Table 5.1.1: List of Urban Monorail Systems Reviewed in the Detailed Case Studies (in Order of Implementation Year)

#	System	Location	Years of Operation
1	Tokyo Monorail	Tokyo, Japan	1964-Present
2	Sydney TNT Harbourlink Monorail	Sydney, Australia	1988-2013
3	Osaka Monorail	Osaka, Japan	1990-Present
4	Okinawa Monorail	Naha, Okinawa, Japan	2003-Present
5	Kuala Lumpur Monorail	Kuala Lumpur, Malaysia	2003-Present
6	Chongqing Monorail (Lines 2/3)	Chongqing, PRC	2005-Present
7	Daegu Monorail (Line 3)	Daegu, South Korea	2015-Present
8	Sao Paulo Monorail (Line 15)	Sao Paulo, Brazil	2015-Present

5.2 Tokyo Monorail

5.2.1 Tokyo Monorail - System Description

5.2.1.1 The 17.8 km long Tokyo Monorail links Haneda Airport to the southeast of Tokyo proper with the downtown area and the circular Yamanote Line (at Hamamatsucho Station on the east side of Tokyo). It is part of Tokyo's extensive urban public transport system that includes numerous heavy rail systems including the Japan Rail and private rail lines, street trams, and APMs, as well as urban buses.



Source: *www.railwaygazette.com*

Figure 5.2.1: Tokyo Monorail Train

5.2.1.2 Three types of services are operated: (i) Haneda Express service (a non-stop 13 minute journey to the airport); (ii) Rapid service (stops at three intermediate stations); and (iii) Local service (stops at all six intermediate stations). Intermediate stations provide access to dense industrial and residential areas south of Tokyo – therefore the line can also be considered an urban trunk line – providing access for these areas to Tokyo proper. The Tokyo Monorail is the busiest airport link in the world.

5.2.2 Tokyo Monorail - Planning Background

5.2.2.1 The background of the Tokyo Monorail starts prior to the 1964 Summer Olympics in Tokyo. A new public transport mode was required to link Central Tokyo and Haneda Airport located to the south (at this time, Haneda was the major airport for Tokyo as Narita had yet to be completed). Urban congestion on Tokyo's streets was growing and had become a serious issue for passengers heading to/from Haneda Airport. While other modes were considered including other rail modes such as heavy rail, monorail was selected to provide the connection to Haneda Airport for the following reasons:

- **Reduced Land Requirements** – A monorail would require less land and space than comparable road based modes or a heavy rail system. Portions of Tokyo Bay were reclaimed to provide land for the monorail track.
- **Simpler Track Construction** – A monorail, with its single beam in each direction, would be simpler to build than a comparable heavy rail system.
- **Shorter Implementation Timeframe** – With the 1964 Olympics approaching, the system needed to be in place and operational well before the start of the Summer Olympics. Monorail could be built faster than a comparable heavy rail line.
- **Smaller Turning Radius and Lower Noise Profile** – Monorail could operate in tighter turns than heavy rail, which would be advantageous

within Tokyo's dense, builtup environment. Also, the lower noise profile would reduce impacts on nearby buildings and residents.

- **Less Visually Impactful** – The thinner beams would allow more sunlight and be less visually impactful than comparable elevated rail systems with wider guideways.

5.2.2.2 After being built, the Tokyo Monorail was a breakthrough for monorail technology when it was opened in September in 1964. The initial segment connected Hamamatsucho, one of the major stations along circular Yamanote Line, which is one of the busiest lines in Tokyo, with Haneda Airport (HND) to the south. The first 13.2 km of the line was financed exclusively by private investors. The nominal FY1964 cost was JPY20 billion for the infrastructure and JPY1 billion for the rolling stock – this is equivalent to FY2015 HK$14.0 billion for the infrastructure and HK$0.7 billion for the rolling stock.[48] The Tokyo Monorail is operated by the Tokyo Monorail Co., Ltd., which is one of the only private railways to use JR East's Suica fare card system.

5.2.2.3 This system was subsequently extended in 2004 to provide a link to the new international terminal at Haneda. The line is now 17.8 km long railway with 11 stations. Currently, there is a proposal to extend the monorail further north to link it with Tokyo Station and provide a more efficient transfer to Haneda for Narita International Airport (NRT) passengers as well as better connections with regional rail lines passing through Tokyo Station from the western, more populous areas of Tokyo. This 3.0 km extension would cost on the order of JPY110 billion (nearly HK$7.0 billion) – equivalent to more than HK$2.3 billion per km.

5.2.2.4 Earlier plans to extend Tokyo Monorail to Yokohama (18 km) and Kamata (4 km) have not materialised.[49]

[48] Monorails in Japan - publictransit.us Special Report No. 9
[49] Monorails in Japan - publictransit.us Special Report No. 9

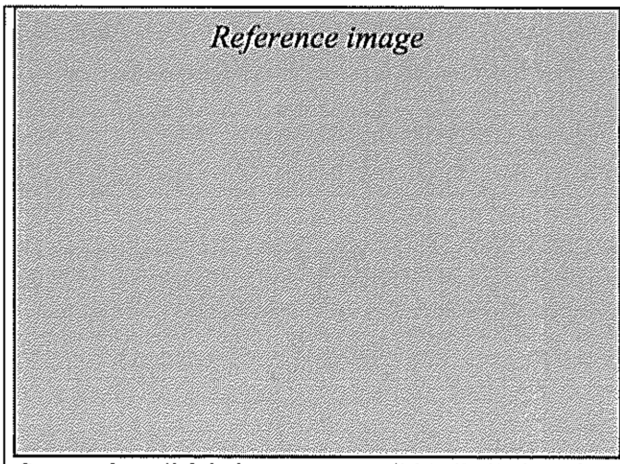
Reference image

Source: *http://www.haneda-airport.jp/en/access.html*
Note: Not all Monorail stations shown. Please refer to ***Figure 5.2.4****.*

Figure 5.2.2: Tokyo Monorail Route Map and Connection to Major Regional Rail Network

5.2.3 Tokyo Monorail - System Characteristics

5.2.3.1 The line is a 17.8 km long double tracked pinched loop (a double track railway with two terminus stations). The total number of stations is 11 (please refer to **Figure 5.2.4**, which depicts all stations and service patterns). An unusual characteristic is that Showajima Station has four tracks with two island platforms. [50] This was introduced 2007 to allow for the express (skip-stop) service.



Source: *http://akihabaranews.com/2014/04/03/article-en/tokyo-monorail-launches-new-cars-1st-time-17-years-its-50th-anniversary-year*

Figure 5.2.3: Tokyo Monorail Depot

5.2.3.2 There are 25 switches on the system. In case of power supply failure, the switches can be operated manually. Two of the stations have scissor crossovers.

5.2.3.3 Design standards are as follows:

- Standard track spacing is 3.7 m;
- Minimum radius is 120 m on main line and 100 m on sidings (with the lower limit for radius for Hitachi Medium type vehicles being 100 m);
- Maximum gradient is 6.0%; and
- Maximum speed is 80 km/h.

5.2.3.4 The pre-stressed concrete track girders are typically 20 m long. The steel or composite girders are up to 66 m long. The elevated stations have side platforms to keep the two mainlines close together along the viaducts, while the underground stations at Haneda Airport Terminal 1 and Terminal 2 have island platforms. The stations are equipped with Automated Platform Gates (APG). There appears to be no evacuation walkways along the elevated portions of the route.

5.2.3.5 Trains were originally of Alweg design (Alweg-Forschung GmbH, Germany). Alweg's technology was licensed in 1960 by Hitachi, which continues to construct monorails based on Alweg technology around the world. The trains were replaced by newer designs in 1969, 1977, 1982, 1989, 1997 and 2014. The current rolling stock fleet consists of 21 train-sets is presented in **Table 5.2.2**. The trains have drivers and are equipped with Automated Train Protection.[51]

[50] http://www.tokyo-monorail.co.jp/english/guidance/syowajima/index.html
[51] New Transit Systems and Urban Monorails in Japan, Japanese Railway Engineering No 171, 2011 publictransit.us Special Report No. 9

Table 5.2.2: Rolling Stock Summary – Tokyo Monorail

Series	Year of First Service	Passengers per Train	Car Length	Mass (tons)	Max Speed (km/h)	Notes
1000 series	1989	584	2 x 16.55 m 4 x 15.20 m	*N/A*	80	Replaced older rolling stock; planned for 2020 phase out
2000 series	1997	600	2 x 16.40 m 4 x 15.20 m	141.0	80	Replaced 1982 rolling stock
10000 series	2014	456	2 x 16.40 m 4 x 15.20 m	141.9	80	Replaced 1000 series

Note: Comparing the capacity with data from Hitachi indicates that the value for passengers per train is based on 4 passengers per square meter.

5.2.3.6 With the 2000 series trains, the line capacity can calculated as 10,800 pphpd, but considering the mixture of rolling stock, the capacity becomes 10,512 pphpd.[52]

5.2.4 Tokyo Monorail - Service Characteristics

5.2.4.1 Service hours are 5:00AM-12:00AM. Normal headway on the system is 4.0 minutes. During the weekday AM peak (between 7:20AM-9:20AM), a headway of 3 minutes and 20 seconds is achieved, equivalent to 18 trains per hour.[53]

5.2.4.2 As noted, three different services are accommodated on the same track. Local trains stop at all 11 stations, with a total running time of 24 minutes. Rapid and express trains operate skip-stop services and serve 7 and 4 stations, respectively. Running times for the rapid and express are 21 and 19 minutes, respectively. Hence, average speeds for the three type of services can be calculated as 44, 51 and 56 km/h, respectively.

Reference image

Source: *http://www.tokyo-monorail.co.jp/english/timetable/*

Figure 5.2.4: Tokyo Monorail Services

5.2.5 Tokyo Monorail - Performance

5.2.5.1 The Tokyo Monorail has a distance-based fare structure ranging from 160 to 490 JPY that has a slight discount for fares paid using the integrated Suica fare card. In terms of ridership, the latest figures from 2015 find the following:

[redacted]

[52] Monorails in Japan - publictransit.us Special Report No. 9
[53] Jane's Urban Transport Systems 2015-2016

[redacted]

5.2.5.2 The annual ridership figure aligns with past 2010-2014 ridership shown in the table below.

Table 5.2.3: Ridership and Car-km for Tokyo Monorail (2010-2014)

Year	Passengers (million)	Car-km (million)
2010-11	45.8	19.9
2011-12	44.2	20.0
2012-13	45.2	20.3
2013-14	45.5	20.3

Source: Jane's Urban Transport System 2015-2016

5.2.5.3 According to the most recent Tokyo Monorail income statement (from March 31, 2008), financial performance was as:[54]

- Annual Operating Revenue: JPY13.6 billion
- Annual O&M Costs: JPY12.4 billion

5.2.5.4 Thus the Tokyo Monorail is able to fully recapture direct O&M costs with a farebox recovery of 110%.

5.2.6 Key Findings from Tokyo Monorail

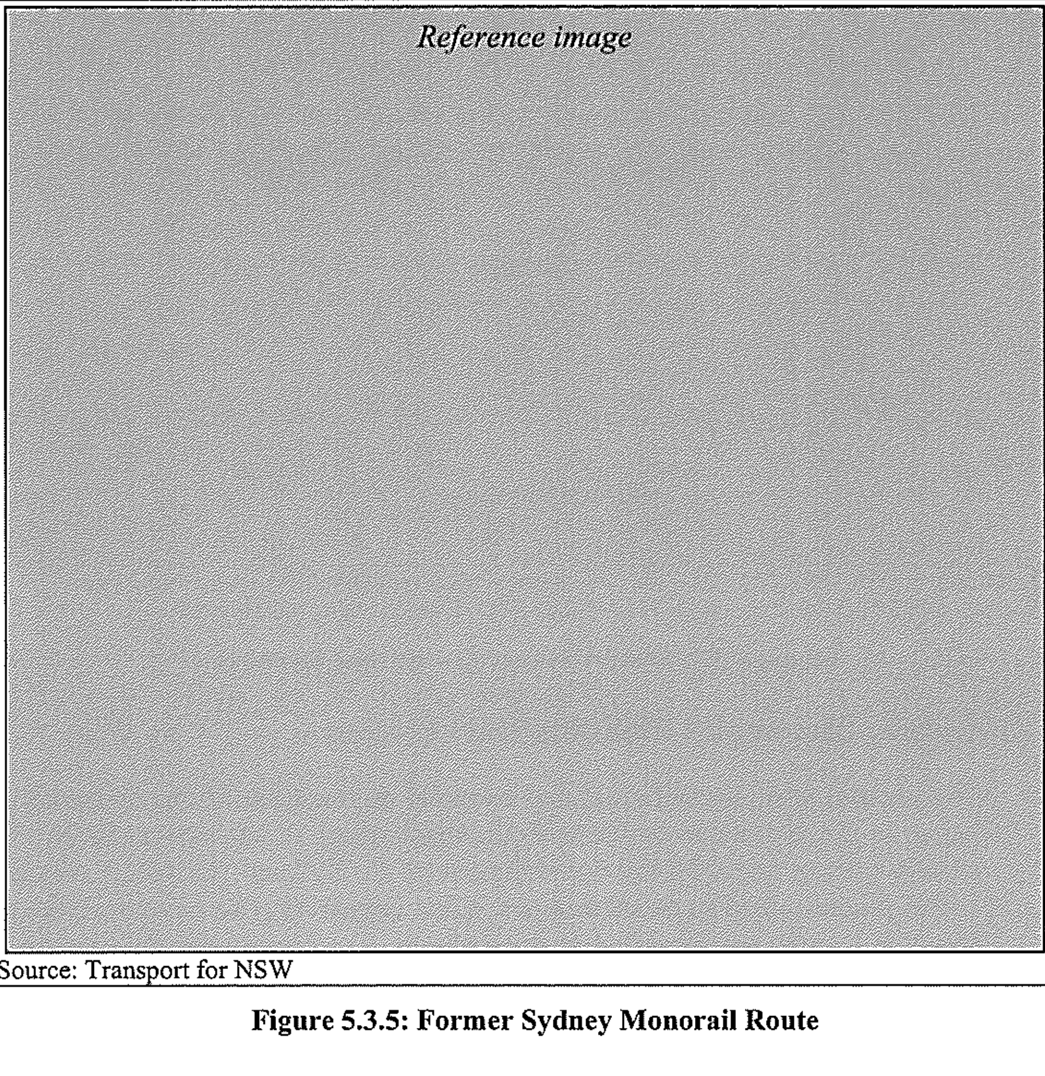
5.2.6.1 The Tokyo Monorail still serves as a vital cog in the overall urban public transport network of Tokyo carrying nearly 10,000 pphpd. It provides a fast and reliable airport connector service, as well as urban trunk line, linking Tokyo with areas to the southwest. Different types of services are provided to match the market – including express service, skipped stop service, and local service. Monorail was selected at the very beginning over other modes for its aesthetic appeal, reduced visual and noise implications, as well as reduced implications on crowded roads and builtup areas in densely packed Tokyo.

[54] Source: http://www.tokyo-monorail.co.jp/company/finance.html.

5.3 Sydney TNT Harbourlink Monorail

5.3.1 Sydney Monorail - System Description

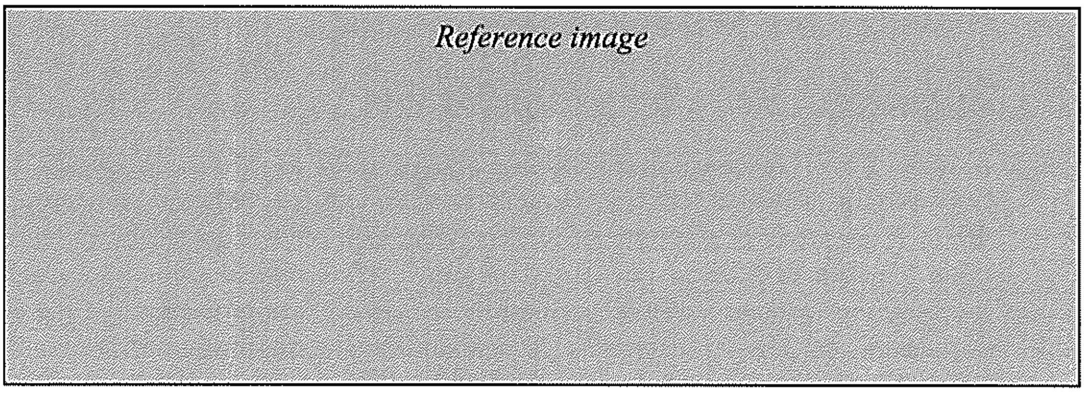
5.3.1.1 Sydney TNT Harbourlink Monorail, later known as Metro Monorail, opened operation in 1988. TNT Harbourlink was awarded a 50-year concession until 2038. It operated in a counter-clockwise direction on a single track railway loop, with a length of 3.6 km and eight stations.[55] The system served several tourist nodes along Darling Harbour including the Powerhouse Museum and the Sydney Aquarium; its former alignment is depicted as the red coloured line in **Figure 5.3.5**. The original purpose of the monorail was to serve as a downtown circulator and rail feeder system and help to facilitate redevelopment of Darling Harbour and areas to the west of the traditional CBD area. The system is no longer operating, having been purchased by the New South Wales (NSW) Government in 2012 and subsequently torn down in 2013.



Source: Transport for NSW

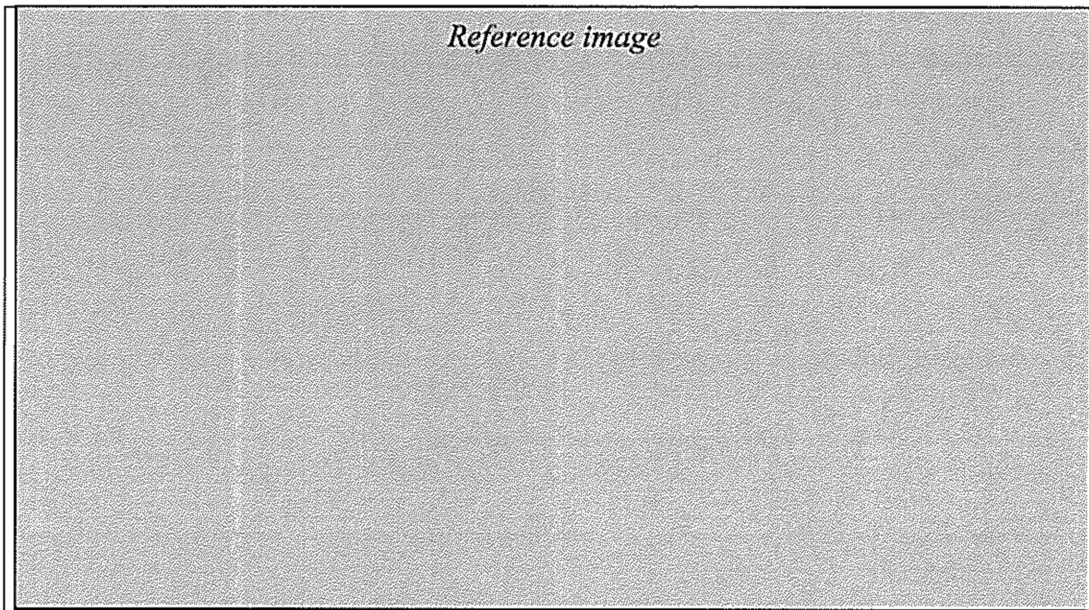
Figure 5.3.5: Former Sydney Monorail Route

[55] Jane's Urban Transport Systems 2002-2003



Source: Transport for NSW

Figure 5.3.6: Sydney Monorail - World Square Station



Source: http://www.dailytelegraph.com.au/news/nsw/sydney-monorail-makes-its-last-loop/story-fni0cx12-1226672054336?nk=d435c628c22bbd120b0cf1f1c2650abc-1450399918

Figure 5.3.7: Sydney Monorail – Darling Harbour

5.3.2 Sydney Monorail - Planning Background

5.3.2.1 The planning, implementation, and eventual dismantling of the Sydney Monorail began in the 1980s and ended with the dismantling of the system in 2013, and is closely intertwined with the development of the Sydney Light Rail system in the 1990s (as described in **Section 4.6.4, Case Study 4**). The history of the Sydney Monorail can be encapsulated in three stages: (i) selection and implementation of the Sydney Monorail in the 1980s; (ii) implementation of the Sydney Light Rail in 1997 and purchase of the Sydney Monorail in 1998; and (iii) Government purchase of both systems in 2012 and subsequent removal of the Monorail in 2013. These stages are described below:

Stage 1: Selection and Implementation of the Sydney Monorail in the 1980s

5.3.2.2 The story of the Sydney Monorail began in the 1980s, when plans were first developed to undertake Australia's largest land re-development at Darling

Harbour, a waterfront area to the west of the CBD and famed Sydney Opera House. At this time, Darling Harbour served as the marshalling yard and freight consolidation centre for the NSW Railways. Owing to its strategic location to the west of the CBD, re-development was prioritised for completion by the 1988 bicentenary celebration for the founding of New South Wales. The plan called for transformation of the dilapidated wharves and warehouses into an entertainment and recreation area including development of the Sydney Exhibition Centre, Convention Centre, Chinese Gardens, and Harbourfront retail and dining developments.

5.3.2.3 In 1985, the NSW Government unveiled plans for the Darling Harbour redevelopment, which included a plan for a "people mover" to link with the Sydney CBD and sought expressions of interest from potential operators. Project requirements included the following objectives: (i) the project must be ready by 1 January 1988 to meet the bicentennial celebrations of Australia (i.e., quick construction and implementation); (ii) the government would incur no costs for development of the project (i.e., the private sector would need to fund and build); and (iii) the project must have on-going financial viability and be self-sustaining (i.e., the project's ridership and other revenues could adequately cover operating and maintenance costs).

5.3.2.4 Two competing transport linkage proposals were submitted – one for a light rail and the other for monorail (submitted by TNT). Selection criteria were identified as: (i) technical efficiency; (ii) financial considerations; (iii) speed of construction; and (iv) environmental impact. While both proposals were thought to be financially viable, the monorail proposal sought no additional government funding or contribution for construction or operating costs. Monorail was thus selected despite no formal review or opportunity for public consultation. The various submissions of interest were never made public, nor was any Environmental Impact Study (EIS).[56] TNT was granted a 50 year concession until 2038. The monorail operated on a flat fare system, meaning the journeys to any station, regardless of distance was the same rate. The fare and ticketing systems were not integrated into the wider public transport system in Sydney. The system operated in a counter-clockwise loop of 3.6 km and 8 stations.

<u>Stage 2: Implementation of the Sydney Light Rail and Purchase of the Monorail</u>

5.3.2.5 In 1994, the Sydney Light Rail Company, a private entity, was awarded a 30-year concession to bring back street running rail services and operate a light rail system. The original terms of the concession agreement gave the existing Light Rail owner the first right to tender for the construction, operation and maintenance and repair of any extension to the Sydney Light Rail system. This line would connect the south edge of the CBD with Chinatown, the western edge of Darling Harbour, and Sydney's first legal casino – a distance of 3.6 km and 10 lines (which was part of the original light rail proposal put forth in the 1980s for the people mover system for Darling Harbour). It would also connect with Central Station, a major regional rail hub for areas south of Sydney.

[56] Dunn, John. Comeng: A History of Commonwealth Engineering, Volume 5: 1985-2012.

5.3.2.6 The Light Rail system was originally operated by TNT Transit Systems, also the owner of the Sydney Monorail. The Sydney Light Rail Company subsequently purchased the Sydney Monorail in 1998. The Sydney Light Rail Line and the Sydney Monorail had overlapping alignments along a portion of the western edge of Darling Harbour for about a quarter of the Monorail's one-way loop route. Although operating on a similar alignment, the services served different purposes (having co-existed for more than 15 years), with the light rail linking into the Central Station and its commuter rail lines, while the Monorail provided a one-way loop service that was more geared for tourists. A subsequent expansion in 2000 extended the Light Rail line by 3.6 km and 4 stops.

Stage 3: Government Purchase of Light Rail and Monorail Operator and Removal of Monorail

5.3.2.7 In 2012, the Government of New South Wales purchased the company now owning the Light Rail and Monorail (Metro Transport Sydney) in order to: (i) eliminate the need to negotiate with the owners over potential light rail expansion (as noted the original contract stipulated the owners had say over future expansions); (ii) spur further re-development of Darling Harbour including the Sydney International Convention, Exhibition, and Entertainment Precinct; and (iii) remove the Monorail to make room for new developments.

5.3.2.8 The Monorail was removed (and the Light Rail retained) due to the following reasons: (i) the Monorail occupied areas intended for further redevelopment of Darling Harbour; (ii) the Monorail was configured as a single, one-way loop which made for long journey times (with a complete loop taking up to 15 minutes); (iii) the Monorail did not link major trip generators in the area and was not well integrated with other public transport modes (furthermore the ticketing system was different than that used by other public transport systems in Sydney); and (iv) the Monorail was poorly used by local residents and workers and became more of a tourist attraction.[57, 58]

5.3.2.9 Following the purchase of the Light Rail, the NSW Government put out its vision to prioritise Light Rail through its Light Rail Future document described in the Sydney Light Rail Case Study and implemented a further expansion of the Sydney Light Rail including extension of the original line now known as the Inner West Rail Line and a new line running north-south to and through the CBD called the CBD and South East Rail Line (see the noted Sydney Light Rail case study for further information on why Light Rail was picked over BRT).

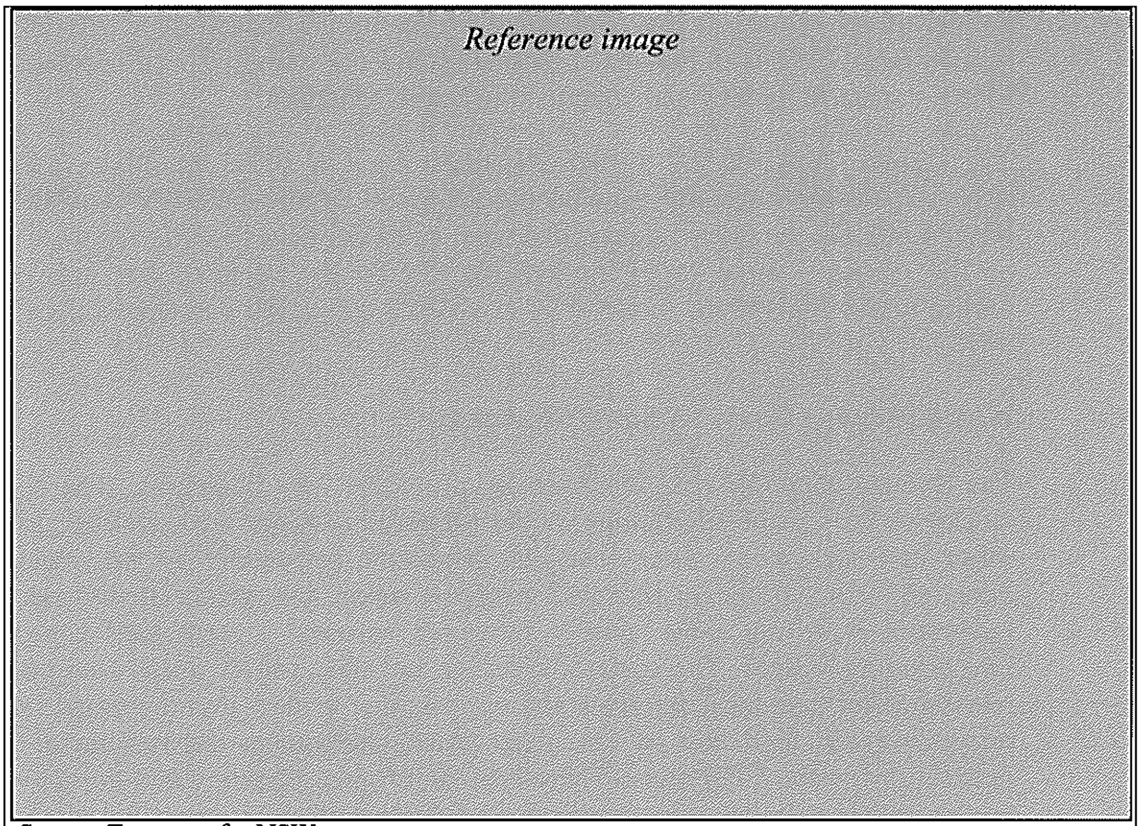
5.3.3 Sydney Monorail - System Characteristics

5.3.3.1 The system had the following characteristics:

- **System Description** – The system had 8 stations on a single 3.6km track in a counter clockwise fashion. The system therefore did not have the capability to provide bi-directional service. Normal operating speed between stations was 33 km/h.

57 http://www.transport.nsw.gov.au/sites/default/files/b2b/projects/Monorail_Heritage_Interpretation_Volume1.pdf
58 http://www.transport.nsw.gov.au/projects-completed/monorail-removal

- **Vehicles** – The system operated with six 32 m long, 7-car trains (manufactured by Von Roll). At any given time, up to four trains ran simultaneously, although the ultimate plan was for nine trains to run concurrently.[59] Typical capacity of the 7 car trains was 130 passengers, although this capacity could be increased to 170 passengers. Vehicles were supposed to be automated, although drivers were retained after breakdowns soon after opening.
- **Track** – The single track consisted of a steel box girder of 94 cm width on steel columns that were 20-40 m apart. The minimum radius on horizontal curves was 20 m and the maximum uphill gradient was 4.4%.[60] In order to increase adhesion between guideway and wheels, a track tape was applied to the steel beam. This track tape needed to be replaced regularly. No evacuation walkways were provided along the track.
- **Depot** – At the depot, a traverser moved trains in and out of service.



Source: Transport for NSW

Figure 5.3.8: Sydney Monorail - Trains Inside Depot (Left) and Traverser (Right)

5.3.4 Sydney Monorail - Service Characteristics

5.3.4.1 The system ran at 4 minutes headway, resulting in maximum capacity of 2,550 passengers per hour (although there were plans to provide 1.5 minute service with a fleet of nine trains, which would have given a maximum capacity of 6,800

[59] Jane's Urban Transport Systems 2002-2003.

[60] TNT Harbourlink: The Darling Harbour Monorail

passengers per hour).[61,62] The system operated from 5:00AM to midnight, seven days a week.

5.3.4.2 Stopping time at each station averaged 40 seconds, including the deceleration, dwell and acceleration times. A complete round trip time on the route took 12-15 minutes, which gives an average speed of 15-18 km/h.[63]

5.3.5 Sydney Monorail - Performance

5.3.5.1 The Sydney Monorail's alignment generated long travel times, sometimes nearly equivalent to walking if not worse. Combined with the high price and poor connectivity and integration with the CBD and the public transport system in Sydney, patronage levels were well below forecast volumes.

5.3.5.2 Shortly after opening, an April 1989 report found that patronage levels of 100,000-120,000 per week were insufficient to allow TNT, the operating and builder of the system, to make adequate returns on the cost of development.[64] A decade later, TNT was broken up and sold and the monorail was purchased by Metro Transport Sydney and renamed the Metro Monorail.

5.3.5.3 The system registered 2.7 million passenger trips in 2008. By 2011, fares had risen to AUD4.90 (at the time, about US$5.00 or the FY2015 equivalent of HK$30.60). On the last weekend of service in 2013, some 16,000 trips were taken on the system – some 210% higher than that on the weekend one year earlier during routine operations (equivalent to about 3,000-4,000 passengers per day in 2012).[65]

5.3.6 Key Findings from Sydney Monorail

5.3.6.1 The Sydney Monorail was controversial from the very beginning. The counter clockwise loop made trips long. As the Monorail was elevated, walking trips in some instances were faster than the Monorail (especially in the clockwise direction). As a privately operated transport mode, the Monorail was not well integrated with the other public transport systems – and had a separate fare/ticketing system. The system, although intended for all users, was used by tourists rather than local residents and workers due to slow journey times, lack of integration and high cost of the ticket. Also, the system did not serve major destinations in the CBD area. Therefore, the original planning and design of the system collectively led to low utilisation of the system and its eventual removal to make way for subsequent redevelopment of Darling Harbour.

[61] Jane's Urban Transport Systems 2002-2003
[62] TNT Harbourlink: The Darling Harbour Monorail
[63] TNT Harbourlink: The Darling Harbour Monorail
[64] http://www.transport.nsw.gov.au/sites/default/files/b2b/projects/Monorail_Heritage_Interpretation_Volume1.pdf
[65] http://www.citylab.com/commute/2013/07/sydneys-sad-monorail-only-became-popular-it-was-shutting-down-good/6147/

5.4 Osaka Monorail

5.4.1 Osaka Monorail - System Description

5.4.1.1 Osaka Monorail is an elevated 28 km long, bifurcated double track railway, which has a main line that serves Osaka's Itami International Airport and a branch line (the Saito Line). The system contains 18 stations.[66] The Osaka Monorail plays an important connector role communities in the northern ring of Osaka, several branch campuses of the University of Osaka, and the airport. It complements the extensive publically operated Japan Railways and privately operated subway network.

5.4.2 Osaka Monorail - Planning Background[67]

5.4.2.1 After World War II, Osaka's metropolitan rail and road networks had been developed in a radial manner – focusing on serving trips into and out of Osaka's central areas. This resulted in an excessive concentration of capacity in these key corridors, but less focus on trips on the perimeter of the city that did not need to enter the city centre. Suburban areas on the outskirts of the city had grown quickly and required public transport systems to accommodate their mobility needs.

Reference image

http://www.osaka-monorail.co.jp/eng/route/

Figure 5.4.9: Route Map of Osaka Monorail

[66] Jane's Urban Transport Systems 2015-2016

[67] http://www.osaka-monorail.co.jp/jpn/company/co07.html

5.4.2.2 Based on a 1971 study, an alternate rail corridor was proposed to link to the existing dense railway network and serve these outer regions. Based on a multi-faceted investigation, monorail technology was chosen for this corridor due to existing traffic congestion and land use issues, as well as the projected financial feasibility of the system.

5.4.2.3 The Osaka Monorail opened in June 1990 with 5 stations. The railway was then expanded as follows:

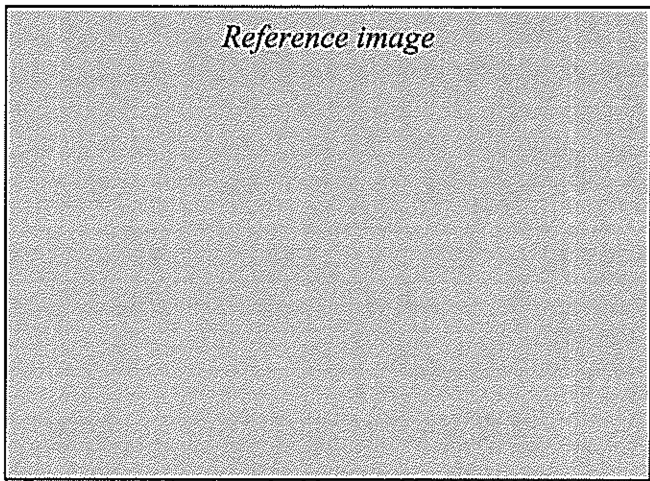
- 2 stations added in September 1994
- 2 stations (including Osaka airport) added in April 1997
- 5 stations added in August 1997
- Branch line (Saito Line) with 2 stations added in October 1998
- 2 stations on the Saito Line added in March 2007

5.4.2.4 In July 2015, a planned 9 km extension, including four stations, was announced. The cost estimate for the extension is JPY150 billion (or HK$9.42 billion). The line currently operates as both an urban rail line as well as an airport connector service.

5.4.3 Osaka Monorail - System Characteristics

5.4.3.1 The line is an elevated double track railway, 28 km long in total. The line is bifurcated with a 21.2 km long main line with 14 stations and a 6.8 km long branch line with four additional stations. The monorail system has no evacuation walkways.

5.4.3.2 The maximum speed on the line is 75 km/h. Minimum horizontal radius is 100 m. Maximum gradient is 6.0%.[68] Hitachi/Kawasaki Type 1000 and Type 2000 4-car trains are used on the system.[69]



Source: http://pazhayathu.blogspot.hk/2009/11/1924-single-railmonorail-railway-at.html

Figure 5.4.10: Osaka Monorail

5.4.3.3 Train operation is with driver, CAP-signalling and Automated Train Protection (ATP). The rolling stock is 21 trainsets (4-car) of Hitachi/Kawasaki Type 1000 and Type 2000 (capacity for 410 passengers)

5.4.4 Osaka Monorail - Service Characteristics

5.4.4.1 The system is designed for 3 minute headways with 6-car trains. It is currently operated with 6 minute, 40 second headways during the peak hour – this equates

[68] Akira Nehashi, New Types of Guided Transport, Japan Railway & Transport Review 26, February 2001
[69] Jane's Urban Transport Systems 2015-2016

to a capacity of about 4,000 pphpd (assuming the Type 2000 rains). If the desired 3 minute headways are provided, capacity could reach up to 8,000 pphpd. During the off-peak, the system operates with 10 minute headways on the main line and 20 minutes on the Saito Line.

5.4.4.2 The system operates from 5:30AM to midnight seven days a week. Average speed is 35 km/h on the main line and 37 km/h on the branch line.[70] Fares are JPY100 (or HK$6.28) for the first 2 km and increases for every additional 2 km up to a maximum of JPY550 (or HK$34.55).[71]

5.4.5 Osaka Monorail – Performance[72, 73,74]

5.4.5.1 In 2014, annual ridership reached 39.4 million, resulting in total fare revenues of almost JPY8.94 billion yen (or the FY2015 equivalent of HK$1.43 billion), with daily ridership averaging 108,000 passengers per day. In 2015, the daily ridership over the year was between 110,000 and 140,000 passengers per day - averaging 122,000 passengers per day.

5.4.5.2 Based on the latest income statement from 2015 on the Osaka Monorail site, fare revenues totalled some JPY10.6 billion versus operating costs of JPY6.3 billion. Therefore, the Osaka Monorail was able to recoup all operating costs with a farebox recovery rate of nearly 170%.

5.4.6 Key Findings from Osaka Monorail

5.4.6.1 The Osaka Monorail was built to serve a moderate density corridor connecting northern perimeter areas of the city, in areas outside of the traditional heavy rail corridors that operated radially into and out of the city. Although it serves Itami Airport (the smaller of the two major airports serving Osaka and the Kansai area), the Osaka Monorail plays a vital role as a low-moderate capacity urban rail system providing fast and reliable service that are not impacted by the dense urban congestion and conditions that characterise Osaka. The Osaka Monorail can accommodate loads of up to 4,000 pphpd (with ultimate capacity of 8,000 pphpd if 3 minute headways are adopted). The system is well used with an average daily ridership of 122,000, with plans to further extend the 25 year old system by 9 km.

[70] http://www.osaka-monorail.co.jp/eng/time/index.html
[71] http://www.osaka-monorail.co.jp/eng/fares/f01_normal_fare.html
[72] Monorails in Japan – Publictransit.us special report No 9
[73] http://www.osaka-monorail.co.jp/jpn/company/co_pop_unyu01.html
[74] http://www.osaka-monorail.co.jp/jpn/company/pdf/PL_2015.pdf

5.5 Okinawa Monorail

5.5.1 Okinawa Monorail - System Description

5.5.1.1 The Okinawa Monorail is the only rail system operating in Okinawa, located in Naha City. The Okinawa Monorail is known as Yui Rail (Okinawa Urban Monorail) and is a 12.9 km system serving 15 stations. The monorail was opened in August 2003, with the purpose of connecting Naha Airport to the rest of the city and providing a means of public transportation besides the often inefficient bus system.[75]

5.5.2 Okinawa Monorail - Planning Background

5.5.2.1 Okinawa Island, Japan's fifth largest island, once had a small railway network serving the southern portion of the island, extending north, east and south from Naha. This was built from 1914 under prefectural sponsorship. Two rural horse tramway lines were built by private companies. Naha had a short (6.9-km (4.3-mi)) electric town tramway line to Shuri, the island's ancient capital, from 1914. Typhoon damage caused the tram line to cease operations in 1933, but the rail lines continued operating until 1944, when they were caught in the middle of one of the deadliest campaigns of World War II. After the fighting was over, U.S. military forces were in control and quickly built wide paved roads, some on the former rail alignments. The U.S. returned Okinawa Prefecture to Japan in 1972. By this time, peak-hour road congestion along Naha's main street, Kokusai-dôri, and other major roads was growing to levels that required improved public transport. Studies began not long thereafter for a public transport solution.

5.5.2.2 Among various modes considered, monorail technology was eventually selected because ground-level alignment and space for a conventional railway was not available, and traffic levels were insufficient to justify the expenditure required for a metro.[76] In addition, monorail's tight turning radii and narrow crosshead profile mean would allow monorail to better fit within the dense urban corridors in Naha (see figure below).[77]

[75] http://www.okinawa-information.com/transport/naha_yui_monorail_japan.htm
[76] http://www.publictransit.us/ptlibrary/specialreports/sr9.JapanMonorails.pdf
[77] http://www.monorails.org/webpix%202/RyanRKennedy.pdf

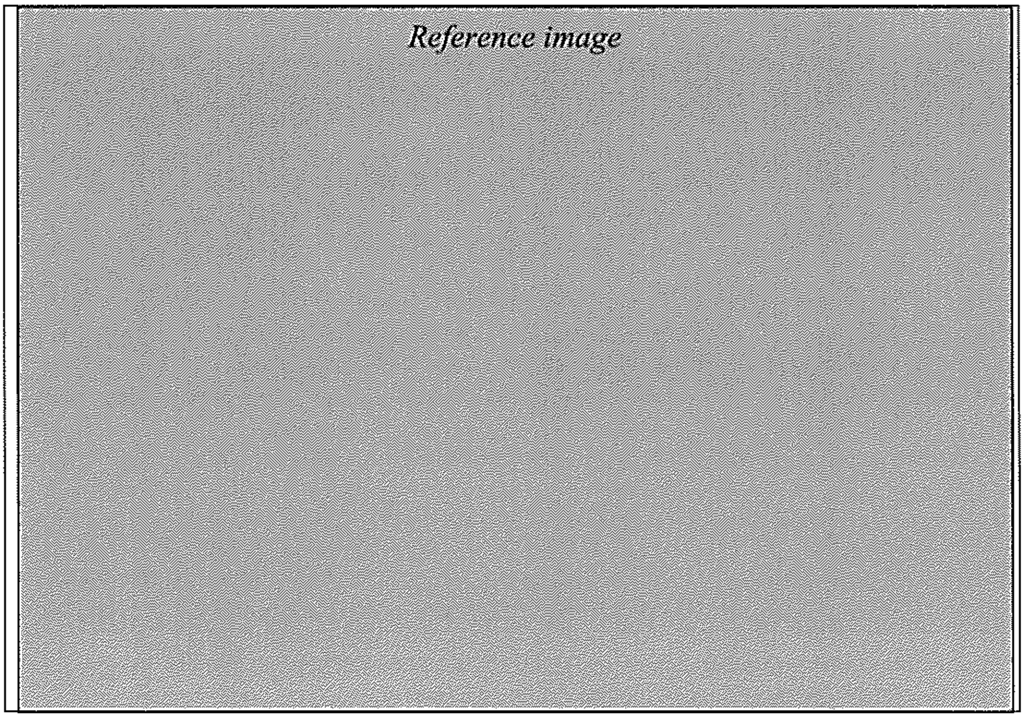
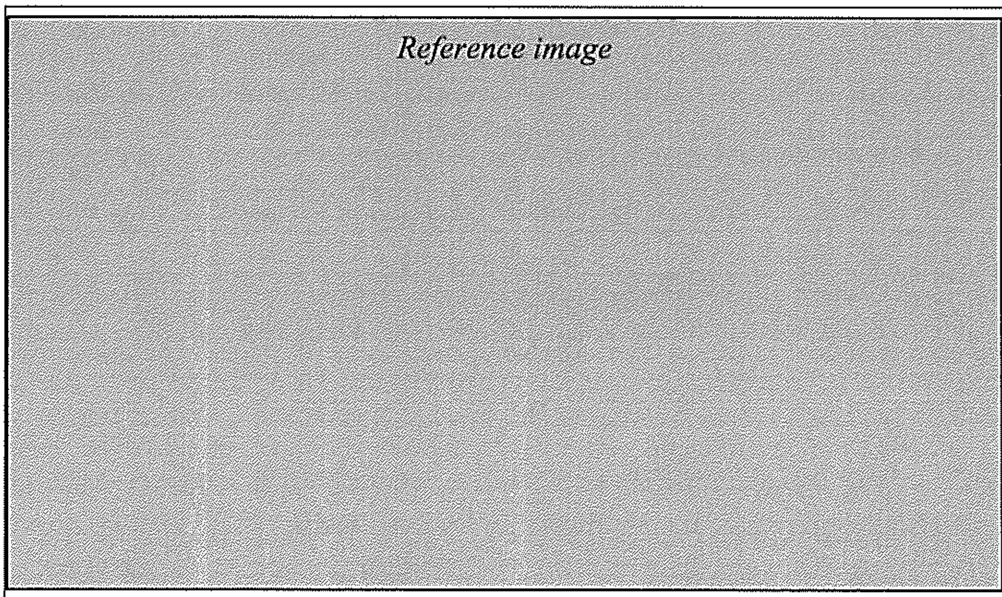


Figure 5.5.11: Alignment of the Okinawa System through Naha City

5.5.3 Okinawa Monorail - System Characteristics

5.5.3.1 The current length of the Yui Rail is 12.8 km, starting at Naha Airport and ending at Shuri Castle Station with a total of 15 stations (approximately 27 minutes one-way journey time). It runs through the city centre, meeting the Kokusaidori twice at Asahibashi Station and Makishi Station. Asahibashi Station is also close to the Naha Bus Terminal.[78] In 2012, a 4.1-kilometer extension was approved. The line will be extended from Shuri Station at the northeastern end of the line, with a completion year of 2019.[79]

[78] http://www.japan-guide.com/e/e7118.html
[79] http://www.japanupdate.com/2015/05/light-railroads-have-long-history-on-okinawa/



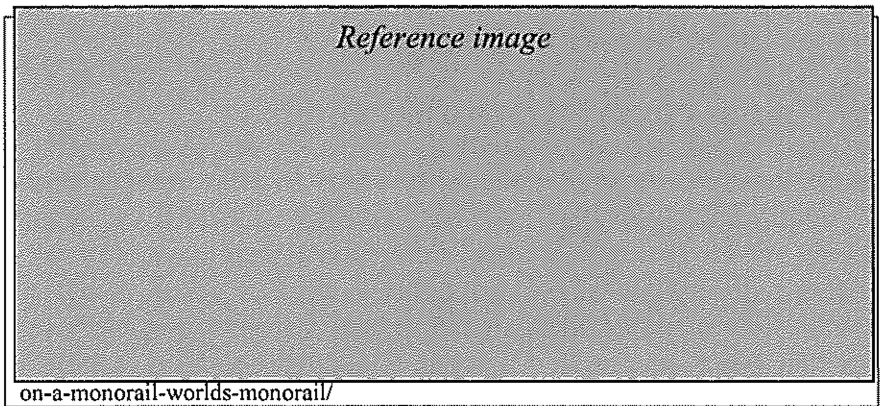
Source:http://web.travel.rakuten.co.jp/HOTEL/136129/136129map_e.gif?TB_iframe=true&height=450&f_width=570px&f_height=350px&width=600

Figure 5.5.12: Okinawa Monorail – System Map and Layout

5.5.3.2 Built from 1996 to 2003, the initial capital cost for the 12.8 km Yui Rail was US$1.1 billion or about US$85 million per km – equivalent to FY2015 HK$21.5 billion for the project or HK$1.68 billion per km.[80] The extension is projected at US$350 million (or HK$2.71 billion) for 4.0 km, which is HK$677 million per km.

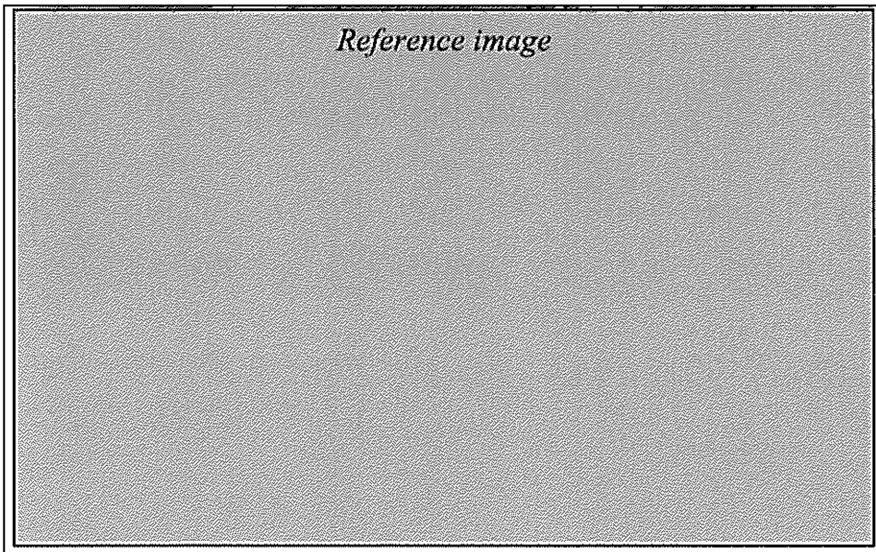
5.5.3.3 Rolling stock consists of Hitachi Series 1000 Monorail with a maximum service speed of 60 km/h.[81] Each train consists of two cars, each 2.98 m wide, and 14 m long.[82] The trains have 65 seats and a total capacity of 165 passengers (seated plus standing passengers at 7 persons per square meter). The trains have drivers and are provided with Automated Train Protection.[83]

[80] https://pedestrianobservations.wordpress.com/2013/08/24/monorail-construction-costs/
[81] http://www.hitachi-rail.com/delivery/monorail/monorail/
[82] http://trainspo.com/model/3423/
[83] New Transit Systems and Urban Monorails in Japan, Japanese Railway Engineering No 171, 2011 publictransit.us Special Report No. 9



on-a-monorail-worlds-monorail/

Figure 5.5.13: Okinawa Monorail Train (Yui Rail)



Source: http://www.samsungcntblog.com/2015/06/world-architectures-have-you-been-on-a-monorail-worlds-monorail/

Figure 5.5.14: Okinawa Monorail Train Interior (Yui Rail)

5.5.4 Okinawa Monorail - Service Characteristics[84]

5.5.4.1 Service hours are from 6:00AM-11:30PM. During peak hours (8:00AM-9:00AM), the system operates with 5.0 minute headways, giving a maximum capacity for the system at 2,000 pphpd. During off peak periods, the headway is 10 minutes. Average speed is 28 km/h.

5.5.5 Okinawa Monorail – Performance[85,86]

5.5.5.1 [redacted] The most recent published financial statement on the Yui Rail website is for FY2012 – in which operating revenue amounted to JPY2.7 billion, while operating and maintenance costs amounted to

[84] http://www.naha-airport.co.jp/en/access/monorail.html
[85] Email: Ustream live@yui-rail.co.jp, May 6, 2016.
[86] http://www.yui-rail.co.jp/company/pdf/h24_accountsbook.pdf

JPY3.1 billion. Thus farebox recovery in 2012 was about 87% - with the shortfall covered by subsidies from the government.

5.5.6 Key Findings from Okinawa Monorail

5.5.6.1 The Okinawa Monorail or Yui Rail was built in 2003 to serve as the island's sole rail-based public transport system to provide enhanced connectivity to Naha's Airport, as tourism and visitors comprise a significant part of the economy. However, this system also plays a role to provide connectivity and mobility for urban residents and is Naha's main public transport cog. Service has expanded such that trains operate at 5 minute frequencies and can handle low peak hour capacity of about 2,000 pphpd. Demand has grown over the past decade and the system now fully recovers all operating costs through farebox revenue alone.

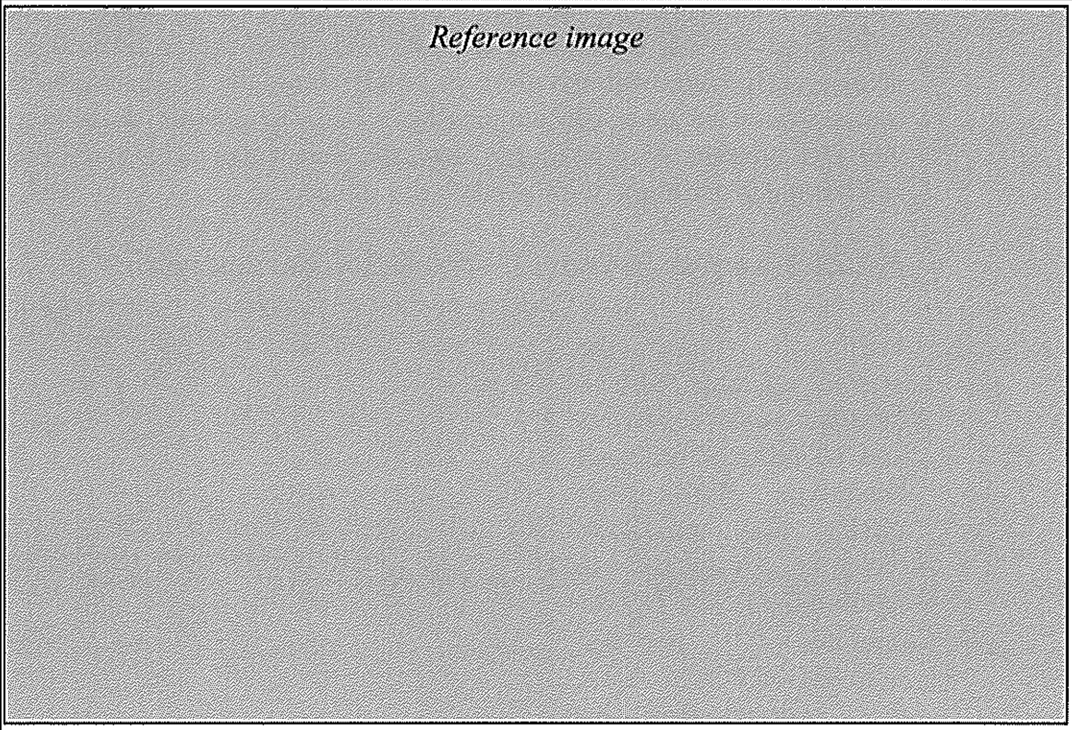
5.6 Kuala Lumpur Monorail

5.6.1 Kuala Lumpur Monorail - System Description

5.6.1.1 Kuala Lumpur Monorail is an 8.6 km long line with 11 stations, running from Sentral Station to Titiwangsa, passing major hotels in the city and serving the central the central shopping district (the Golden Triangle).[87] It is part of a multimodal system serving Malaysia's capital, with 7.3 million people in its metropolitan region, which includes two elevated Light Metro systems, extensive commuter rail services, as well as most recently BRT.

5.6.2 Kuala Lumpur Monorail - Planning Background

5.6.2.1 The Kuala Lumpur Monorail (or KL Monorail) was conceptualized in the 1980s. Construction started 1997 and the Monorail opened in August 2003, with 11 stations running 8.6 km on two parallel elevated tracks. The original concept was as a downtown circulator to link 90% of the hotels and shopping centres in the Central Area and as a distributor between other transit systems. The design length was originally 16 km but only 8.6 km was built.



Source: http://www.kuala-lumpur.ws/transportation/kl-monorail.htm#

Figure 5.6.15: Route Map for Kuala Lumpur Monorail

5.6.2.2 The operator has a 40 year concession, signed December 2000. The opening of the system was delayed due to financial and technical problems. Due to financial problems, Syarikat Prasarana Negara Berhad (SPNB), a state-owned national infrastructure company, has taken over the ownership of the monorail, and SPNB's subsidiary KL StarRail Sdn Bhd operates the system.

[87] Jane's Urban Transport Systems 2015-2016

5.6.2.3 According to the Greater KL/Klang Valley Land Public Transport Master Plan, a subsequent extension of the monorail has been proposed to connect Tun Sambathan with Taman Gembira (Phase 1). Phase 2 would include a further extension. This project would provide congestion relief to the LRT lines. The future length of the KL Monorail network will be 16 km with 20 stations. The completion year is estimated in 2020.

5.6.3 Kuala Lumpur Monorail - System Characteristics

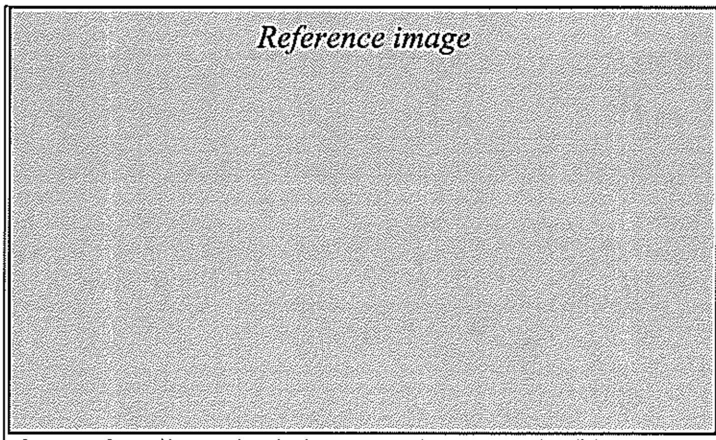
5.6.3.1 The line is an 8.6 km long double tracked pinched loop (a double track railway with two terminus stations), with a total of 11 stations, all provided with side platforms. However, the two terminus stations (KL Sentral and Tittiwangsa) only have single tracks. The trains are capable of operating with a horizontal radius of 50 m, vertical radius of 500 m, and up to 6.0% gradient. Design speed for the trains is 90 km/h. The maximum speed is 55 km/h. The trains are provided with ATP (Automated Train Protection). The system runs on 750V DC power.

5.6.3.2 The system has one depot and five substations. There are no evacuation walkways on the viaducts.

5.6.3.3 The monorail originally operated with twelve 2-car trains manufactured by Scomi (20m long and 3m wide, with 48 seats and space to accommodate 196 standing passengers). Some stations were originally built for longer trains than the 2-car trains. Platforms on seven stations have been lengthened to allow for operation with 4-car trains, 45.4 m long. Currently, new 4 car trains have been introduced and the old 2-car trains will be taken out of service.

5.6.4 Kuala Lumpur Monorail - Service Characteristics

5.6.4.1 With 12 trains, the system operates with 4 minutes peak headways and 10 minutes off-peak headways. With 2-car trains, the maximum passenger capacity is 3,600 pphpd. The system operates between 6:00AM-12:00AM each day. Average speed on the system is 30 km/h.[88]



Source: http://www.kuala-lumpur.ws/transportation/kl-monorail.htm#

Figure 5.6.16: Kuala Lumpur Monorail

[88] Jane's Urban Transport Systems 2015-2016

5.6.5 Kuala Lumpur Monorail – Performance

5.6.5.1 The monorail was completed at a total cost of MYR1.18 billion (FY2003) by the KL Infrastructure Group (KL Infra).[89] This is equivalent to FY2015 HK$3.2 billion. Annual ridership is about 25.0 million, with daily ridership at about 69,000 (as of 2015).[90] The system operates near its capacity of 3,600 pphpd.

5.6.5.2 For reference, daily ridership and annual revenues for the monorail are as follows from FY2003-2012. No cost information has been made publically available.

Table 5.6.4: Average Daily Ridership – Kuala Lumpur Monorail

Year	Passengers per Day	Annual Revenue MYR (million)
2003	32,000	4.5
2004	30,000	17.4
2005	40,000	23.0
2006	48,000	27.4
2007	55,000	32.5
2008	60,000	35.6
2009	58,000	33.9
2010	61,000	35.6
2011	66,000	37.2
2012	67,000	37.2

Source: Consumer Satisfaction of Public Transport Monorail User in Kuala Lumpur (Amsori Muhammed Das, et al, 2013).

5.6.5.3 Revenues have not covered the costs. For example in 2004, the loss amounted to MYR46.2 million (or the FY2015 equivalent of HK$124.17 million). A detailed breakdown of revenues and costs is shown for the three month period between May and July 2005 is shown below.

[89] Consumer Satisfaction of Public Transport Monorail User in Kuala Lumpur (Amsori Muhammed Das, et al, 2013)
[90] http://www.mot.gov.my/en/Statistik%20Rel/2015%204%20-%20SUKU%20IV%202015/JADUAL%202.9.pdf

Table 5.6.5: Breakdown of Revenues and Costs – Kuala Lumpur Monorail (May-July 2005)

Revenues	**MYR (thousand)**
Monorail Operations	5,796
Advertising	3,539
Property rental	50
Sum Revenues	9,385
Results	**MYR (thousand)**
Monorail operation	2,652
Advertising	2,063
Property rental	4
Holding company and others	-41
Operating profit before depreciation and interest expense	4,678
Depreciation	-2,587
Interest expense	-20,962
Loss before taxation	-18,871
Taxation	0
Loss after taxation	-18,871

Source: Notes to the Financial Report for the First Financial Quarter ended 31 July 2005; bankrupt.com/misc/KLInfrastructureNotesQ12006.doc

5.6.5.4 According to a study by the Institute for Transportation and Development Policy (ITDP), the system has had to rely heavily open operating subsidies due to the Kuala Lumpur Monorail's cost structure (high interest repayment and depreciation costs) and limited capacity.[91] Purportedly, the system's first 8 months of operations, operational debts of RM 46.24 million (US$ 13.6 million) were accumulated.

5.6.5.5 The ITDP Study further notes that in May 2007, the Kuala Lumpur monorail system went into receivership after KLIG failed to repay a loan to a Malaysian bank. Subsequently in 2007, Syarikat Prasarana Negara Berhad (SPNB), a state-owned national infrastructure company that also owns and operates two other nearby urban rail lines, took over the Kuala Lumpur Monorail and its subsidiary, KL StarRail Sdn Bhd operates the system. This arrangement persists today.

5.6.6 Key Findings from Kuala Lumpur Monorail

5.6.6.1 The Kuala Lumpur Monorail is a low-moderate capacity monorail operating as an urban distributor to connect the major urban transport hub with the Golden Triangle Shopping Area. It also serves as a connector role to other major transport systems in the area including the two Light Metro lines, regional commuter service, as well as the Airport Express Line. It serves a daily ridership of about 69,000 passengers per day and operates near its capacity of 3,600 pphpd.

5.6.6.2 It is noted that the Kuala Lumpur Monorail was unable to achieve financial sustainability as operating costs outweighed operating revenues soon even after

[91] Source: https://www.itdp.org/special-report-monorails-back-to-the-future/

opening. Studies concluded that this was likely due to how the cost structure, which resulted in high depreciation and interest costs, but also relatively low fare revenues due to limited capacity of the system.

5.6.6.3 Compared to other Monorail systems operating within dense urban areas, the Kuala Lumpur Monorail's capacity of 3,600 pphpd is fairly low, which limits the potential trip capture during peak periods. Although there are transfer opportunities at 5 of the 11 stations, the transfers are sometimes inconvenient including multiple vertical transfers and walks of up to 250m (for instance at KL Sentral). This discourages riders and transfers between lines. Thus two key issues to consider are the peak capacity and loading to accommodate, as well as the transfer experience with other rail lines.

5.7 Chongqing Monorail

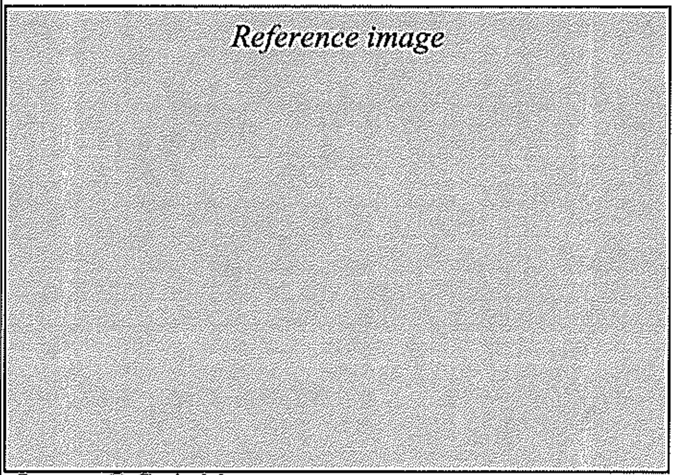
5.7.1 Chongqing Monorail - System Description

5.7.1.1 Chongqing Monorail has two lines, currently with a total length of 100.6 km long and comprising 70 stations. The two lines have a common interchange station (Niujiaotuo) and four interchange stations with the metro.[92]

5.7.2 Chongqing Monorail - Planning Background

5.7.2.1 Chongqing City (7.46 million inhabitants in the urban area and some 32 million people in the metropolitan area) is characterised by a hilly topography, which has led to a highly dispersed development pattern among its 12 urban districts. As a result of rapid economic development (as high as 15% per year), traffic situation in the city had become serious with 95% of residents relying on public transport, principally on urban buses (with 80% of service concentrated in central areas). This concentration of public buses on urban roads combined with the topography of Chongqing resulted 70% of main roads in the central city suffering from constant traffic congestion. This resulted in significant air pollution and health problems.[93] Monorail was thus considered the most appropriate mode on the eventual Line 2 given topography conditions in Chongqing as well as monorail's ability to operate on tight bends and generate a low noise profile.

5.7.2.2 The Chongqing Rail Transit (Group) Co Ltd was established in 1992 to oversee the building of its first monorail line (Line 2), which started in March 2001. Planned construction was slated to take only 41 months (until July 2004). However, Line 2 opened in June 2005, even though all installation works was not finished until December 2005 (a total period of 58 months, 41% longer than planned). The construction project exceeded the budget with 4%, mainly due to fluctuations of exchange rates.



Source: @ Craig Moore

Figure 5.7.17: Chongqing Monorail Line 2

5.7.2.3 The second line (Line 3) opened in September 2011. Currently, the Monorail system contains two lines with a total length of 86 km double track, which makes it the largest monorail system in the world. A 10 km long extension to Line 3 is under construction. Overall, Chongqing has an integrated system of two monorail

[92] Jane's Urban Transport Systems 2015-2016

[93] Kenichi Inazawa, Ex-Post Evaluation of Japanese Loan Project – Chongqing Urban Railway Construction Project, 2009.

lines (Lines 2 and 3) and two heavy rail metro lines (Lines 1 and 6) as of 2016, with four additional lines under construction.

5.7.3 Chongqing Monorail - System Characteristics

5.7.3.1 The length of line and number of stations of the monorail system are listed as shown in the table below.

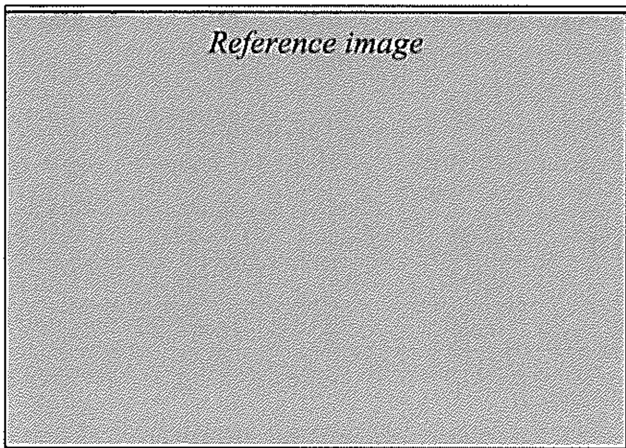
Table 5.7.6: Operating Characteristics by Line – Chongqing Monorail

Line	Planned Length	Planned # of Stations	# of Trains	# of Depots
Line 2	37.2 km	28	162	2
Line 3	63.4 km	42	348	2

Source:
Stations: 大渝網, retrieved from http://cq.qq.com/zt2011/cqqg/
Trains: 重慶跨坐式單軌列車的維護與管理, retrieved from http://www.cqima.com/upload/files/2015/7/2115834875.ppt
Depots: 重慶跨坐式單軌列車的維護與管理, retrieved from http://www.cqima.com/upload/files/2015/7/2115834875.ppt

5.7.4 Infrastructure and System Requirements

5.7.4.1 Line 2 is a 37 km long double tracked pinched loop (a double track railway with two terminus stations), with a total of 28 stations. The line runs both elevated and in tunnel (2.2 km, including three stations). Line 3 is a 55.5 km long double tracked pinched loop with 39 stations. Line 3, but not the older Line 2, is provided with evacuation walkways on the viaducts.



Source: Japan International Cooperation Agency (JICA)

Figure 5.7.18: Depot Adjacent to Dayancun Station

5.7.4.2 Minimum horizontal radius is 100 m on the main lines and 50 m in the depot. Maximum gradient is 5.0%.[94]

5.7.4.3 The Chongqing Monorail operates mainly with 4-car trains manufactured by Hitachi or Changchun Railway Vehicles Co (under license of Hitachi). In September 2012, 6-car trains started to be used, and nowadays, on Line 3 some trains are of 8-car consist (with a capacity of 1,800 passengers). The trains are provided with an on-board signal system and ATP (Automated Train Protection).

[94] Taketoshi Sekatini et al., China's First Monorail System in Chongqing, Hitachi Review Vol 54 (2005), No 4

5.7.5 Chongqing Monorail - Service Characteristics

5.7.5.1 The system operates daily between 7:00AM and 10:00PM. Peak headways can reach as low as 2.5 minutes. This is equivalent to 43,200 pphpd with the current train set. The average speed on the system is 30 km/h.

5.7.5.2 Initially, the fares were 2-5 CNY for a one-way ticket, depending on the length of the journey, and the average fare paid by the passengers was 2.7 CNY. Surveys indicated that the respondents thought the fare level was reasonable.[95]

5.7.6 Chongqing Monorail – Performance

5.7.6.1 For Line 2, the average construction cost (FY2005) was CNY230 million per km or the FY2015 equivalent of HK$297 million per km. Construction cost (FY2005) for an elevated station was CNY20 million (or FY2015 HK$25.0 million), while the cost for an underground station was CNY100 million (or FY2015 HK$125.0 million). The first 39.1 km and 29 stations of Line 3 cost CNY13.8 billion (FY2011) – this is equivalent to FY2015 HK$19.5 billion.

5.7.6.2 Line 2 performance from 2005 to 2008 is shown in **Table 5.7.7**:

Table 5.7.7: Performance Details – Chongqing Monorail Line 2

Year	Fare Revenues (Million CNY)	Passenger km (Million)	Car-km (Million km)
2005 (June-December)	29.2	73.1	11.2
2006	47.4	151.9	21.5
2007	69.4	223.6	27.7
2008	77.2	256.8	28.3

Source: Kenichi Inazawa, Ex-post Evaluation of Japanese Loan Project – Chongqing Urban Railway Construction Project, 2009.

Note: Car-km is the total number of km travelled by all trains in the system.

5.7.6.3 Results were lower than expected, likely due to overestimation, as well as the fact Line 3 represents China's first monorail project. For an evaluation in 2008, the monorail accounted for 2.2% of all daily trips in Chongqing, compared to forecasts of 4.9% for 2005 and 7.0% for 2010, respectively.

5.7.6.4 O&M costs for Line 2 between 2005-08 are as follows:

Table 5.7.8: Cost Breakdown – Chongqing Monorail Line 2 (Million CNY)

Year	Operation Costs	Maintenance Costs	Total
2005 (June-December)	36.0	2.0	38.0
2006	60.0	9.0	70.0
2007	86.0	14.0	100.0
2008	120.0	37.0	146.0

Source: Kenichi Inazawa, Ex-post Evaluation of Japanese Loan Project – Chongqing Urban Railway Construction Project,

[95] Kenichi Inazawa, Ex-post Evaluation of Japanese Loan Project – Chongqing Urban Railway Construction Project, 2009.

2009.

5.7.6.5 The maintenance costs have risen quickly since warranties for rolling stock and infrastructure expired. According to Kenichi Inazawa, Line 2 has an FIRR of 3.3% (originally estimated 4.2%). Another source from 2006 states that O&M costs amount to CNY45-48 million per month, while revenues are CNY42 million per month.[96] More updated financial performance data is unavailable.

5.7.6.6 Since the evaluations in 2006 and 2010, patronage has increased substantially. The number of passengers (for both Lines 2 and 3) amounted to 140 million in 2009.[97] Statistics from 2014 indicate that for Line 2, daily passenger flow is about 234,000, with a peak hour flow about 15,000.[98] For Line 3, the daily passenger flow is about 683,000, with a peak hour flow is 32,000. The utilization of the existing monorail system comprises 60% of all rail-based trips in Chongqing.

5.7.7 Key Findings from Chongqing Monorail

5.7.7.1 Chongqing's Lines 2 and 3 represent the most extensive and well utilised monorail system in the world. Lines 2 and 3 are both considered high capacity monorail lines and can accommodate capacities on-par with moderate capacity heavy rail systems (at around 40,000 pphpd). Lines 2 and 3 serve as part of the core urban rail network, accounting for 60% of all rail trips per day. Line 3 has recently been extended as well. Chongqing's unique hill topography, monorail's ability to operate on tight curves with a low noise profile, and its congested urban roads were the reason for selecting monorail as the mode of choice for Lines 2 and 3.

[96] Construction and Operation of Chongqing Monorail System, 2006, retrieved from http://www.doc88.com/p-1178556762855.html
[97] Jane's Urban Transport Systems 2015-2016
[98] http://cq.cri.cn/115/2014/11/21/5s720.htm

5.8 Daegu Monorail

5.8.1 Daegu Monorail - System Description

5.8.1.1 The Daegu Monorail started operation in April 2015 as Line 3 of the Daegu Metro. Line 3 is about 24 km long and has 30 stations, including two interchange stations with the other two metro lines.[99] Line 3 is elevated and fully grade separated.

5.8.2 Daegu Monorail - Planning Background

5.8.2.1 Daegu is South Korea's fourth largest city after Seoul, Busan and Incheon – located in southeastern Korea, with a metropolitan population of about 2.5 million. Two heavy rail metro lines (Lines 1 and 2), with a total length of 57.3 km, were opened in 2005 operating in the east-west direction to ease road traffic congestion.

5.8.2.2 In 2006, the Mayor of Daegu, Mayor Cho, proposed an elevated light rail system in the north-south direction. Priority was placed on implementing a system that would be cheaper to build and operate than the existing two metro lines.[100] When comparing alternatives, monorail technology was selected for Line 3 over another metro line for the following reasons:[101]

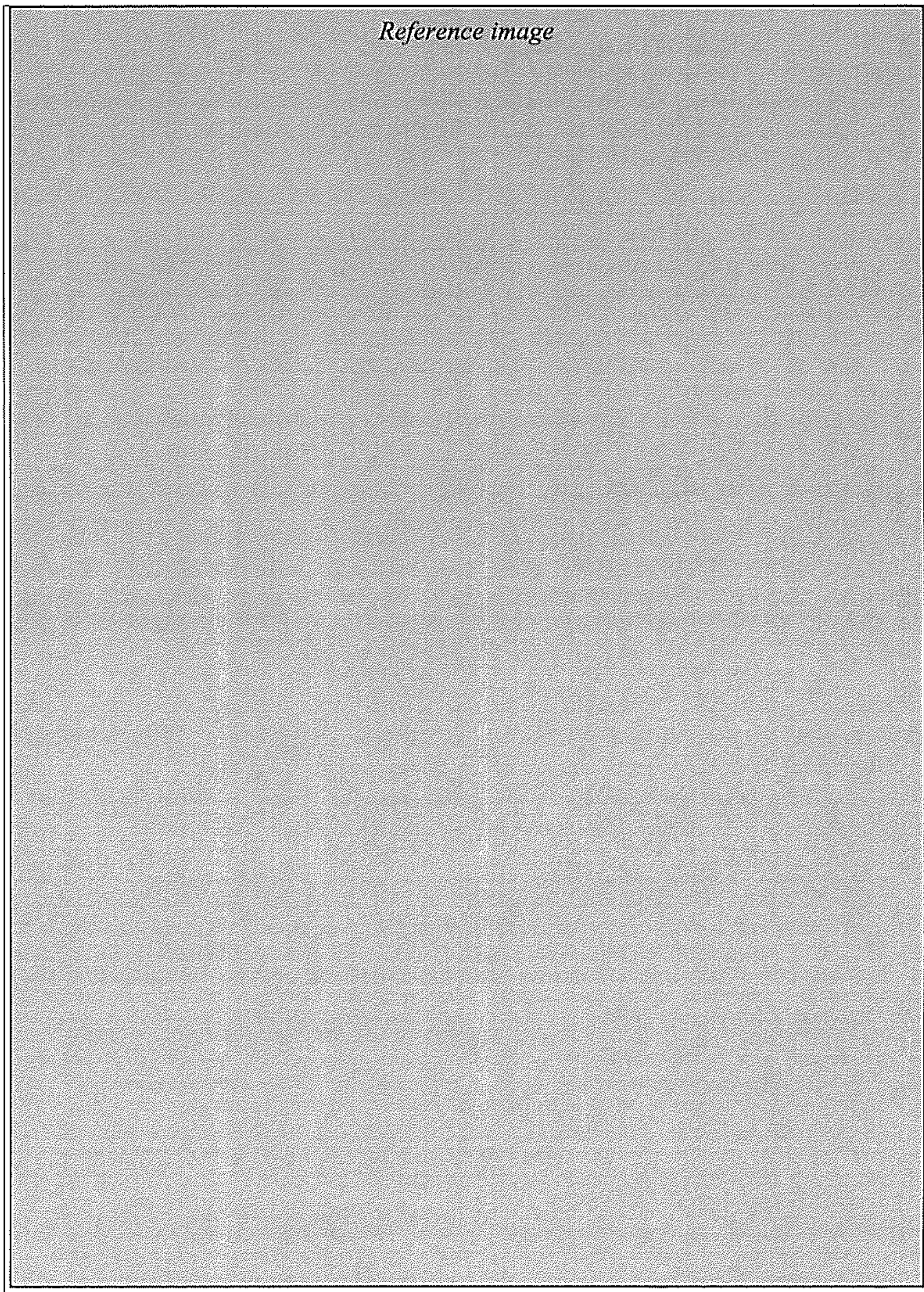
- **Lower Construction Costs** - The construction cost for a monorail was estimated to be much lower than that for a traditional subway system.[102] A monorail system would be 22-31% less expensive than any other alternative rail transit in terms of construction cost.[103]
- **Topography and Urban Conditions** – Monorail would be able to handle steeper grades (min 6%) and smaller turning radii (minimum 60 m) compared to heavy rail, thus making monorail more flexible and suitable for a hilly city like Daegu.[104]
- **Environmental Implications** – Monorail would generate fewer impacts in terms of noise, emissions, and vibration compared to other rail based modes and would have a thinner guideway that would be less visually intrusive.[105]
- **Road and Land Implications** - The elevated rail track would minimise interruption to road traffic and saved land resources.
- **Existing Precedent in Chongqing** - Implementation of the Chongqing Monorail was instructive to Daegu as both cities share common topographic conditions.[106] The local design institutes, which were

[99] Jane's Urban Transport Systems 2015-2016
[100] *"Daegu Plans to Introduce a Magnetic Levitation Train"*, 2006, http://english.daegu.go.kr/cms/cms.asp?Menu=522&Category=0&Action=view&Current=0&BoardId=7975
[101] Email Se-haw Jeon, Daegu Metro, April 14, 2016.
[102] *"Urban Railway Development Policy in Korea"*, Page 28
[103] CDM – Executive Board, June 2012, *"Project Design Document – Daegu Metro 3rd Urban Railroad"*, Page 15
[104] Advantages, http://www.hitachi-rail.com/products/rolling_stock/monorail/feature02.html
[105] Advantages, http://www.hitachi-rail.com/products/rolling_stock/monorail/feature02.html
[106] Chongqing Evening Paper, 2014, *"2 minutes and 10seconds, Shortest Headway for Metro Line 3"*, [Chinese]

responsible for the monorail lines in Chongqing, also participated in design work of Monorail Line 3.

5.8.2.3 Construction of the Daegu Line 3 took nearly 8 years, with construction starting on June 30, 2009, with the first day of operation on April 23, 2015. Total cost was about 1.43 trillion won.[107]

[107] http://kojects.com/2012/02/21/daegus-third-line-to-be-monorail/



Source: DTRO Website – Line Map, http://www.dtro.or.kr/open_content/en/user_guide/line_map/

Figure 5.8.19: Daegu Metro System Network Map (Yellow Line for Monorail)

5.8.3 Daegu Monorail - System Characteristics[108]

5.8.3.1 The total length of Monorail Line 3 is 23.95 km with 30 stations.[109] Average station spacing is 800 m, with a minimum inter-station distance of 600 m. Lengths for all lines comprising the Daegu Metro system are listed in **Table 5.8.9** below:

Table 5.8.9: Metro Network Length in Daegu

Line	Opening Date	Length
Line 1	November 1997	25.9 km
Line 2	October 2005	31.4 km
Line 3 (Monorail)	April 2015	24.0 km

Source: DTRO website, http://www.dtro.or.kr/open_content_new/en/main/

5.8.3.2 Each monorail train for Line 3 is 46.2 m long and 2.9 m wide with 3 cars. Capacity for each train is 265 passengers with normal load and 398 passengers for crowded trains.[110] The system operates with a total of 84 cars and 28 trainsets (with 3 cars each).

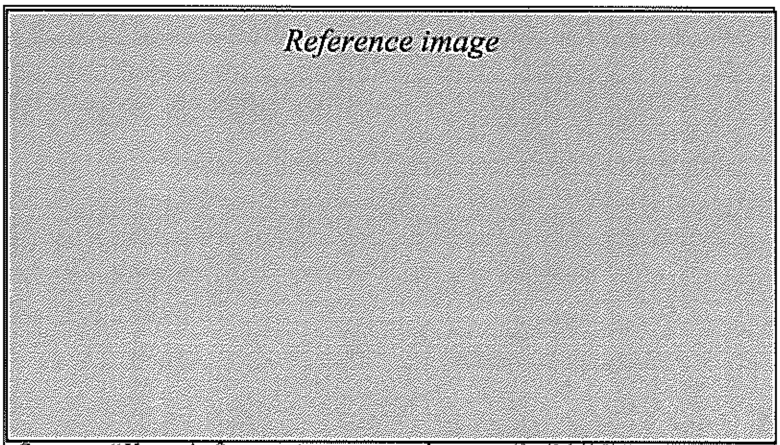
5.8.4 Daegu Monorail - Service Characteristics[111]

5.8.4.1 Daegu's Line 3 operates from 5:00AM-11:30PM each day. During peak periods, Line 3 operates at 5 minute peak and 7 minute off-peak headways – equivalent to a peak capacity of 3,200 pphpd on average (and 4,800 pphpd on heavily loaded trains). Travel time along the 23.1 km route is about 48.5 minutes, which is equivalent to an average operating speed (including stops) of 30.0 km/hour. [112]

[108] Email Se-haw Jeon, Daegu Metro, April 14, 2016.
[109] K.Hwang, JD.Chung, et al, 2014, *"Feasibility Analysis on Ground-level Stations and Wireless Power Transfer Technology Applications for Monorail Systems"*
[110] *"Line 3 Monorail Finally Unveiled"*, http://english.daegu.go.kr/cms/cms.asp?Menu=521&BoardId=14146&Action=view
[111] Email Se-haw Jeon, Daegu Metro, April 14, 2016.
[112] http://www.railway-technology.com/projects/daegu-urban-railway-line-3/

5.8.5 Daegu Monorail – Performance[113]

5.8.5.1 [redacted]



Source: *"Korea's first major monorail opens (04/23/15)"*, http://www.monorails.org/tMspages/News.html

Figure 5.8.20: Daegu Metro Line 3 Monorail Train

[redacted]

5.8.5.2 [redacted]

5.8.6 Key Findings from Daegu Monorail

5.8.6.1 The Daegu Monorail (Line 3) is one of the newest urban monorail lines implemented in the world. It operates in a north-south corridor that was not previously served by any other rail-based modes. Monorail was selected for Line 3 due to its ability to handle steeper grades and sharper turns, which made monorail more suitable for Daegu's topographic and built-up conditions. Line 3 provides moderate capacity urban service, accommodating nearly 4,000 pphpd. [redacted] Line 3 represents another example of monorail playing the role of a secondary urban connector, complementing the heavy rail network.

[113] Email Se-haw Jeon, Daegu Metro, April 14, 2016.

5.9 Sao Paulo Monorail

5.9.1 Sao Paulo Monorail - System Description

5.9.1.1 There are several monorail lines currently under partial operation and construction in São Paulo, Brazil, the country's most populous city. Line 15 (extension of Line 2) was the first monorail line constructed in Brazil and partially started operation in August 2015, while Line 17 is under construction. Concession of Line 18 which is also a monorail system was signed in Aug 2014 with a completion scheduled in 2018.[114]

5.9.2 Sao Paulo Monorail - Planning Background

5.9.2.1 Like other metropolitan cities, São Paulo (with a population of 11,000,000) was facing serious transportation issues such as traffic congestion. Buses accounted for 65% of motorized transport, with rail modes accounting for 22%, respectively. The average speed during the PM peak hour was 21.8 km/h in 1997, which fell to 17.2 km/h in 2007.[115]

5.9.2.2 São Paulo experiences more than 150 km of traffic queuing on its road network each day, resulting in a loss of 2% of the annual GDP from lost productivity, additional fuel consumption, health impacts and road accidents.[116] The initial proposal to ease congestion in São Paulo was to construct a dedicated bus lane for its BRT system, which would use diesel vehicles to transport 250,000 passengers a day. The plan was subsequently revised to propose a more environmentally friendly solution, with an electric monorail system having a capacity of more than 550,000 passengers a day.[117]

5.9.2.3 Besides the traditional objective of improving urban transport condition in the city, catering to the visitors to the 2014 FIFA World Cup served as a strong motivation for selection and implementing monorail.[118] It was expected that monorail would help to ease the road traffic conditions (while also taking up less land than the aforementioned BRT system), promote urban regeneration, reduce travel time, and create a more integrated and sustainable transport environment.

5.9.2.4 The Japan International Cooperation Agency (JICA) and the Municipal Secretary of Transport (SMT) initiated a "Preparatory Survey for Urban Transport Development Project in Sao Paulo" in 2008. The objectives of the JICA Study were to select an appropriate transit system on each of the study routes and to prepare a feasibility study for an urban transportation system on seven proposed routes (with six of these routes forecast to have ridership exceeding 20,000 pphpd).

[114] *"São Paulo monorail Line 18 concession signed"*, 2014, http://www.railwaygazette.com/news/news/cs-america/single-view/view/sao-paulo-monorail-line-18-concession-signed.html

[115] Japan International Cooperation Agency, May 2010, *"The Preparatory Survey for Urban Transport Development Project in São Paulo"*

[116] J.Rebelo, Jul 2014, *"São Paulo and Mumbai: Improving Mass Transit in Two BRIC Megacities"*, http://blogs.worldbank.org/transport/s-o-paulo-and-mumbai-improving-mass-transit-two-bric-megacities

[117] S.Edwards, Aug 2013, *"São Paulo Metro's Line 15 Monorail Project"*, http://metroamericas.com/2013/08/06/sao-paulo-metros-line-15-monorail-project/

[118] *"Metro Line 15 São Paulo"*, http://www.bnamericas.com/project-profile/en/linea-15-metro-de-sao-paulo-linea-15-plata

5.9.2.5 The JICA Study investigated several modes including: (i) Light Metro (called LRT in the report); (ii) LIM (Linear Motor Railway); (iii) monorail (straddle type); (iv) monorail (suspended type); and (v) APM (called Automated Guideway Transit in the JICE Report). The table below provides a summary of performance indicators for considered systems.

Table 5.9.10: Performance against Indicators for Different Rail Modes in JICA Study

	Light Metro / Tram (LRT)	LIM Train	Monorail (Straddle type)	Monorail (Suspended type)	APM (AGT)
Length (m)	53.4	96	90	90	54
Number of cars	9	6	6	6	6
Curve radius (lower limit) (m)	20	100	60	50	50
Gradient (upper limit)	4%	6%	6%	6%	6%
Passengers per train (at 6 passengers per sqm)	430	980	1,000	710	470
PPHPD (at 3 minute headway)	8,600	19,600	20,000	14,200	9,400
PPHPD (at 2 minute headway)	12,900	29,400	30,000	21,300	14,100

Source: Japan International Cooperation Agency, May 2010, *"The Preparatory Survey for Urban Transport Development Project in São Paulo"*

5.9.2.6 The major criterion for the selection of mode was capacity. It can be seen that LIM train and Monorail (straddle type) were the only modes that could meet the demand on all lines (i.e., a minimum of 20,000 pphpd). LIM trains were excluded due to the limited number of suppliers and limited track records.

5.9.2.7 Heavy rail was also considered for these routes, although gradients and horizontal curves for several of the potential routes were more suitable for monorail operation than heavy rail. Furthermore, the overall patronage on some of the routes could not justify the costs for an underground heavy rail system.

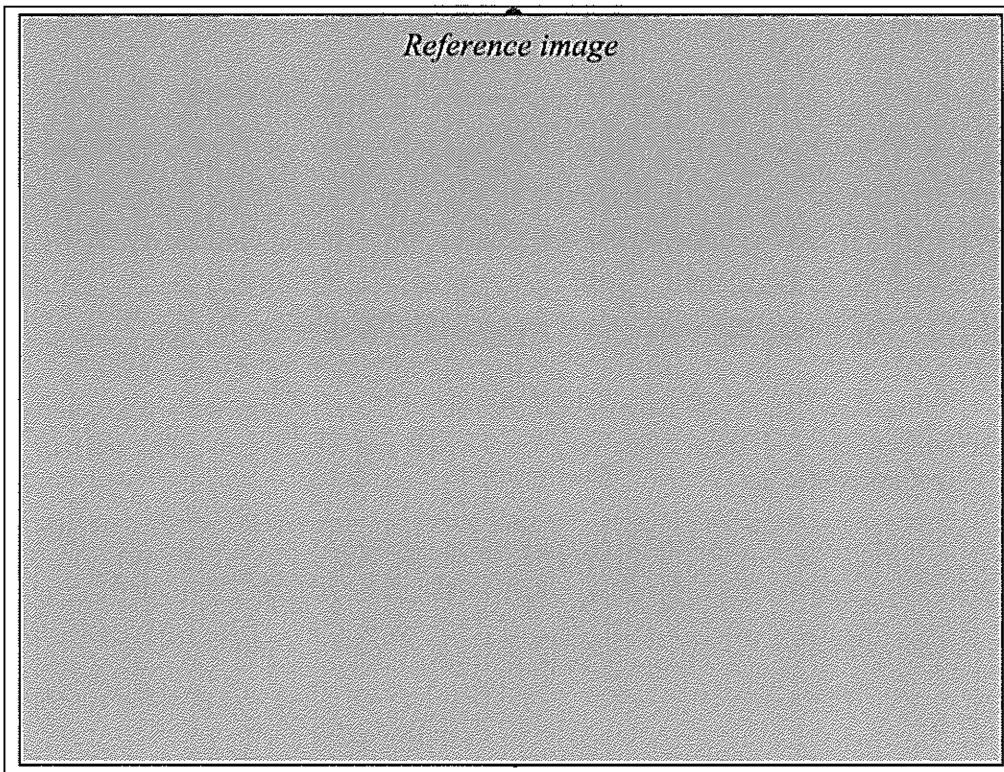
5.9.2.8 The JICA Study further recommended the following:

- Average speed on the recommended scheme would be 30 km/h and minimum theoretical headway during peak periods 2 minutes (operational headway 2 minutes and 15 seconds). During off-peak periods, headway should not be longer than 10 minutes in order to keep the service attractive.
- Recommended station spacing on the lines ranged from 600 m to 1,500 m, even though in one case, spacing of 380 m was recommended for Line 2A. For intermediate stations, side platforms were recommended in order to avoid extra horizontal curves before and after the station. No evacuation walkways were recommended. Instead JICA, mentioned "spiral chutes" as one possible evacuation method from a failed train on viaduct.
- The various monorail lines in the JICA Study were recommended to open for traffic in October 2015 – March 2015 (Phase 1), July 2016 (Phase 2) and April 2018 (Phase 3).

5.9.2.9 The recommendations from the JICA Study have evolved into the three monorail lines noted earlier: (i) the existing Monorail Line 15 (Silver) opened in 2015; (ii) the planned Monorail Line 17 (Gold); and (iii) the planned Monorail Line 18.

5.9.3 Sao Paulo Monorail - System Characteristics

5.9.3.1 The actual development of the monorail system has been slow. Currently, the entire Sao Paulo Metro (SPM) consists of 6 lines with a total of 81.9 km as shown in the figure. The length of each route is show in **Table 5.9.11**. The existing Line 15 Monorail is depicted by silver line (extended past the eastern Green Line terminal at Vila Prudente).



Source: https://goo.gl/mCC8E4

Figure 5.9.21: Sao Paulo Metro Network Map

Table 5.9.11: Network Length of Sao Paulo Metro

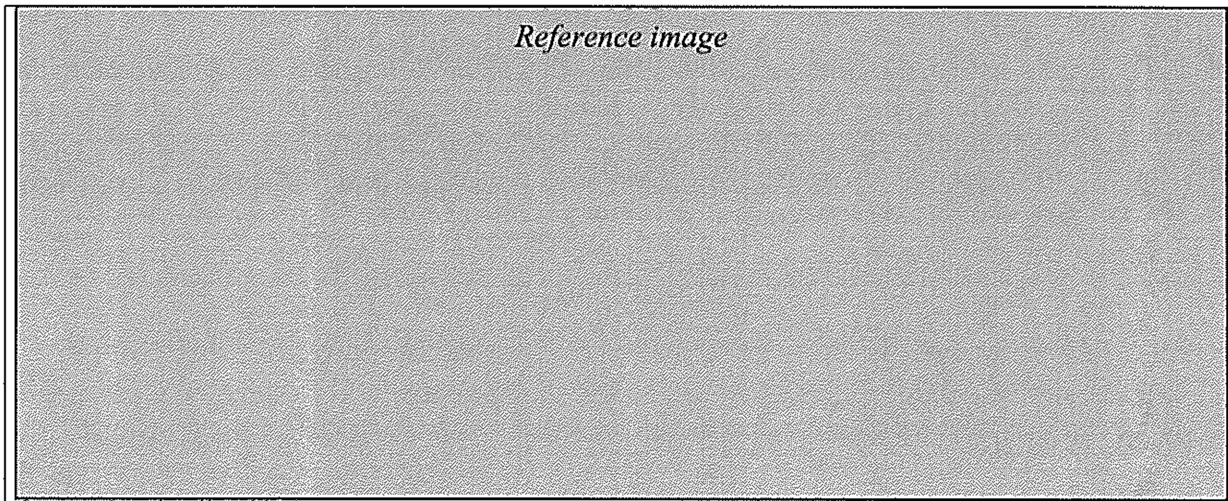
Line	Opening Date	Length (km)
Line 1 – Blue	Sep, 1974	20.2
Line 2 – Green	Jan, 1991	14.7
Line 3 – Red	Mar, 1979	22.0
Line 4 – Yellow	Sep, 2011	12.8
Line 5 – Lilac	Oct, 2002	9.3
Line 15 – Silver (Monorail)	Aug, 2015	2.9

Source: *"Management Report 2014"*, http://www.metro.sp.gov.br/en/pdf/ra2014ingles.pdf

5.9.3.2 The eventual Monorail Line 15 (Silver) is planned to be 24.5 km long with 17 stations. The initial section of Line 15 contains 2 of the planned 17 stations.[119]

[119] http://www.metro.sp.gov.br/en/your-trip/line-15-silver/oratorio-station.aspx

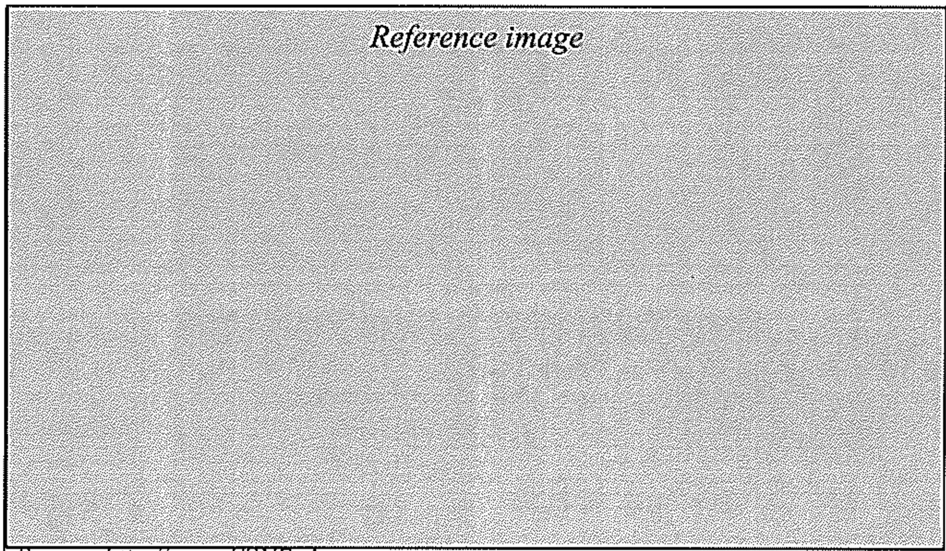
Monorail Line 17 (Gold) is planned to be 18 km long with 18 stations (with construction having already begun in 2012).[120] Monorail Line 18 is planned to be 15 km long with 13 stations. The monorail in Sao Paulo has been provided with evacuation walkway between the two tracks, and with intermittent handrail.



Source: Bombardier, 2016.

Figure 5.9.22: Sao Paulo Monorail with Evacuation Walkway

5.9.3.3 Ultimately, Line 15 will operate with 54 7-car trains with a capacity of 1,000 passengers per train. The length of each car is 13.2 m (end car) or 11.845 m (intermediate car).



Source: http://goo.gl/SY7n4s

Figure 5.9.23: Seven-Car Driverless INNOVIA Monorail 300 (Line 15)

120 *"Management Report 2014"*, http://www.metro.sp.gov.br/en/pdf/ra2014ingles.pdf

Reference image

Source: *INNOVIA Monorail 300 Technology*,
http://www.monorails.org/pdfs/INNOVIA%20300.pdf

Figure 5.9.24: INNOVIA Monorail 300 Detail Drawing

5.9.4 Sao Paulo Monorail - Service Characteristics

5.9.4.1 The operating hours for SPM are listed in **Table 5.9.12** below, with Line 15 currently operating from 7:00AM-7:00PM. The minimum headway for Monorail Lines 15 and 17 is designed to be 90 seconds.[121,122] This equates to a design capacity of 40,000 pphpd based on the 1,000 passenger trainsets.

Table 5.9.12: SPM Operating Hours

	Hours of Operation	
Line	Sun-Fri	Sat
Line 1 (Blue)	4:40AM-0:06AM	4:40 AM–1:00 AM
Line 2 – Green	4:40 AM–0:07 AM	4:40 AM–1:00 AM
Line 3 – Red	4:40 AM–0:00 AM	4:40 AM–1:00 AM
Line 4 – Yellow	4:40 AM–0:00 AM	4:40 AM–1:00 AM
Line 5 – Lilac	4:40 AM–0:10 AM	4:40 AM–0:10 AM
Line 15 – Silver (Monorail)	7:00 AM–7:00 PM	7:00 AM–7:00 PM

Source: São Paulo Metro Website, http://www.metro.sp.gov.br/en/metro/about-us/index.aspx

5.9.5 Sao Paulo Monorail – Performance

5.9.5.1 The total project cost of Monorail Line 15 was estimated to be US$1.6 billion.[123] Operating costs of entire São Paulo Metro System (Monorail Line 15 not included) was R$1.76 million (US$0.45 million) in 2014.[124]

5.9.5.2 For monorail, Line 15 only opened two stations in August 2015. No ridership data has been publically released. It was expected that Line 15 will handle up to 550,000 passengers/day.[125] Line 17 is estimated to handle some 511,000 passengers/day.[126]

[121] *"Monorails of South America"*, http://www.monorails.org/tMspages/SaoPaulo.html
[122] *"Thales Urban Rail Signalling, São Paulo – Line 17 Monorail"*, https://www.thalesgroup.com/sites/default/files/asset/document/seltracr_in_saopaulo_monorail.pdf
[123] *"São Paulo Monorail System, Brazil"*, http://www.railway-technology.com/projects/saopaulomonorailsyst/
[124] *"Management Report 2014"*, page 71, http://www.metro.sp.gov.br/en/pdf/ra2014ingles.pdf
[125] *"Management Report 2014"*, page 5, http://www.metro.sp.gov.br/en/pdf/ra2014ingles.pdf
[126] *"Management Report 2014"*, page 7, http://www.metro.sp.gov.br/en/pdf/ra2014ingles.pdf

5.9.6 Key Findings from Sao Paulo Monorail

5.9.6.1 Sao Paulo's Line 15, 17 and 18 represent some of the newest urban monorail lines implemented in the world. These lines are meant to serve as high capacity monorails – serving some 40,000 pphpd, putting Lines 15 and 17 on par with moderate capacity heavy rail systems. Monorail was selected over BRT, other rail modes, and heavy rail for the following reasons: (i) capacity (only monorail and LIM could serve the required capacities of nearly 20,000 pphpd predicted on several key corridors); (ii) financial feasibility and operations (monorail would be more suitable than heavy rail due to patronage levels, expected cost of a heavy rail system, as well as operating constraints); and (iii) congestion (monorail would reduce congestion and could more effectively serve mobility demands than BRT).

5.10 Summary of Key Findings from Monorail Case Studies

5.10.1 The eight monorail case studies explore the applicability and operation of monorail for urban, core service. A summary of key points is as follows:

- **Vital and Proven Cog in the Urban Public Transport System** – Monorail is a proven technology that has served as a key urban transport cog for the last 40 years. The case studies show that monorail can serve a variety of roles, but can also serve as a primary trunk line with moderate-high capacity. The monorail lines in these and the other case study cities are well integrated into the overall urban public transport network and serve as key trunk line corridors.
- **Moderate Capacities Can Be Achieved** - The Tokyo Monorail is able to handle about 10,000 pphpd, while Chongqing and Sao Paulo are able to handle 40,000 pphpd or more – equivalent to a moderate capacity heavy rail or metro line. Therefore, monorail has capacity to serve in the urban core system as a daily commute mode.
- **Unique Characteristics of Monorail** – The selection of monorail over other road-based and rail-based modes owes to the unique characteristics of monorail to provide a reliable and time-competitive journey. Compared to other elevated heavy rail, monorail can operate with much tighter turning radii and climb steeper grades. The monorail track is thinner and less visually impactful than guideways for other types of elevated rail systems, allowing for better daylighting on the ground. In several cases, monorail was found to be a cheaper and more cost-effective alternative for a moderate-density corridor, where ridership may not sustain a more costly heavy rail system. Elevated monorail also would generate fewer impacts on the street level and would not reduce the number of travel lanes as significantly as a BRT system or modern tram system with dedicated lanes.
- **Monorail Technology Is Not Root Cause of Poor Performance in Sydney or Kuala Lumpur** – The Sydney Monorail was eventually closed in 2013 after about 20 years of service. Poor performance, however, was due largely to route planning, inconvenient station location, as well as inefficient service. The Sydney Monorail operated as a single track loop on the outskirts of the CBD – this meant it was not used on a daily basis by everyday commuters. In addition, as a single track loop, journey times were not competitive with walking or other transport modes in the "reverse"

counter-clockwise direction. Due to these issues, low ridership was generated, which led to poor financial performance. The Kuala Lumpur Monorail was designed with limited capacity – 3,600 pphpd – and has relatively inconvenient transfers with other modes at key intermodal stations. In addition, high depreciation and interest payment costs led to operating deficits (i.e., fare revenues insufficient to cover operating costs).

- **New Monorail Systems Still Being Built** – Daegu and Sao Paulo both opened new monorail lines in 2015. Sao Paulo has plans for two additional monorail lines. Osaka has recently approved an extension of the Osaka Monorail. Chongqing has recently extended its Line 3 Monorail. Thus, there is a market and a need for a medium-capacity rail-based system that can deliver reliable and cost-effective service, yet still has capacity to expand.

5.10.2 In conclusion, although Monorail is not as commonplace as other green transport modes including BRT, Modern Tram, and Heavy Rail, it is nonetheless a mature and proven technology. The findings from this Literature Review confirm that Monorail has successfully played a key role in several large cities around the world, providing both feeder and trunk service with moderate levels of capacity. Although two notable systems have struggled financially – the root cause was due to system planning and design, rather than the underlying Monorail technology. Thus in summary, there is nothing to suggest that Monorail should not be considered in the subsequent assessment of feasible green transport modes to serve as KE EFLS.

6 Summary

6.1 Overall Summary

6.1.1 **Table 6.1.1** provides a high-level, qualitative assessment of key characteristics that separate the road- and rail-based modes presented in this paper. This list of initial operating characteristics may form a subset of the selection criteria used to identify the most feasible modes for EFLS for KTD.

6.2 Summary of Road Based Modes

6.2.1 In summary, road-based and rail-based modes have different applications in the overall transport hierarchy and have different operating characteristics including capacity, speed and reliability. Key findings are as follows:

- **For road-based modes**, the highest capacity system is BRT, if dedicated corridor and priority at junctions are provided. BRT operates in dedicated bus lanes and rail-like amenities including stations, off-board fare payment, level boarding, and traffic signal priority. The level of segregation that the buses enjoy in the bus lanes determines how fast and how reliable the service is. As it is though, most BRT systems in an urban context must cross intersections at-grade, meaning that some delay may still occur at the crossings, even with signal priority and special lanes or bus phases. Higher-end BRT systems such as the Guangzhou and Bogota BRT systems have passing lanes at the stations and longer boarding platforms with multiple bays. This allows BRT stations to board multiple routes simultaneously. Studies have found that these systems have capacities comparable to Light Metro and medium-capacity Heavy Rail systems. A key implementation issue with BRT is the willingness of the area to reallocate road space to the bus lanes and stations, which can require right-of-way width of up to 11-15 m at stations (11m stations would include the two bus lanes and a median platform, while a 15m profile would also include one or more passing lanes). This tradeoff impacts traffic and road capacity. BRT is the most capital intensive road-based system. Road based modes have low visual impact as they operate at-grade.
- **Trolleybus and conventional bus** (regardless of propulsion – either diesel, electric, or hybrid) function as local circulation and feeder role. Both modes operate principally in mixed flow lanes and can handle low ridership volumes compared to BRT or rail modes. These modes are both subject to interference from road users and this affects overall operating speed and travel time reliability. Stops for trolleybus and bus stops are not designed for quick boarding and alighting – both still use on-board fare payment. Multiple routes using the same stop location can conflict with one another, whereas in BRT the station sizing is large enough to allow vehicle to independently dock and load. Trolleybus requires overhead catenary (although technology has evolved such that trolleybus can operate on battery power for short stretches) – therefore it is less flexible than BRT or conventional bus, which can operate independently of the catenary structure. This limits where trolleybus can operate and how trolleybus can

react to accidents or congestions upstream. Trolleybus has moderate visual impact due to overhead catenary wires (which would still be less visually impactful compared to an elevated fixed guideway rail system).

- **Cable cars** in the form of aerial cable cars have typically been used to link locations in valleys or mountainous areas. For the most part, they have been for tourist purposes rather than as an urban linkage system. Aerial cable car also has less aesthetic impacts and requires a smaller amount of land then BRT for instance. Cable car, however, besides the limited capacity, can be impacted by poor weather, high winds, and low visibility conditions – with service often stopping in these conditions. Aerial cable cars have moderate visual impact compared to ground-based modes, but less impact than fixed elevated fixed guideway systems.
- **Travellators** are used for local access and shorten effective walking times and distances. They can also provide feeder connections to major transportation hubs such as rail and bus stations. They essentially extend the walking catchment of trunk public transport systems, allowing direct and easier access to final destinations. Travellators move passengers slowly compared to other mechanised modes as they must allow for passengers to stand safely on the moving walkway. Travellators have low visual impact as they are typically at-grade.

6.3 Summary of Rail Based Modes

6.3.1 **For rail**, there is a considerable overlap of the characteristics of many rail-based transport systems. Key findings are as follows:

- **Heavy Rail (or Metro)** has the highest capacity and is the most expensive rail-based system. Rigid rules for alignment force most urban Heavy Rail systems to be underground (even though they sometimes are at grade or elevated). Hence, the system is only cost-effective on trunk lines with heavy ridership. Elevated heavy rail would have high visual impacts due to the fixed guidway.
- **Light Metro, APM and monorail** are perceived similarly by passengers (in terms of train size, train interior, platform arrangements, need for segregation from other modes of transport, line capacity). Station distances are also similar. These systems provide a high degree of reliability similar to a Heavy Rail system, but are more suitable for moderate levels of demand. The major difference between the systems is the impact of the infrastructure on the surroundings (for example visual impact of viaducts for plain line, crossovers, and junctions). Monorail's thin beam is often seen to be an advantage of monorail. APMs run on rubber tires, while monorail may also use rubber tires. Technologies also differ in the way infrastructure can be added to or modified on existing operational systems. Elevated Light Metro and APM would have high visual impacts due to the fixed guideway. Monorail would have moderate-high visual impacts as the beam is less obtrusive and bulky compared to the typical elevated fixed guideway rail systems.
- **Cable-drawn vehicles** can be similar to APM vehicles, but are lighter since they do not contain propulsion motors. Hence, the viaducts can be slimmer. However, with vehicles permanently attached to the cable,

capacity will be low. With vehicles detachable from the cable, there are operational issues (difficult to arrange local speed restrictions on small radius curves, complicated switch mechanisms, etc.) must be analysed in detail. Most cable-drawn shuttles have been implemented for specific purposes – such as a rail connection to the airport. These systems would have a moderate-high visual impact as the guideway would be less bulky than other elevated rail systems given the lighter vehicles and lack of on-board motors.

- **PRT** represents a fundamentally different system for the passengers. It can be regarded as an automated personalised guideway taxi system that provides on-demand and non-stop service for passengers. Passengers may choose their destination. Capacity of stations/stops and the vehicles themselves is relatively low. PRT is still emerging, but systems have been implemented as district or urban circulators and not as a core system. PRT would have moderate-high visual impacts due to the guideway – although vehicles are smaller and the guideways would be less bulky than traditional elevated rail systems.
- **Modern tram**, if street running, means that there must be a driver on the vehicle. The services will be less reliable than other rail-based modes (risk for delays, risks for accidents) due to street conflicts – although this can be somewhat mitigated with dedicated lanes and signal priority. When operating in dedicated lanes, modern tram will occupy width of the roadway and potentially reduce vehicular capacity. Most new tram systems today implement dedicated corridors to improve performance and reliability, with mixed flow, shared segments only where dedicated lanes are infeasible. If the tram system is completely segregated from other modes of transport, it can be considered as a Light Metro. Modern tram would have low-moderate visual impacts depending if overhead catenary wires are used for propulsion.

Table 6.1.1: Summary of Modes by Key Characteristics

	Road-Based Green Public Transport Systems					Rail-Based Green Public Transport Systems						
	Aerial Cable Car	**Bus (Electric/ Hybrid)**	**Bus Rapid Transit (BRT)**	**Travellator**	**Trolleybus**	**APM**	**Cable-Drawn Shuttles**	**Heavy Rail**	**Light Metro**	**Modern Tram**	**Monorail**	**PRT**
Photo	*Reference image*	*Reference image*	*Reference image*	*Reference image*	*Reference image*	*Reference image*	*Reference image*	*Reference image*	*Reference image*	*Reference image*	*Reference image*	*Reference image*
Typical Role in Urban Transport Hierarchy	Feeder	Local Service & Feeder	Trunk Service & Feeder	Last-Mile Connector	Local Service & Feeder	Trunk / Feeder / Urban Circulator	Feeder	Trunk	Trunk	Trunk / Feeder	Trunk / Feeder / Urban Circulator	Last-Mile Connector
Principal Trips Served	Local	Local	Local / Regional	Very Short Local	Local	Local/Regional	Local	Regional	Regional	Local/Regional	Local/Regional	Local
Maximum Capacity (passengers per hour per direction - pphpd)	Up to 3,500 pphpd	Up to 1,500 pphpd	Up to 38,000 pphpd	3,500-6,000 * pphpd (* theoretical only, higher end assumes one person per step)	Up to 1,500 pphpd	Up to 9,000 pphpd	Up to 4,500 pphpd	85,000 pphpd (urban line such as Island Line)	Up to 20,000 pphpd	Up to 13,500 pphpd	Up to 10,000 pphpd (six car trains (Tokyo)); Up to 43,000 pphpd (8 car trains (Chongqing))	Up to 1,500 pphpd
Runningway/ Guideway	Aerial	On-Street	Dedicated Bus Lanes	-	On-Street / Bus Lanes	Grade-Separated Right-of-Way (ROW)	Grade-Separated Right-of-Way (ROW)	Grade-Separated Right-of-Way (ROW)	Grade-Separated Right-of-Way (ROW)	On-Street / Grade-Separated Right-of-Way (ROW)	Grade-Separated Right-of-Way (ROW)	Grade-Separated Right-of-Way (ROW)
Reliability	Low	Low	Moderate-High (subject to level of segregation)	N/A	Low	High	High	High	High	Moderate-High (subject to level of segregation)	High	High
Average Speed (km/hour)	Up to 18 km/hour	Up to 15 km/hour	25-30 km/hour	2.0 km/hour (0.5 m/s)	Up to 15 km/hour	Up to 30 km/hour	Up to 35-40 km/hour	Up to 35-40 km/hour (urban lines)	Up to 35-45 km/hour (urban lines)	Up to 20-25 km / hour (urban lines)	Up to 35-40 km / hour (urban lines)	Up to 50 km / hour (straightaway without stops)
Land Requirements	Low-Moderate	Low	Moderate-High	N/A	Low	Moderate-High	Moderate-High	Very High	Moderate-High	Moderate-High	Moderate-High	Low-Moderate
Visual Implications (Assuming Elevated Rail System)	Moderate	Low (assumes at-grade operations)	Low (assumes at-grade operations)	Low (assumes at-grade operations)	Moderate (assumes overhead catenary)	High (for elevated system)	Moderate-High (for elevated system)	High (for elevated system)	High (for elevated system)	Low-Moderate (depends if overhead catenary used)	Moderate-High (for elevated system)	Moderate-High (for elevated system)
Capital Costs	HK$150-600 million / km	HK$2.5–4.2 million / unit	HK$50-300 million / km (higher end for elevated BRT)	HK$200-500 million / km	HK$100-150 million / km	HK$900-1,300 million / km	HK$1.0-$1.3 billion / km	HK$3.0-4.3 billion / km	HK$600-1,300 million / km	HK$250-800 million / km	HK$1.1-1.2 billion / km	[redacted]
Examples	Hong Kong Ngong Ping 360, Singapore Sky Network, Medellin Metrocable	Citybus Electric Vehicles, Shenzhen BYD, London TfL	Bogota, Guangzhou, Xiamen	HKIA, Lok Ma Chau BCF, Mid-Levels Escalator, Central-Hong Kong MTR Stations, Toronto Pearson	San Francisco, Seattle, Shanghai, Zurich	Singapore Sengkang, Punggol LRT, Tokyo Yurikamome Line	Caracas Cabletren Bolivariano, Oakland Airport Connector, Zurich Airport Skymetro	Hong Kong MTR, Singapore MRT	Copenhagen Metro, London Docklands Light Railway (DLR), Vancouver SkyTrain	Dublin LUAS Barcelona TRAM	Chongqing Monorail, Daegu Monorail, Kuala Lumpur Monorail, Tokyo Monorail	London Heathrow ULTra Masdar 2getThere Suncheon SkyCube

Notes: (i) Findings are based on Literature Review (thus some systems not included in the Literature Review may have higher costs or higher capacity, etc.); and (ii) capital costs per unit are for reference only and are not directly comparable across all modes (for instance, travellators are for very short connections, while other modes are for longer-distance trips).