Wellington Public Transport Spine Study

RAILWAY STATION TO HOSPITAL

International Review of Public Transport Systems

International Review of Public Transport Systems, Base Report

Railway Station to Hospital

Prepared for

Greater Wellington Regional Council

Prepared by

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NOTE REGARDING COST/FINANCIAL DATA IN CASE STUDIES – THE COST/FINANCIAL INFORMATION CONTAINED INTHE CASE STUDIES (APPENDIX B AND APPENDIX C) AT THIS STAGE DOES NOT TAKE INTO ACCOUNT THE EFFECTS OF INFLATION AND EXCHANGE RATES SINCE THE VARIOUS SCHEMES HAVE BEEN IMPLEMENTED. ALL COST/FINANCIAL INFORMATION HAS BEEN CONVERTED INTO NEW ZEALAND DOLLARS ON THE BASIS OF FEBRUARY 2012 EXCHANGE RATES ONLY.

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Abbreviations

Abbreviation	Definition
CBD	Central Business District
BBC	Treasury's Better Business Case Framework
BRT	Bus Rapid Transit
GWRC	Greater Wellington Regional Council
LRT	Light Rapid Transit
MRT	Mass Rapid Transit (e.g. heavy rail)
MTR	Mass Transit Rail (e.g. heavy rail)
NZTA	New Zealand Transport Agency
PPHPD	Passenger per hour per peak direction
PT	Public Transport
PRT	Personal Rapid Transit (also refer to as Urban Light Transit)
PTTS	Wellington Public Transport Spine Study
RTN	Rapid Transit Network
TOD	Transit-Orientated Development
TSD	Transit Supportive Development
WCBR	Wellington City Bus Review
WCC	Wellington City Council
ULT	Urban Light Transit (also referred to as Personal Rapid Transit)

EXECUTIVE SUMMARY

This report is part of a suite of documents being prepared for Greater Wellington Regional Council (Greater Wellington) for the Wellington Public Transport Spine Study (PTSS). Its purpose being to learn from the implementation of public transport systems overseas to inform the PTSS in assessing the feasibility of long term public transport options for Wellington. Thirty-five case studies were investigated from across the globe to inform this report. The key findings from the research are:

Modal Attributes

1. Key attributes by mode are:
   - **ULTra, or Personal Rapid Transit (PRT).** This mode is considered to provide low carrying capacity. Furthermore, it's not suited to applications with strong uni-directional flows, or where concentrated interchange is required from another form of mass transit. These modes are completely segregated from other vehicles through a dedicated corridor. Guideways are relatively narrow and provide good flexibility when designing a route. Capital expenditure is estimated across a broad range, between NZ$9 million – NZ$20 million per km.
   - **Bus on-street.** This mode is considered to provide low to medium carrying capacity. Generally, these modes are not conducive to attracting significant percentages of passengers away from the private vehicles as buses-on-street do not generally provide as high a priority and / or public image as other public transport modes. Capital expenditure is estimated at between NZ$0.1 million – NZ$25 million per km depending on various factors including degree of priority on street, and whether it is a trolley, articulated or standard bus.
   - **Bus Rapid Transit (BRT)**. This mode is considered to provide medium carrying capacity. With this solution, there is generally a higher quality of service provided to passengers. This is typically through improved reliability and travel speeds, as BRT systems are predominately a segregated facility which gives absolute right-of-way to buses, via a dedicated corridor with enhanced stops. Capital expenditure is estimated at between NZ$500,000–NZ$25 million per km depending on treatment and construction e.g. bus lanes and / or exclusive right of way for buses. BRT provides a realistic option with lower costs for a city unable to support LRT, or MRT.
   - **Light Rapid Transit (LRT).** This mode is considered to provide medium carrying capacity. The benefit of LRT is that it is segregated from general traffic but equally, not limited to operating within the traffic. It is seen by many as environmentally friendly. Solutions with LRT - more than any other public transport mode - have been supported by comprehensive land use strategies. For the case studies reviewed, the projected passenger forecasts were often surpassed with supporting lines and transit supportive development planned to support increased growth. The range of capital expenditure is estimated to be between NZ$12 million – NZ$141 million per km.
   - **Mass Rapid Transit (MRT)**. This mode is considered to provide high carrying capacity. Stations are generally more widely spaced than other options and therefore need to be carefully selected. Capital expenditure is estimated at NZ$105 million per km. Solutions including MRT require extensive upfront capital investment but can still be cost effective if placed in high demand corridors, with feeder buses and other modes servicing MRT networks. MRT is also good at unlocking economic potential by supporting compact land use development on corridors and around stations.

Land Use Transformation and Value Uplift

2. There is a direct correlation between access to passenger transport services and increased property values. The following value uplifts have been identified:
   - Bus on-street, little attraction of new development investment.

- Bus Rapid Transit (BRT), property prices rise by up to 20% when compared to surrounding suburbs.
- Light Rapid Transit (LRT) and Mass Rapid Transit (MRT), property price increases up to 25%.

Success Factors

3. The key success factors of passenger transport systems reviewed has been dependent on:
   - Setting a long-term strategy which is achievable, realistic, which the public understands and can survive the political cycle.
   - Inter-government agency co-operation has been a key feature to provide funding or undertaking redevelopment of land surrounding stations and corridors.
   - To achieve maximum operational efficiency consideration must be given to what a city can reasonably afford.

Design and Operational Factors

4. The key design and operational considerations that have been drawn from the case studies include:
   - Spatial constraints to accommodate passenger transport system.
   - A comprehensive design that can support and is flexible to future changes e.g. growth, technology.
   - Integration with existing character.
   - Impact of street layouts that can impose constraints, e.g. vehicle length, access to platforms/stations.
5. Key principles to shape the design of a passenger transport system are:
   - Peak direction carrying capacity (forecast demand growth), with systems ranging generally from low cost, low performance (e.g. bus) through to higher cost but higher capacity and performance (e.g. Mass Rapid Transit).
   - Network coverage, the higher the passenger-km a network carries the more likely it is to be economically sustainable. Hence, accessibility enhancement, rather than the type of transit system, is far more important to influence land development, and ultimately attracting passengers.

This report provides the base information to inform the PTSS.

1.0 INTRODUCTION

1.1 Background

In August 2011, AECOM was appointed by Greater Wellington Regional Council (Greater Wellington) to undertake the Wellington Public Transport Spine Study (PTSS), "the Study". This is a joint study led by Greater Wellington Regional Council (GWRC) in partnership with the New Zealand Transport Agency (NZTA) and Wellington City Council (WCC).

The purpose of the PTSS is to assess the feasibility and the merits of a range of longer-term options for providing a high frequency and high quality public transport system between the Wellington Railway Station and the Wellington Regional Hospital. It will consider possible connections to the north and south-east, and will seek to support the urban intensification of this growth corridor.

1.2 Report Purpose

This Report (International Review of Public Transport Systems) is part of a suite of documents being prepared as part of the PTSS, the purpose being to learn from the implementation of passenger transport systems overseas that are similar to Wellington.

The findings from this review will provide input into the option evaluation, design, operation and costs of passenger transport options so that the PTSS is informed by the successes and failures of comparable approaches elsewhere.

This report is a Base Report. It contains the base information to inform the PTSS.

The work in this report has been undertaken by AECOM, with Chapter 4.0 Land Use and PT Triggers Points Literature Review written by MRCagney.

1.3 Report Outline

This report is structured as follows:

- Chapter 2 provides an overview of the approach adopted for the international review, including the Wellington characteristics so as to determine the relevance of international case studies; the initial filtering questions posed to international researchers; and the approach to incorporating these findings into the Study.
- Chapter 3 provides an overview of five modal alternatives (e.g. bus, light rail), and includes relevant comparative information about typical patronage and travel patterns, design and operational factors, corridor and station layouts, Costs, and Success Factors for each mode alternative.
- Chapter 4 provides the results from a literature review, primarily investigating the relationships between passenger transport and land use.
- Chapter 5 presents the summary of the key findings, in particular around Land Use Transformation and Value Uplift, Success factors, and Design and Operational Consideration.
- Appendix A: Glossary of Terms.
- Appendix B: Case Study Summary, sets out a summary of the findings from all case studies for that mode, by the case study questions.
- Appendix C: Case Study Datasheets contains the datasheets providing details of each case study.
- Appendix D sets out the references to the literature review.

2.0 REVIEW APPROACH

2.1 Approach

The international review was undertaken in accordance with Greater Wellington requirements by AECOM employees from North America (covering North American case studies), UK (covering European case studies), and Australia (covering Asian and Australian case studies).

The approach to this international review was through five steps:

- Identify Wellington characteristics that international case studies should be similar to;
- Choose case studies from Asia, Australia, Europe and North America;
- Prepare questions for international reviewers to respond to each case study;
- Undertake land use and public transport trigger points literature review; and
- Consolidate findings.

2.1.1 Wellington Characteristics

There is an abundance of public transport systems around the world many of which would not be applicable to Wellington for reasons such as different topography, population, income, employment levels. Therefore, for this international review it was important to research public transport systems that have similar characteristics to Wellington, or attributes required for this Study. Case study criteria were established from site observations and factors noted in the Ngauranga to Wellington Airport Corridor Study (2008), Regional Land Transport Strategy (2010-2040), Wellington Regional Public Transport Plan (2011-2021) and the PT Spine Engagement Surveys (2011).

The criteria that case studies should adhere to were either:

1) a bus based system with capacity problems, where improvements have been sought;
2) a relatively constrained narrow CBD with a strong public transport Spine;
3) a suburban rail line (metro) which stops short at one end of a CBD, which requires journeys to be undertaken by another mode.

2.1.2 Case Studies

Thirty-five case studies were investigated that were akin to the Wellington environment based on cities which meet one or more of the above criteria. The Case studies also covered:

- Low carrying capacity modes e.g. PRT
- Medium carrying capacity modes e.g. BRT, LRT
- High capacity carrying e.g. heavy rail/metro.

Bus/trolley bus were not researched in detail as these modes already exist in Wellington. Relatively more research was undertaken on medium capacity carrying modes as these systems are plentiful around the world (i.e. very few PRT systems exist) and an earlier appreciation of public transport demand at a screenline south of Wellington Railway Station suggests that a medium level of passenger transport carrying capacity (passenger / hour / direction) will be required in the future.

The case studies investigated are presented in Table 1.

2.1.3 Case Study Questions

Questions based on modal attributes, land use transformation and value uplift, success factors, design and operational considerations, financial and procurement of passenger transport systems were responded to for each case study. A full list of questions is presented in Appendix B, and cover:

Modal Attributes:

- Modal characteristics i.e. capacity by passenger transport type, peak hour capacity, design characteristics (e.g. operating speed, turning radii), capital expenditure (per km), cost of vehicle, technology requirements.

Land Use Transformation and Value Uplift

- Land use transformation/redevelopment (property value uplift) per passenger transport mode.
- What planning restrictions (such as car park limits) should accompany new developments to ensure successful utilisation of the passenger transport network.
- How the demand for passenger transport responds to prevailing land use patterns, and in turn what infrastructure /services should be provided in response to the demand for passenger transport.

Success Factors

- Constraints on the capacity of systems (e.g. corridor capacity, terminal capacity, depots).
- How different modes might perform in environments such as Wellington.
- General characteristics in successful systems and unsuccessful systems of bus operation in non-dedicated space (i.e. in general traffic).

Design and Operational Considerations

- Design issues that have previously been experienced (by mode).
- Operational issues that have been experienced by mode, and by multi-modes of transport.

Financial and Procurement

- What are the range of procurement and governance models for high quality passenger transport schemes, their financial impacts and other strengths and weaknesses.

2.1.4 Land Use and Public Transport Trigger Points Literature Review

A literature review was undertaken on land use and public transport trigger points. This was to understand the interdependence between land use patterns/densities and transport infrastructure and what the trigger points are that support the other. This work was undertaken as an initial step for the land use assessment component of the PTSS.

2.1.5 Consolidation of Findings

The findings from the case studies, augmented by research from additional PT publications, was drawn together to identify key lessons and modal parameters that should be drawn on for the PTSS.

2.2 International Review Inputs to PTSS

The findings of this report will feed into the following areas of the PTSS:

Strategic Evaluation: Long List to Medium List

- Modal characteristics in particular whether the mode has the carrying capacity to move future predicted demand from the Wellington Transport Strategic Model (WTSM).
- Evaluation criteria as appropriate for the Strategic Evaluation (e.g. attractiveness to user or ability to grow the CBD).

Technical Evaluation: Medium List to Short List

- Inputs to traffic model for different modes e.g. speed, costs.
- Development of innovative concepts through success factors ascertained from global studies.
- Analysis of potential design concepts.
- Locations where land use intensification may occur and the relative interdependencies between land use patterns/densities and passenger transport modes.
- Capital (CAPEX) and operational (OPEX) cost estimates.
- Evaluation criteria as appropriate for the Technical Evaluation.

Contextual Evaluation: Options for Next Steps

- As per medium to short list above (but a finer detail).
- Funding examples for short listed modes.
- Evaluation criteria as appropriate for the Contextual Evaluation.

NOTE REGARDING COST/FINANCIAL DATA IN CASE STUDIES – the cost/financial information (OPEX/CAPEX, etc) contained inthe case studies (Appendix B and Appendix C) at this stage does not take into account the effects of inflation and exchange rates since the various schemes have been implemented. All cost/financial information has been converted into New Zealand dollars on the basis of February 2012 exchange rates only.

Table 1: Summary of International Case Studies Investigated

Geography	Personal Rapid Transit (PRT)	Bus Rapid Transit (BRT)	Light Rapid Transit (LRT)	Mass Rapid Transit (MRT)
Australia/Asia		Beijing, China Xiamen, China (1,3) Brisbane, Australia (4) Adelaide, Australia (2) Auckland, NZ (1)	Gold Coast, Australia (1) Melbourne, Australia (4) Hong Kong Island (2) Kagoshima, Japan (3)	Mumbai, India (3, 4) Hong Kong (2) Republic of Singapore (1, 2)
Europe / Middle East		Rouen, France (2) Nantes, France (4)	Bergen, Norway (2) Frieburg, Germany (2) Karlshurse, Germany (2,3) Dublin, Ireland (3) Rouen, France (2) Eidenhoven, Netherlands (4)	Lyon, France (3)
North / South America	West Virginia, USA (4)	Los Angeles, USA Cleveland, USA (1,2,) Denver, USA (1,2,3) Bogota, Colombia Curitiba, Brazil	Minneapolis, USA (1,3) Portland, USA (1,2) San Diego, USA (1,2,3) San Francisco, USA (3) Seattle, USA (1,2) Vancouver, Canada (2)	

The above identifies case studies investigated. Where there is a bracket after a case study name this represents case studies where a comprehensive response has been obtained to the questions asked. These case studies are detailed in Appendix C. For those case studies without brackets we have drawn on specific information that is of relevance to the PTSS and are studies referenced in this report.

The number in the brackets identifies how each case study has similar characteristics to Wellington, or attributes required for this study. These are:

1) A bus based system with capacity problems, where improvements have been sought;

2) A relatively constrained narrow CBD with a strong public transport Spine;

3) A suburban rail line (metro) which stops short at one end of a CBD, which requires journeys to be undertaken by another mode.

4) Other. The reason why this study has been referred to is discussed in Appendix C for each Case Study. For example, Melbourne has a strong tram/LRT spine which commuters use to connect to employment locations from the rail network.

3.0 CASE STUDIES, LESSONS LEARNT

3.1 Overview

Chapter 3 presents the characteristics of the five modal alternatives (Personal Rapid Transit, Bus On-street, Bus Rapid Transit, Light Rapid Transit, Mass Rapid Transit). It sets out the key learning's from 35 investigated studies from five continents and discusses key criteria and lessons for each mode that should be considered and applied to the PTSS. This includes patronage and travel patterns; design and operational characteristics, costs and financial procurement methods, key study success factors. Details of case studies researched are presented in Appendix C.

It should be noted that the characteristics in this Chapter are based on case studies and international averages, which draw on the combined passenger transport experience of the international literature review team.

This Chapter therefore provides basic parameters for evaluating the long and medium list options. A more detailed concept design and costing plan will be prepared from this source material and parameters to determine factors such as costs for the short listed options.

3.2 Personal Rapid Transit

3.2.1 Modal Attributes

Pod cars, or personal rapid transit (PRT), or urban light transit (ULTra) are designed as personal vehicles and typically carry four to six passengers per vehicle. They can operate at-grade (provided that total segregation can be achieved), or on elevated systems with multiple point to point services. Some systems in place today, (e.g. Masdar City (UAE) and West Virginia (USA)), service Universities and potentially have a high service frequency typically less than one minute apart. Figure 1 illustrates a PRT operating system.

Figure 1: Examples of PRT Systems

PRT Heathrow Terminal 5

PRT vehicles operating on a 3.6 km corridor of elevated structures and stations.

Table 2 provides a summary of the typical PRT characteristics drawing on the findings of the case studies and international publication for PRT systems.

Table 2: Typical Personal Rapid Transit Characteristics4

Vehicle capacity	4–6 (subject to luggage)
Peak hour capacity (pphpd)	500
Service frequency	<1 minutes (on demand)
Capital expenditure (per km)	NZ$9 million - NZ$20 million
Operating speed (km/h)	40 km/h
Turning radii (m)	<10 m
Power source	Electric/Battery

3.2.2 Patronage and Travel Patterns

PRT systems can only travel on pre-determined corridors segregated from roads. Typically there are no intermediate stops in a journey even though the vehicle may pass a number of stations.

Operating over a 3.6 km corridor, Heathrow's Terminal 5 PRT system is forecast to eliminate 50,000 bus journeys on roads surrounding the airport. It provides a faster and more direct alternative to buses which used to connect a business use car park with Terminal 5. Pod cars are activated by passengers using a touch screen interface. The vehicles have capacity for four to six passengers and luggage. Therefore, although sufficient for the demands of the airport, alternative locations or extensions could be limited by capacity constraints.

3.2.3 Land Use Transformation and Value Uplift

No value uplift figures were obtained for the case studies researched. This is to be expected as two of the PRT systems considered operated at a University and an airport. No data was available for the city of Masdar.

3.2.4 Success Factors

The success of PRT is that it supplements other transport infrastructure providing destination to destination services.

Where PRT operates e.g. Masdar City (UAE), West Virginia (USA) and Heathrow Terminal 5 (UK), it has been successful as an alternative passenger transport mode replacing bus services and car travel by transporting people between two fixed points.

3.2.5 Design and Operation Considerations

A PRT network is required to be completely segregated from traffic. The lightweight design of a purpose built, automatic, driverless PODs on guideways may be customised to suit a variety of environments which allows the infrastructure to be retrofitted into the existing environment and integrated with future buildings. Like all elevated infrastructure, PRT can be visually intrusive, and if built outside an existing trafficked corridor will require additional land take to support structural piers and stations. There is the ability to build PRT at-grade. However, it must still operate in a segregated corridor. Speed is limited to 40 km/h.

PRT's guideways are approximately 2.1 m wide, including the outer kerbs, and therefore relatively narrow. The dimensions of the infrastructure give the system greater flexibility when designing the route. For example, the Heathrow Terminal 5 alignment includes a section that runs underneath an existing highway. The PRT network does not release local pollution or contribute greatly to noise levels as the system operates on battery.

The success of the PRT at Heathrow's Terminal 5 has been attributed to a 60% improvement in travel time and 40% operating cost savings. However, the development and operation of PRT is likely to come from the private sector and suit specific applications such as Universities and airports even though manufacturers, as supporters of the technology, argue strongly to the contrary. The fact is that PRT is not suited to applications with strong unidirectional flows, or where concentrated interchange is required to the system from another form of mass transit.

3.2.6 Financial

Manufacturers of the ULTra pod system suggest that the costs are approximately NZ$9 million - NZ$20 million per km.

3.3 Bus On-street

3.3.1 Modal Attributes

Buses are flexible, and are a comparatively cheap system to operate compared to other public transport modes. However, in terms of attracting significant percentages of people away from the private vehicles, standard buses[2] operating on local street networks do not generally provide as high priority and/or public image as other public transport modes.

Case studies for bus on-street and trolley bus have not been investigated in detail as these modes already exist in Wellington. Typical characteristics of a bus system are presented in Table 3.

Greater Wellington Regional Council is currently reviewing Wellington City bus services through the Wellington City Bus Review (WCBR), in accordance with the area-wide service review programme laid out in the Wellington Regional Public Transport Plan 2011-2021. Greater Wellington is currently consulting on significant changes to the network in early 2012. Final service changes will be dependent on the outcome of the public consultation process and will be implemented from 2013.

The WCBR has a short to medium term in focus (i.e. what can be implemented in the next three years with a ten year contract life) and must work with existing infrastructure (other than minor changes) and within existing public transport expenditure. Although services will be repeatedly reviewed on approximate five to six yearly cycles, service reviews do not take a long-term focus or look at additional investment. The PTSS will therefore confirm, particularly medium to long term (10+ years) bus options on the PT Spine that require significant additional capital investment.

[2] A New Zealand standard bus is between 12.6 m to13.5 m in length and 2.60 m wide with a carrying capacity of 75 persons (sitting and standing). For further details refer to: http://www.aucklandtransport.govt.nz/about-us/publications/ManualsandGuidelines/Documents/AT-ARTA-Guidelines-Bus%20Stop%20Infrastructure%20Guidelines %202009.pdf http://www.nzta.govt.nz/consultation/urban-buses-standard/docs/nz-national-minimum-std-urban-buses.pdf

Table 3: Typical Bus Characteristics4

Vehicle capacity (Total)	75 (standard) to 110 (articulated)
Peak hour capacity (pphpd)	Up to 3,000*
Service frequency	1-10 minutes during peak
Capital expenditure (per km)	NZ$ 0.1 million - NZ$ 25 million*
Operating speed (km/h)	50 km/h-100 km/h*
Turning radii (m)	10.0 m *
Power source	Various (diesel, natural gas, hybrid, battery/capacitor electric trolley bus (overhead wires)
Station Spacing	250 m-400 m

* these figures are dependent on many factors including the degree of priority on street, whether it is a trolley, articulated or standard bus and axle configuration etc.

3.3.2 Land Use Transformation and Value Uplift

The value uplift of property adjacent or within walking distance (10 minutes) of a conventional bus service is not as measurable as seen with other modes of passenger transport. In addition, there is little attraction of new development investment due to availability of a bus service, especially on low- to mid-frequency routes.

3.4 Bus Rapid Transit

3.4.1 Modal Attributes

Bus rapid transit (BRT) is a term applied to a variety of public transportation systems using buses to provide faster, more efficient service than an ordinary bus line. Often this is achieved by making improvements to existing infrastructure, vehicles and scheduling. The simplest form of BRT can typically comprise of bus lanes and signal priority allowing buses to queue jump at congested points in a network. A higher specification BRT system can be fully grade separated with specialised vehicles.

Key elements that identify BRT over standard bus services is a higher overall passenger experience, more frequent service, improved reliability and travel speeds. This is achieved as BRT systems are predominantly a segregated facility, with enhanced stops, providing buses the absolute right-of-way priority.

The following photos illustrate examples of BRT systems operating in Brisbane, Australia and Xiaman, China.

Figure 2: Examples of BRT Systems

South East Busway, Brisbane

An exclusive BRT system operating adjacent to the motorway

Xiaman Busway, China

An exclusive busway operating on a elevated structure within a urban corridor

Table 4 provides a summary of the typical BRT characteristics drawing on the findings of the case studies and international publications for BRT systems.

Table 4: Typical Bus Rapid Transit Characteristics[4]

Vehicle capacity (Total)	60-150
Peak hour capacity (pphpd)	1,000-36,000 1,000-40,000 (world bank estimate)
Service frequency	<1-10 minutes during peak
Capital expenditure (per km)	NZ$ 0.5 million - NZ$ 75 million[3]
Operating speed (km/h)	40 km/h-100 km/h (lower speeds operate in Transit Malls)
Turning radii (m)	7.0 m –13.1 m (subject to vehicle axle and length)
Power source	Various (Diesel, Overhead Electric, Hybrid e.g. use of battery in city centres a range of 3 km–4 km)
Station Spacing	500 m-1,000 m

[3] Capital expenditure is dependent on treatment and construction e.g. bus lanes and/or exclusive right of way for buses.

3.4.2 Patronage and Travel Patterns

The peak hour capacity of a BRT is dependent on the extent of the exclusive right-of-way, size of vehicle and service frequency. For example, the Xiamen, China system can handle 7,900 passengers per hour in the corridor whereas the Adelaide O'Bahn carries around 36,000 passengers per hour in the peak direction. Other systems such as Bogota in Colombia claims to be able to handle 67,000 passengers per hour in a corridor.

3.4.3 Land Use Transformation and Value Uplift

Beijing, Brisbane, Bogota and Curitiba are but a few locations where BRT is having a positive impact on land development. Beijing's Southern Axis BRT Line 1 opened in 2004 and it is not only more affordable than LRT or MRT but is positively contributing to value uplift. Local real estate agents believe that the introduction of BRT dramatically altered land use and property values in proximity to the BRT Corridor. Estate agents estimated that people would pay a premium of 10% to 25% of rental or capital value near to the corridor. For residential properties, the average increase of 2.3% occurred between 2004 and 2009 within a 500 m radius of a BRT station compared to those not served by BRT. In Bogota, Colombia, the value uplift strongly related to the access on foot with rental properties increasing between 6.8% and 9.3% for every five minutes of walking time to the BRT Station. Properties around the Brisbane BRT have recorded increases of up to 20% when compared to surrounding suburbs. However, the Brisbane BRT is a highly prioritised BRT system that has very high service frequencies.

3.4.4 Success Factors

The design of BRT systems overall are successful where buses are given preferential treatment throughout the corridor and where the design of the BRT system reverts to street running in city centres e.g. signal priority and bus lanes are provided.

The success of BRT is also dependent on its operation with most case studies showing that they are operated under the responsibility of one transit authority which is responsible for operational and maintenance issues of the system and buses.

Conventional BRT is significantly cheaper than guided busways and offers greater flexibility when additional buses are required to operate within the corridor, e.g. during special events or higher peak capacity periods. However, many cities are not suited to BRT without significant land purchases or road space reallocation.

BRT is a more realistic option, with lower costs for a city unable to support LRT or MRT. A key success factor is offering many of the service quality features of light rail at a lower cost.

3.4.5 Design and Operation Considerations

The design and operation of BRT is influenced by the spatial environment and policy frameworks for passenger transport investment. The following highlights some BRT examples:

- The Cleveland BRT system operates for 6.6 km within the general street environment, however this includes a section of about 4.4 km's with dedicated central median lanes. The lack of dedicated central median lanes throughout the 6.6 km scheme contributes in-part to some restrictions on the travel speeds, reducing the travel journey time benefit, resulting from high pedestrian movements and frequent number of intersections within the city centre. Measures to enhance operational efficiency include increased speed limits for buses within lanes, signal priority and limiting general traffic movements at some intersections.
- The Adelaide O-Bahn is an example of a guided busway designed to serve long distance commuters. This system operates in its own right of way (only specially fitted vehicles are able to use the guide way), is fully grade separated, has limited stops and a narrow corridor (approximately 8.0 m). The guide way and limited stop spacing enable high operating and running speeds (average 50–60 km/h operation with maximum 100 km/h operating speeds). Buses come off the guide way to enter the city and operate as on-street buses with associated priority issues.
- China's Xiamen BRT is an exclusive elevated busway, with station spacing varying between 800 m to 1 km. The elevated BRT system was designed to improve low bus speeds during peak hour congestion and serves an area of intense activity which the existing railway system does not adequately service, as shown in the map in Appendix C. The use of an elevated solution can be applied in congested cities where there is sufficient space to accommodate the support piers, and the street reservations are wide enough to accommodate the elevated structure and stations at an aesthetically acceptable distance from the buildings, e.g. privacy/visual issues associated with building windows, light penetration into the street below.
- Auckland's Northern busway is mainly a dedicated busway operating alongside State Highway One. It allows buses to travel at higher operating speeds of 100 km/h and 80 km/h on approach to bus stations without the restrictions of other general traffic and congestion.

- Brisbane's South East busway also operates at similar speeds along the South East Freeway in dedicated grade separated lanes and bus only tunnels. To enter the CBD, buses are required to re-enter the public street networks which may reduce travel time gains if no priority treatments operate.

Table 5 highlights some of the key design and operational factors of BRT over standard bus services drawing on the international review of existing BRT systems.

Table 5: Typical BRT Design and Operational Factors

Design Factors	Operational Factors
- Priority treatments at intersection where BRT merges with general traffic (entry/exit gateways). - Improved passenger transport vehicles, marketing and branding to improve the image of public transport. - Streetscape improvements, pedestrian provisions part of corridor revitalisation and economic development. - BRT stations and interchange facilities located for quick transfers, access to significant buildings, open spaces and park and ride facilities. - For alignments with high levels of segregation there is also potential for subsequent upgrade to LRT if there is further growth in demand. - Station/stop designed with good weather protection, safety, information and 'off bus' fare collections to allow faster boarding and alighting. - Lane width of 3.5 m to 4.0 m is recommended depending on system design. The width of lanes at stations may be 10 m to permit overtaking and manoeuvring. As such the total width of the busway may be in the order of 8 m to 18 m wide excluding park and ride and buffers between adjoining land use. - Buses operating often branded and supporting by marketing and image campaigns.	- Operational Speeds – a fully segregated BRT corridor with exclusive right-of-way from general traffic/ pedestrian environment can minimise operational issues vs BRT systems operating within the general streetscape environment. - BRT single lanes/station design – during peak periods buses can queue on approach to bus stations, hindering travel time reliability of buses unable to overtake buses at stations. - Traffic Signal Priority – a lack of traffic signal priority for buses entering / existing the BRT system, results in slower speeds than planned. - Noise, emissions and vibration associated with buses operating at the elevated level will be dependent on the frequency of buses, the age of vehicle technology operating and the maintenance of vehicles. The degree of nuisance will be subjective and dependent on the surrounding land use and proximity between adjoining uses to structures. - Use of ITS technology and monitoring to ensure more bus passenger efficiency. - Buses operating on BRT systems are often longer in length for example, with some bus types e.g. double articulated bus better suited to the straight alignments with minimal or no sharp/ steep gradients.

3.4.6 Corridor and Station Layouts

The configuration of a BRT network is dependent on the type of system adopted based on funding and spatial requirements. A BRT corridor could potentially operate either alongside existing routes (e.g. Lambton Quay, Jervois Quay) as a dedicated facility integrated into the central median or designed to take over the entire or partial sections of the corridor (e.g. Bogota in Colombia or Portland in USA). The lane width for a dedicated bus lane is typically 3.0 m to 3.5 m, or between 3.5 m to 4.0 m for central medians or own right-of- way subject to the BRT operating speed. A desirable lane width of 3.5 m to 4.0 m is recommended for BRT lanes across all corridor types with the exception of guided systems operating at higher speeds in smaller corridors requiring greater amounts of infrastructure. The overall corridor width will significantly increase at stations due to the introduction of space required for the station platform unless these are integrated within the roadside pedestrian realm. In addition, a typical lane width of 10 m at a station would permit overtaking and manoeuvring. As such, the total width of the busway at stations may be in the order of 8 m to 18 m wide and excludes any additional land required such as buffers between adjoining land use.

Typical BRT station spacing varies between 500 m within high density and downtown locations to 1 km or greater for longer commuting distances. Stations typically are located and accessible either at-grade or via lifts and stairs to elevated or underground platforms with pedestrians segregated from all busway lane operations. Platforms can be arranged to cater for larger numbers of vehicles, with boarding and alighting predominately operating at kerb-side platforms with single or multiple bus bays.

Fare collection systems are either fare gate or honour system (via the use of on-board contactless cards) in order to reduce delays. Use of optical guidance systems that facilitate precision docking can also assist with reducing delays at stops.

Stations are typically modern with clutter free spaces, improved security, retail spaces where room permits and real time information on services and may include provision for cyclists e.g. showers and bike storage. Where space permits stations are designed to allow overtaking lanes for express and skip stop services to operate. Both Auckland and Brisbane enable buses to bypass stops unlike Xiamen BRT which does not allow buses to pass and thus restricts bus throughput capacity.

3.4.7 Financial

The capital cost for BRT is relative to the complexity of services and infrastructure investment. For example, if bus lanes with signal priority at intersections and bus stop shelters is the only infrastructure built the cost per kilometre can range between NZ$500,000 to NZ$2.0 million[4] depending on the surrounding environment. In contrast, a BRT System which features grade separation, tunnels or elevated structures can range between NZ$5 million to NZ$75 million per km. Table 6 highlights capital cost associated with six case studies.

The operational cost for BRT is a reflection of the technology, fleet and vehicle types. For BRT systems which use standard or articulated buses, the operating costs will be similar to regular city buses. However, BRT systems which operate on guided bus ways with custom vehicle types such as the O-Bahn in Adelaide and Phileas in Eindhoven in the Netherlands typically have higher operational and maintenance costs. The range of operational costs for bus vehicles operating on BRT systems is between NZ$0.66 million to $6.2 million per km.

Table 6: BRT Capital Costs per km (Appendix C also refers)

BRT Line	Approximate Capital Cost per Kilometre
Adelaide, Australia	NZ$10.5 million
Brisbane, Australia	NZ$74 million
Cleveland, USA	NZ$23.4 million
Denver, USA	NZ$64.6 million (NZ$62.1 million for Mall)
Xiamen, China	NZ$17.4 million
Nantes, France	NZ$12.7 million
Rouen, France	NZ$8 million
World Bank estimate	NZ$18 million

3.5 Light Rapid Transit

3.5.1 Modal Attributes

Light Rapid Transit (LRT)[5] normally runs on a dedicated alignment but can share road space with other users. LRT is more cost effective in dedicated road reserves as opposed to elevated corridors due to the additional cost involved and the impact the structure has on the streetscape.

Figure 3 illustrates types of LRT operating systems.

Figure 3: Examples of LRT Systems

Portland, Oregon LRT **Frieburg, Germany, LRT**

LRT operating within shared pedestrian environments
Source: Tobias Benjamin Kohler

Table 7 provides a summary of typical LRT characteristics drawing on the findings of the case studies and international publications for LRT systems.

[4] Typical mode characteristics were derived from the case study findings and other publications. Outliers were removed, where appropriate.

[5] For the purpose of this report LRT covers trams. Trams are generally smaller, slower speed, less prioritised vehicles.

Table 7: Typical Light Rapid Transit Characteristics[4]

Carriage capacity	110-350
Peak hour capacity (pphpd)	3,500-20,000+ 12,000-36,000 (world bank estimate)
Service frequency	40-90 seconds peak 5-12 minutes off-peak
Capital expenditure (per km)	NZ$12 million to NZ$141 million
Operating speed (km/h)	60 km/h–120 km/h
Turning radii (m)	10-25 m (subject to the vehicle type and length)
Power source	Overhead/Battery
Station spacing (m)	500 – 1,000

3.5.2 Patronage and Travel Patterns

The peak hour capacity of an LRT is dependent on vehicle length (i.e. carriage sets) and the frequency in which the service operates, corridor location and integration with surrounding land use activity. The range of throughput achieved is between 6,000 and 20,000+ passengers per hour. Success has been achieved where LRT systems have:

- Supported compact land use development on corridors and around stations for example, C-Street LRT San Diego, creating economic stimulus and new forms of urban development, e.g. transit oriented development is a common feature of many LRT systems built in the USA[6] and redefining urban and suburban growth.
- Preserved historic towns and supported pedestrian “car free” environments, e.g. Freiburg LRT Germany.
- Responded to existing and/or new travel patterns to reduce congestion levels and vehicle km’s travelled, e.g. Bergen Bybanen (Line 1) Norway.

It is worth noting that for LRT case studies reviewed, the projected passenger forecasts are often surpassed with future lines and supporting transit orientated developments planned to accommodate increased growth as illustrated on the Hiawatha Line, Minneapolis, whereby several stations on the LRT route are designated as “catalyst” stations predicted to attract 7,000 new housing units. In December 2010, the reality was 8,100 new housing units constructed with another 7,700 proposed by developers.

3.5.3 Land Use Transformation and Value Uplift

LRT (and MRT) systems have a dramatic effect on property values around stations and the corridor. Both systems are more likely to attract development and increase property values more than conventional bus transit systems as there is more certainty around LRT and MRT as these are fixed systems, not flexible like on-street bus systems.

Expected property prices – globally for commercial and residential within 200 m to 500 m of an MRT route it can be in the range of 15% to 25% depending on the location of the property to the stations compared to properties 1.5 km away. European cities show that the price premium for office space is 23% higher when compared to 8.9% for residential accommodation in close proximity to stations.

3.5.4 Success factors

The growth of LRT networks, more so than other passenger modes have been supported by comprehensive and progressive land use and strategic planning that has sought to maximise potential modal shift away from private cars in order to reduce congestion within city centres[7].

The success of LRT networks is through the sustained political will and commitment of transport and urban development authorities, backed by public engagement. It has resulted in cities like San Diego, Freiburg and Bergen being recognised as models of sustainable travel. For example, the Bergen Bybanen LRT was recently named at the 2011 Global Light Rail Awards as the Light Rail Project of the Year.

LRT routes serve a wide range of land uses connecting residents to places of employment e.g. CBD/downtown areas, medical and educational facilities and places of recreation etc. They are seen by many as an environmentally friendly and efficient mode of travel reducing some of the negative impacts of single occupancy vehicles. It is important to recognise from the case studies reviewed that the LRT network has demonstrated it is part of multi-modal transport system linking to bus services, metro and heavy rail systems in order to provide integrated passenger transport services throughout an area.

[6] The New Urbanism Movement which includes the work of founding members like Peter Calthorpe strongly advocate pedestrian pocket neighbourhoods and transit oriented development. Calthorpe has been named one of 25 “innovators on cutting edge” for redefining urban and suburban growth in America (www.calthorpe.com)

[7] Ascari (2010)

The decision to implement the design of LRT systems can vary significantly and is dependent on a number of influencing factors including:

- increased throughput capacity;
- addressing congestion;
- accommodating future growth by unlocking economic potential of light rail infrastructure through to revitalisation and redevelopment of land around stations to higher mixed use and housing densities.

The timescales for planning and implementation of LRT lines and networks did vary significantly between two to 30 years for the case studies reviewed. The three overarching factors influencing LRT implementation are:

1) carrying capacity and travel speeds of buses constrained;
2) funding availability; and
3) sustained commitment to passenger transport at both political and community levels.

The importance of public engagement and their commitment should be noted, as the indirect benefits to areas not served by the LRT were not seen by some to compensate for the toll charges being used to pay for the construction.

The construction cost of LRT is comparative to BRT with higher costs per km associated with schemes involving undergrounding, segregated and /or elevated structures to support alignments and stations. While Seattle chose a high cost strategy for the construction and design of its passenger transport system, it appears to be a successful approach longer term, when compared to San Diego's LRT system which was initiated as a low-cost approach to get the system up and running. While the San Diego LRT system has been successful, it has been hindered to some degree by its inability to increase capacity through land use development around older sections of the LRT network due to numerous upgrades and rehabilitation work which has been required on the earlier sections of the network. More recently extensions to the San Diego LRT system have been designed to higher standards and higher costs. Appendix C provides further details on the Seattle and San Diego studies.

The two most common constraints imposed on LRT networks are constraints on passenger throughput as a result of existing vehicle types and headway delays where LRT vehicles operate within shared street environments or are required to stop at intersections at-grade.

Overall, Light Rail systems are seen as providing environmentally friendly, efficient and a direct transport system along a corridor where there was particular high demand. They provide and offer greater travel choice for passengers and help to reduce some of the negative aspects of car travel, including movement within the city and downtown areas.

3.5.5 Design and Operation Considerations

The design and operation of LRT is strongly influenced by the spatial environment, policy and investment frameworks for passenger transport.

Table 8 highlights some of the key design and operational factors of LRT drawing on the international review of existing LRT systems.

Table 8: Typical LRT Design And Operating Factors

Design Factors	Operational Factors
- The LRT system should be recognisable and easily located in the streetscape. - Interchanges between modes should be legible and easily accessed, within line of sight where possible. - Station and interchange locations should be designed to be appropriate for the location, safe and accessible for all ages and users including those with disabilities. - Integrated provision for bike lockers at stations and the provision of commuter parking in outlying areas, e.g. Norway, USA. - Information available for all users e.g. viable message signs with automatic voice. Station staff available onsite for assistance. - Public and private retail services and government agencies are also an integral part of interchange/ station designs.	- Passenger circulation should avoid cross flows and allow for an orderly hierarchy of decision points e.g. exit/enter, ticketing purchase, platform locations are readily apparent. - Station platforms have sufficient length and width for safe queuing and are integrated with safe connections to adjoining buildings, surface and underground connections. - Where integration with traffic occurs priority is given to LRT. - Potential to increase operational capacity by inserting additional vehicles (especially where segregated).

3.5.6 Corridor and Station Layouts

LRT systems generally operate in their own right-of-way either within road corridors or within their own right-of-way located either in the centre of the road, split to the kerb lanes or double tracks on one side of the corridor. By operating in the central median they can have greater operational flexibility due to reduced side friction from other vehicles turning in/out of side roads. The distance between intersections (blocks of buildings) will also influence the corridor design and station spacing. It is noted from the case studies that block lengths less than 300 m reduce the number of carriages a LRT system is able to operate. Another consideration is the width of LRT vehicles; a common width of vehicles is 2.65 m allowing for greatest flexibility in manoeuvrability of LRT vehicles within city centres.

Station layouts will be central island platforms or side running platforms, depending on corridor and track configuration. The most common means of accessing platforms is via at-grade pedestrian crossings or in some cases via pedestrian overbridges or via underground stations. Platforms accommodate low floor LRT vehicles which provide access for wheelchair users to all stations and reduce dwell times via the elimination of wheelchair lifts.

The corridor width for newer LRT systems is between 5 m to 10 m depending on corridor configuration of tracks and width of vehicles operating with additional space required to accommodate stations and intersections. Station spacing is similar to that of BRT. Typical LRT spacing varies between 500 m within high density and downtown locations to 1 km or greater for longer commuting distances and are designed with similar features to that of BRT.

3.5.7 Financial

The capital cost for LRT, like BRT, is relative to the complexity of services and infrastructure investment. For example, the costs of LRT systems operating exclusive right-of-ways (either at-grade or elevated), can start from NZ$12 million. This rises if the system needs to be elevated and /or tunnels are required. For LRT which operates within partial or shared street environments the cost per kilometre can start at NZ$15 million and quickly increase depending on the surrounding environment and construction methods. For example, the total cost of Portland Transit Mall, established in 1978, is estimated to be NZ$19.36 billion to date with LRT vehicles replacing the number of buses servicing the Mall. Table 9 highlights capital cost associated with several case studies reviewed (Appendix C also refers).

The operational cost for LRT is a reflection of the technology operating and fleet and vehicles types. Vehicles purchased should be able to operate on existing lines without imposing higher operational and maintenance costs. The range of operational costs per kilometre is between NZ$1.2 million to NZ$3.5 million in a year.

Table 9: LRT Capital Costs per km (Appendix C also refers)

LRT Line	Approximate Capital Cost per kilometre
Bremen, Germany	NZ$16.7 million
Bergen, Norway	NZ$46.4 million
Karlsruhe, Germany	NZ$29.4 million
Edmonton, Canada	NZ$11.5 million
Gold Coast, Australia	NZ$31 million
Minneapolis, USA	NZ$44.8 million
San Diego, USA	NZ$25.0 million
San Francisco, USA	NZ$28.6 million
Dublin, Ireland	NZ$56.9 million
Eidenhoven, Netherlands	NZ$11.6million
Rouen, France	NZ$50 million
Seattle, USA	NZ$275 million (bus tunnel)
St Kilda	NZ$19 million
World Bank estimate	NZ$45 million

3.6 Mass Rapid Transit

3.6.1 Modal Attributes

Mass Rapid Transit (MRT[8]) operates on dedicated stand-alone corridors and is at the high end of the passenger transport spectrum of modes for passenger carrying capacity. Mass Rapid Transit has distinctive operating characteristics. They are:

- high carrying capacity;
- operate a simple, easy to understand service pattern where every train calls at every station;
- have straightforward and self-contained lines;
- the lines could run across the urban area through the central activity district (e.g. from Johnsonville) to avoid an interchange for those people choosing to use this mode for access to the CBD; and
- Stations and routes will be more widely spaced and therefore need to be carefully selected and sited to simultaneously minimise journey time and maximise accessibility.

Good examples of MRT include Singapore's North East Line, Hong Kong and Lyon Metro Line D.

These systems required extensive upfront capital investment and can be cost effective if placed in high demand corridors, with feeder buses and other modes servicing MRT networks. Figure 4 illustrates types of MRT systems operating and connecting via surface or underground stations to businesses, shopping and most residential areas.

Figure 4: Examples of MRT Systems

Singapore MRT

Elevated structure servicing surrounding urban catchments

Source: http://www.skyscrapercity.com/showthread.php?t=202421

Hong Kong MTR

Prince Edward Underground Station

Source: http://www.panoramio.com/photo/6841129

Table 10 provides a summary of typical MRT characteristics drawing on the findings of the case studies and international publications for MRT systems.

Table 10: Typical Mass Rapid Transit Characteristics

Carriage capacity	140 - 280
Peak hour capacity (pphpd)	<30,000 - 90,000
Service frequency	20 - >40 seconds peak 5 -12 minutes off peak
Capital expenditure (per km)	$105 million (based on World Bank research)
Maximum Operating speed (km/h)	80 km/h -120 km/h
Turning radii (m)	>250 m (with some lower examples but affects comfort)
Power source	Electric
Station Spacing	800 m – 1,500 m

3.6.2 Patronage and Travel Patterns

MRT and Heavy Rail (regional commuter services) can have very similar capacities in terms of both passengers per vehicle and passengers per hour. MRT systems operate on a segregated right-of-way which may be either partially underground or elevated structures within cities. While most MRT systems are primarily radial, a number of orbital lines have been built to provide for more comprehensive network coverage in response to growth patterns and the need to reduce congestion. Some extensions to MRT lines include spur lines to

[8] Hong Kong refers to MRT as MTR. For simplicity MRT is referred as a more commonly used abbreviation in this report.

expo centres and airports (Appendix C provides illustrations).

The peak hour capacity of an MRT is dependent on train length (i.e. carriage sets) and the frequency at which the service operates, corridor location and integration with surrounding land use activity. The range of throughput achieved is between 30,000 and 62,000 passengers per hour. High levels of patronage have been achieved where:

- MRT systems have supported compact land use development on corridors and around stations for example, Singapore MRT systems are the back-bone to the cities/state transport network to accommodate high density populations within compact land constraint areas.
- Comprehensively planned MRT systems can respond to existing and/or new travel patterns to reduce congestion levels and vehicle kms travelled.
- MRT systems may replace other PT systems if the patronage increases significantly.

It is worth noting that for the MRT case studies reviewed, the projected passenger forecasts are often surpassed with the need for future lines and supporting transit orientated development planned to accommodate increased growth, for example San Francisco BART, Washington and Miami Metros have experienced increased ridership.

3.6.3 Land Use Transformation and Value Uplift

MRT systems have a dramatic effect on property values around stations and the corridor. Value uplift is similar to that noted in LRT.

3.6.4 Success Factors

MRT networks have been supported by comprehensive and progressive land use and strategic planning, which has replaced or supported existing forms of passenger transport modes e.g. buses reduce congestion within city centres. The success of MRT networks is through the sustained political will and commitment of transport and urban development authorities, backed by public engagement. For example, Singapore's LTA was convinced in 1967 that by identifying the need for a rail-based urban transport system to facilitate growth and movement of people by 1992 Singapore would see additional expansion in response to the transport authority's "*A World Class Land Transport System*". The report is responsible for the replacement of the bus network by rail-based transportation as the primary mode of passenger transportation. It is anticipated that daily ridership in 2020 will have grown to 4.6 million from the current 1.4 million passengers.

The addition of lines currently under construction and those approved for construction will bring the MRT network to 278 km by 2020. More recently LRT has also been developed in Singapore to complement the MRT by bringing people almost directly to their homes. However, this has not been as successful as anticipated with buses and taxis providing more direct door to door connections. MRT projects take a long period to design and build and therefore can be affected by short-term political cycles, hence many successful systems operating occur where governments have longer or fixed terms and the urban form is compact and densely populated.

MRT's require extensive upfront capital investment but can be cost effective if placed in high demand corridors, with feeder buses and other modes servicing MRT networks. To be effective, the location of an MRT is critical in connecting via surface or underground stations to businesses, shopping and most residential areas providing, in some instances, venture capital opportunities for private developers and government. It is important to recognise from the case studies reviewed, that the MRT network has demonstrated it is part of a multi-modal transport system linking to bus services, and LRT in order to provide integrated passenger transport services throughout the area.

Overall, MRT systems are seen as providing environmentally friendly, efficient and a direct transport system that can be integrated into buildings, providing both surface and subterranean commercial and retail opportunities. The success of MRT is that it services high demand corridors and catchments.

3.6.5 Design and Operation Considerations

Like all passenger transport, the design and operation of MRT's is influenced by the spatial environment and policy frameworks for passenger transport investment. As such, various forms of MRT systems exist and operate globally. **Table** 11 highlights some of the key design and operational factors of MRT that are not dissimilar to LRT or Regional Rail (Heavy Rail). The following draws on international reviews of existing MRT systems.

Table 11: MRT Design and Operational Factors

Design Factors	Operational Factors
- Transit times must be minimised to encourage use. - A MRT corridor can be inserted into or near to high density commuter corridors and/or areas of high intensity, land use development. - A MRT system should be recognisable and easily located, accessible and where possible integrated with other transport modes e.g. buses, taxis, through well placed interchanges. - Station and interchange locations should be designed to be appropriate for the location and be safe and accessible for all ages including those with disabilities. Stations may be designed to support local identity incorporating art into station design to create “place identity”. - Information should be freely available for all users, i.e. variable message signs with automatic voice; station staff available onsite for assistance. - The experience of using MRT systems should be aesthetically pleasing, safe and simple.	- Well suited to driverless operation which can lead to lower operational costs. - Passenger circulation should avoid cross flows and allow for an orderly hierarchy of decision points e.g. exit/entry, ticketing purchase, platform location being readily apparent. - Station platforms have sufficient length and width for safe queuing and are integrated with safe connections to adjoining buildings, surface and underground connections. - Performance of the MRT needs to consider the geometric (curvature and gradient) conditions with respect to station spacing and the ability to integrate the station with existing buildings. - Fare collection is seamless and integrated with all other forms of passenger transport allowing for either free zone fare within the CBD or a transferable period between modes ranging from one to two hours. Fare cards used for on passenger transport with stored value may also be used for payment of other goods and service.

3.6.6 Corridor and Station Layouts

The distance between stations varies between cities ranging from 500 m – 800 m within high density and downtown locations with spacing increasing at urban fringes where the station is integrated into key shopping centres and districts along the route.

Station layouts are either central island platforms or side running (lateral) platforms, depending on corridor and track configuration. Central platforms may be ideal for stations where spatial constraints are an issue. While costs will vary, station layouts are typically narrower than the combined width of side-platforms and concourse. Other benefits of central platforms are the potential reduction in the number of escalators and lifts required to reach the surface and/or mezzanine level(s). While central platforms may be better for handling surge loads this is also seen as a disadvantage over side platform arrangements alongside issues of emergency exiting. Side-platforms while often more expensive than central platforms built underground due to wider corridor and vertical circulation required, are capable of handling higher station capacity and scheduling with the ability to accommodate future capacities via widening/ lengthening of platforms. Both platform configurations accommodate and provide access for wheelchair users, which traditionally has not been a consideration in cities like Singapore and Hong Kong where stations have been upgraded to accommodate lifts to access platforms.

3.6.7 Financial

Table 12: MRT Capital Costs per km (Appendix C also refers)

MRT Line	Approximate Capital Cost per kilometre
Singapore	NZ$ 1.2 billion expansion
Mumbai, India	NZ$ 65 million
Hong Kong, China	NZ$ 526 million
World Bank research	$105 million

4.0 LAND USE AND PUBLIC TRANSPORT TRIGGER POINTS LITERATURE REVIEW

This Chapter investigates the empirical relationships between passenger transport (PT) and land use. The aim of this literature review is to assist in understanding the interdependence between land use patterns (especially densities) and PT infrastructure and services. Key relationships considered are:

- The impact of land use patterns on PT demand;
- The impact of PT infrastructure on land use patterns; and
- Thresholds for the provision of PT infrastructure and services.

The outputs of this Chapter shed light on the PTSS sub-objective which is to understand the interdependence between land use patterns/densities and transport infrastructure and what the trigger points are for one to support the other. The literature review identifies a series of relationships between land use and PT demands drawn from literature sources examining a variety of contexts.

The relevance and magnitude of the relationships identified in the literature need to be tested and calibrated for the Wellington context. This calibration is the subject of a future piece of work for the PTSS. The outcomes of the literature review and the calibration will inform the assessment of the long and medium modal option lists as well as the land use assessments.

The literature findings are drawn from many different contexts. As identified later in this Chapter, site specific factors should be considered in each case when interpreting density parameters for PT service provision or indeed for all transport improvements. The usefulness of these findings is in creating expected ranges and in identifying key variables for later study.

4.1 Land Use and Public Transport Infrastructure Relationships

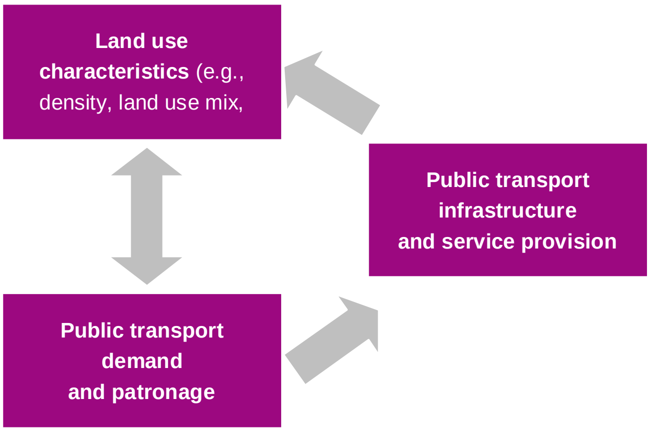
PT and land use exist in a mutually interdependent relationship. Increased PT provision tends to support more intensive land use patterns, while those areas with higher land-use densities may warrant and demand further PT services. This interdependent relationship complicates empirical analysis, because a clear causal relationship does not exist between these two factors.

For example, from this literature review it will not be possible to conclude that the intensive land use patterns around Wellington's train station are purely a result of PT accessibility. Indeed, there are many other reasons why more intensive land use patterns have emerged in the same areas as PT infrastructure and services, such as proximity to waterfront port areas. Isolating the impacts of these compounding factors is therefore a key focus of the international literature.

Land use characteristics and passenger transport demand patterns have a mutually reinforcing relationship with each having a measurable impact on the outcomes of the other. Land use outcomes will also be influenced by the passenger transport infrastructure in a certain area, which is in turn determined by passenger transport demand and patronage levels to drive these improvements.

Figure 5 summarises these broad relationships.

Figure 5: Illustration of the Land Use and Passenger Transport Relationship



4.2 Impact of Public Transport Infrastructure on Land Use

There are a number of land use characteristics that are likely to influence the travel patterns associated with particular geographic areas. The literature in this area focuses on PT patronage as the key outcome of interest, examining both the frequency of usage and also distance travelled. The most relevant land use factors that impact on PT patronage are summarised in Table 13, adapted from Litman and Steele (2011).

Table 13: Impacts of Land Use on Transport Outcomes (Litman and Steele, 2011)

Land Use Factor	Definition	Relation to Passenger Transport Demand
Density	People or jobs per unit of land area	Correlates vehicle ownership and travel and increases use of alternative modes (including PT)
Land use mix	Proximity between different land uses (housing, commercial, institutional)	Reduces vehicle travel and increases use of alternative modes
Regional accessibility	Location of development relative to regional urban centre	Reduces per capita vehicle mileage. Central area residents typically drive 10-40% less than those at the urban fringe
Centredness	Portion of jobs and other activities in central activity areas	Increases use of alternative modes. Typically 30-60% of commuters to major centres use alternative modes compared with 5-15% at dispersed locations
Roadway design	Scale, design and management	Multi-modal streets increase use of alternative modes
Transit quality and accessibility	Quality of transit service and access from transit to destinations	Increases PT ridership and reduces automobile trips. Residents of transit oriented neighbourhoods use alternative modes 2-10 times more than other areas
Site design	Whether oriented for auto or multi-modal accessibility	More multi-modal site design can reduce automobile trips
Integrated smart growth programs	Travel impacts of integrated programs that include land use management strategies	Reduces vehicle use and increases alternative mode use. Smart growth community residents typically drive 20-40% less and use alternative modes 2-10 times more than other residents

Four of these land use factors are seen to have a much greater impact on PT patronage:

- Density of residents and employment;
- Land use mix;
- Distance to central city area; and
- Street connectivity (roadway design).

The impact of these land use factors on transport outcomes have been studied extensively across the international literature. While the focus is more often on the impacts of private vehicle travel, there has also been significant research undertaken into how land use impacts on passenger transport patronage. This has been studied using both qualitative analysis and also regression modelling of both single and multi-variable land use factors (Litman and Steele, 2011). Impact by PT patronage levels in the international literature is outlined below.

4.2.1 Residential and Employment Density

Both population and employment density have significant impacts on transport patterns across urban centres. Population density in residential areas has been studied in relation to all forms of transport outcomes, and is of particular interest to PT planners and academics alike, looking for links between densities and appropriate service levels and modal types as cities expand. Employment density is approached in a similar way, as the level of commuters in an area can be linked to the potential demand for PT services.

4.2.2 Residential Density

Residential density remains one of the most studied land use components in relation to the impacts on transport. There are a number of compounding factors, but increased residential density has been illustrated across the literature to both decrease household private vehicle travel and increase the use of alternative modes, including PT and active modes (walking and cycling). In a study investigating the links between household characteristics and transit patronage, Beaton (2006) found that local density had a greater impact on the level of transit patronage than household income – which has historically been a reasonably significant indicator of patronage levels.

Krizek (2003) analysed travel data from 2,000 households to investigate the effects of neighbourhood and regional accessibility on mode choice and vehicle travel in the Puguet Sound Region, Washington State from 1989-1996. His measure of neighbourhood accessibility combined three variables: population density, land use mix, and street patterns. Results showed that increased neighbourhood and regional accessibility was associated with a reduction in the distance travelled, but this was slightly offset by an increase in the number of trips that were undertaken. The number of trips taken by alternative modes also increased as all three variables increased, particularly population density.

Vance and Hedel (2007) analysed German data on 4,328 individual travellers in 1,899 different postcodes for the period 1996-2003. They considered the effects on vehicle mode share and vehicle travel for four urban form variables: accessibility to PT, street density, commercial density, and commercial diversity. They found that both accessibility to PT and commercial density reduce the likelihood that people will travel by car, with elasticity calculated of 3% and 5% respectively.

Cervero et al (2004) also examined both residential and commercial density to investigate the impact of these factors on transit ridership in areas surrounding train and bus stations. They found that increases in both measures of density, combined with improved connectivity of pedestrian infrastructure lead to statistically significant increases in transit ridership. In particular, increasing residential density around a transit station from 10 to 20 units per gross acre was found to increase the commuting share of transit from 20% to 24%. If these were combined with pedestrian infrastructure improvements, average commuting share increased to 28%.

4.2.3 Employment Density

Barnes (2003) argues that employment density may in fact affect commuting mode share even more than residential density. This is attributed to a number of factors, including a greater scale for the operation of efficient PT services and increased competition for parking space in employment centres. The impacts of employment density are often researched along with the distance to the central areas, as these two factors tend to have a strong influence on each other.

Frank and Pivo (1995) also investigated employment densities and the impacts on travel patterns, finding that private vehicle commuter travel declines significantly when workplace densities reach 50-75 employees per gross acre. Their findings indicate that there may be a threshold of employment density at which PT services should be prioritised, and this is discussed further in Section 4.4. Barnes and Davis (2001) found similar results, that increasing density of employment in central areas encourages both higher transit usage, and also ridesharing, leading to a significant reduction in single occupancy vehicle travel.

Susilo and Maat (2007) considered the influence of urban form on trends in commuting journeys in the Netherlands, using data from 1985-2005. As expected, jobs-housing balance reduces cross-commuting between cities, while proximity to train stations increases PT patronage. They caution that the effects of urban form on travel patterns do not appear to be static and may in fact change over time.

4.2.4 Land Use Mix

Patterns of various land use activities taking place also impact on the level of PT patronage that an area will be able to support. In general, established corridors that link residential areas with employment centres are likely to see high PT patronage levels. Similarly, areas that have a significant diversity in land use tend to support higher levels of alternative mode travel, reflecting both inward and outward travel. Ewing and Cervero (2010) found that mixed use area residents are significantly more likely to commute by alternative modes, controlling for both the location of the neighbourhood and surrounding density levels.

The difficulty in analysing the impacts of land use mix on transport outcomes results from the fact that it is a less quantifiable measure of a neighbourhood than other factors like employment density. As a result, these are typically measured by indices which attempt to quantify the diversity of land uses in a close proximity. Researchers tend to use either entropy indices, which calculate the number of different uses in a neighbourhood as a proportion of the total number of parcels; or dissimilarity indices, which calculate a ratio of the number of adjacent parcels that have different land uses in a certain area (Litman and Steele, 2011).

A significant area of the literature examines the impacts of transit oriented developments (TOD), which often have much higher land use mixes than automobile-centric developments. Gard (2007) found that TODs typically increases per capita transit ridership from between two to five times, while also reducing total vehicle trip generation by between 8% and 32%, compared with conventional land use development.

Ohland and Poticha (2006) use these indices to investigate the impacts of both land use mix, and transit provision on modal share of total trips in Portland, Oregon. They first classified each neighbourhood and then surveyed average modal splits within each category. The results are shown in Table 14.

Table 14: Modal split in Portland, Oregon (Ohland and Poticha, 2006)

	Modal Share of Total Trips			
Neighbourhood Description	Transit	Active Modes	Automobile	Other
Good transit and mixed use	11.5	28.9	58.1	1.5
Good transit only	7.9	16.6	74.4	1.1
Rest of region	1.2	6.9	87.3	4.0

The results show the clear importance that good transit provision has on the use of transit for total modes, increasing from 1.2% of trips on a regional average to 7.9% for those in areas of good transit coverage. However, more interestingly the results also clearly highlight the importance of mixed land use on both improved transit mode share, but also an almost doubling of active mode share. The authors point to increased variety of destinations that are able to be served by transit in such mixed use areas, but also a total reduction in the number of trips as residents have an increased number of services in their local area.

4.2.5 Distance to Central Areas

Distance of neighbourhoods to central areas (particularly employment centres) also has a major impact on transit usage. As commuting journeys have the highest transit mode share of any journey type (Litman and Steele, 2011), proximity to employment centres will have a major impact on how attractive transit is for local residents. Evans and Pratt (2007) found that the average modal split of commuters in Washington DC declines steadily moving outward from the city centre, from 75% in the downtown area, to around 10% near outer suburban stations.

SACOG (2008) assert that while access and distance to regional centres has little effect on total trip generation, they have a major effect on trip length and modal choice. People who live and work further from major centres tend to drive more, generally reflecting the lower opportunity cost of driving compared with those closer to major centres. However, recognising that there is a more standard relationship between distance to commercial centres and transit usage, the literature tends to cover this characteristic in multi-variable studies rather than investigating this at an individual level. Distance to central areas is often used as a controlling variable in studies on the impact of land use characteristics on transport outcomes.

4.2.6 Street Connectivity

Street connectivity in the context of land use characteristics refers to the degree to which a road or path system is connected, and therefore the directness of travel (Litman and Steele, 2011). Ewing and Cervero (2010) find that intersection density and street connectivity of neighbourhoods has the second greatest impact on travel activity of all land use factors analysed, following density levels. Larco (2010) indicates that increasing connectivity in suburban developments significantly increases use of alternative modes. Residents of more connected developments were more likely to use transit options for all types of journey, and also more than twice as likely to use active modes as those residents in less connected neighbourhoods.

In investigating the impacts of these on passenger transport patronage levels, the most studied factors relate to the connectivity of streets to local transit stops. Bento et al. (2003) examined the impacts of road distance to rail transit stations on household travel patterns, finding that a 10% reduction in distance reduces total vehicle minutes travelled (VMT) by about 1%, and that a 10% increase in the number of rail services further reduces driving 4.1%.

Evans and Pratt (2007) also investigated this relationship in relation to passenger transport patronage, finding that transit mode share for commuting trips decreased by twelve percentage points for every additional 1,000 feet of distance between home and a local rail transit stop. In a similar study Lund, Cervero and Wilson (2004) found that residents living in close proximity to transit stations are five times more likely to commute by transit than the general population.

Beacon (2006) in a study of neighbourhoods in the Boston region looked specifically at those within a close proximity to commuter rail stations. He found that those located within a 10 minute drive not only had higher transit ridership than all other areas, but also that these areas supported both higher land use densities, and had lower commercial property vacancy rates. His study also highlighted the lasting impacts that urban form and street connectivity can have on patronage patterns. A number of neighbourhoods in Beacon's study were in close proximity to rail stations that had faced degradations in service provisions since the 1970s. However despite these reductions the neighbourhoods still retained high rates of transit ridership, indicating that urban form can have as much of an impact on transit patterns as transit provision itself.

4.3 Impact of PT on Land Use Patterns

As noted previously, transport infrastructure can also have a major impact on land use outcomes. While passenger transport infrastructure is limited in relation to general transport infrastructure (particularly roads) in most Western cities, they are still able to have a major shaping influence on land use patterns. Passenger transport infrastructure and the resulting patronage patterns impact not only the types of activities that develop in certain locations, but also the densities that can be supported, and the resulting land values. In the context of this project, we are particularly interested in how *changes* in passenger transport infrastructure can impact on land use patterns. As such, in this section we discuss the impacts of passenger transport investment on both primary land use outcomes of land use mix and densities and also secondary impacts of land values and productivity.

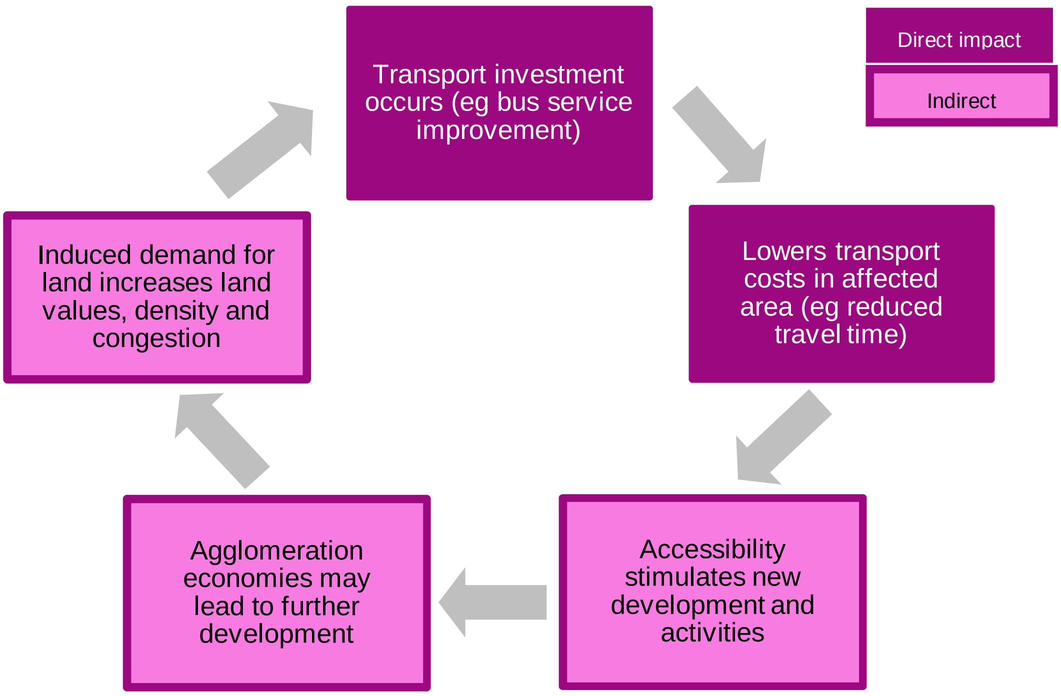
The impacts of transport on land use – in particular urban form – have received more attention in recent times. The National Infrastructure Plan observed (National Infrastructure Unit, 2010):

Major infrastructure projects, especially transport projects, can have a significant impact on the location and form of economic activity in our cities: they tend to shape urban development, guiding or influencing households and firms to make particular locational choices. In this way, the decisions made about where, when and what infrastructure is constructed, whether it is significant transport investment or social infrastructure investment, such as schools and hospitals, can have a significant influence on the future anatomy of a city, locking in patterns of demand for generations

This statement highlights the link between transport and *locational choices*. Transport investments have impacts that extend beyond their effects on travel costs – they also impact on where people choose to travel to undertake the activities that support their lifestyles. Efficient transport infrastructure can lower commuting costs and increase accessibility, which subsequently supports greater levels of development and can have positive impacts on economic indicators such as land values and economic productivity.

A visual representation of the relationship between transport investment, travel demands, and land use outcomes is shown in Figure 6. The direct effects of a change in transport infrastructure are in the dark red boxes, which show how a particular transport investment can lower transport costs in a particular area. This is where traditional economic analyses typically stop – that is, they do not consider the *induced demand* associated with changes in development and activities (those in the light boxes), which may ultimately bring the situation back to its original stating point.

Figure 6: A cyclical relationship exists between transport investment and land use outcomes

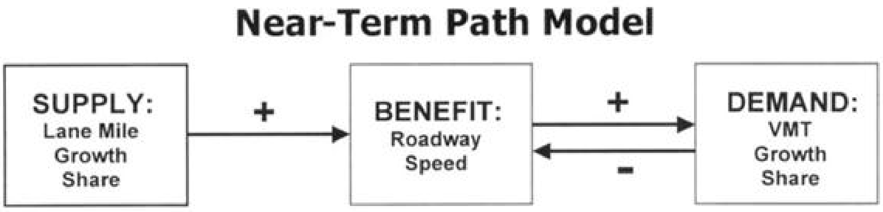


Thus, in places where transport investment deliver transport cost savings that are sufficiently large to impact on the location of future development, travel-time savings are not a robust indicator of the economic benefits that may result from the project. Induced development will mean that travel-time savings are only a transient phenomenon that are quickly neutralised by increased travel demands. These reasonably intuitive observations have prompted considerable debate.

Noland (2001) investigated the relationship between highway capacity and the demand for vehicle travel. He identifies several ways in which increased road supply might "induce" additional demand for vehicle travel, namely mode shift (i.e. changing from bus to car), route changes (i.e. travelling from A to B via another route), trip redistribution (i.e. travelling from A to C instead of A to B), generation of new trips (i.e. more frequent trips from A to B), and land use changes. Noland's analysis suggested that extra highway capacity is in the long run almost completely off-set by induced demand, with long term effects more than twice as large as the short term impacts – which suggest that a large amount of the induced demand effects are likely to stem from change in land use, rather than behaviour.

Such results were criticised, however, on the grounds that they did not adequately control for the fact that road capacity is usually provided in advance of demand growth. To investigate the validity of these objections to the induced demand hypothesis, Cervero (2003) presented a more refined path analysis, shown in Figure 7.

Figure 7: Path analysis of the impacts of transport on land use and development (Cervero, 2003)



Cervero goes on to develop and apply an empirical model to attempt to disentangle these various near and long term effects, as illustrated below. Results provide robust evidence to support both hypotheses – that is, the supply of transport infrastructure does induce considerable additional demand while increased demand also induces additional transport infrastructure (+0.49). The main source of the additional demand seems to come from changes in behaviour (+0.64), while changes in development activity are less important (+0.17). These are summarised in Figure 8. On balance, there is fairly clear evidence that the effects of transport improvements do not stop at lower transport costs.

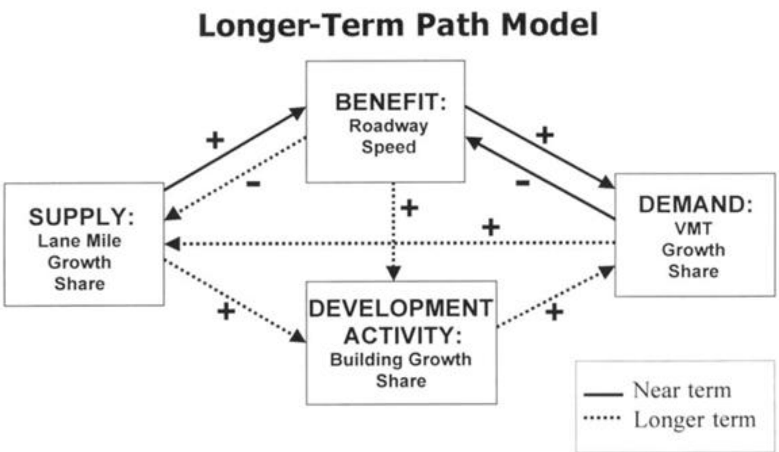


Figure 8: Impacts of transport on urban form (Cervero, 2003)

Cervero's (2003) study highlights the difficulty in separating short and long term effects on land use of each transport improvement. As such, most of the literature looks at total effects, rather than direct impacts of transport changes. Melo et al. (2010) analyse the effects of road and rail infrastructure on the formation of new firms in Portugal. They find that a 10% expansion in a local rail and highway networks is associated with an increase in new plant openings in that area of 0.9 to 2.7% (rail) and 0.7 to 2.6% (highway). The effects of local improvements are found to have "spillover" benefits for plant openings in neighbouring regions. As expected, expansions in the rail network tended to benefit primary industries whereas expansions in the highway network were felt more strongly in financial services, business, education, and health.

Analyses of the impacts of transport improvements on secondary economic impacts have also received attention in the literature, particularly the impact on land values. Song and Knaap (2003), for example, consider 50,000 property transactions in Washington County, covering ten years from 1990-2000. They include a wide range of variables including transport network connectivity, land use density, land use diversity, and pedestrian walkability. Ultimately, results suggest that residents are willing to pay a premium of around 15.5% for high quality urban areas, where most of the value is associated with features of the street network. In a similar, Enström and Netzell (2008) model the effects of street network connectivity on commercial office rents in Stockholm, Sweden. They find that a 10% increase in the degree to which a street is connected to surrounding streets is associated with a 5-10% increase in commercial office rents. While not directly pertaining to public transport infrastructure, we note that these street improvements are often also present in those areas with good transit coverage and service provision.

4.4 Thresholds for PT Demand and Land Use Patterns for the Provision of PT Infrastructure

The realm of determining appropriate thresholds for passenger transport infrastructure has typically been the responsibility of government organisations, at either a regional or national level. As such, the literature in this area is limited to either conceptual discussions of the correct metrics to use for developing such thresholds, or evaluations of projects post-implementation to determine whether the costs of such projects have been justified by projected patronage increases.

As discussed in Section 4.2, residential and employment densities are only two of the many land use characteristics that may help to determine the appropriateness of various passenger transport infrastructure improvements. In one of the most comprehensive reviews of density thresholds, Demery et al. (2005) discuss at length the development process for density thresholds of rail transit in New York. The authors mainly look to build upon the work of Pushkarev et al. (1982) whose report established minimum traffic densities for low-cost light rail transit. In doing so, they establish threshold criteria for enhanced bus and rapid transit facilities, but also offer insights into how thresholds are developed in a wider passenger transport context.

Pushkarev et al. (1982) suggested five criteria that would need to be met to support the development of rail infrastructure in New York. These were the ability to attain:

- desired passenger space and service frequency;
- labour savings over bus operations;
- energy savings;
- land savings; and
- an efficient level of investment per unit of service provided.

They determined that the most effective way to ensure that infrastructure and service provision improvements met these criteria would be to determine threshold levels based on travel densities – that is the total number of people travelling along a particular route each day as a proportion of the total distance of the route.

Demery et al. (2005, p34) while finding that the conclusions of Pushkarev et al. have been "corroborated to a remarkable degree by similar analysis from other developed economies", advise caution in using peak hour density volumes as the exclusive determinant for PT service levels. While the threshold levels established by Pushkarev et al. were deemed to be conservative based on patronage levels actually achieved over time, Demery et al. argue that these thresholds alone should not provide sufficient evidence to build rail transit in any city. Instead, they assert that site-specific issues should be understood and addressed when considering both potential transport improvements, and also planned degradations of existing services.

Engineers and transportation planners have also attempted to develop generic threshold levels that theoretically would support various passenger transport service levels. There has been significant focus on linking these to residential densities.

Table 15 summarises those established by the Institute of Transport Engineers in 1989, which were still being used as recently as 2004 by the

Transportation Research Board. Ewing (1996) provided similar guidelines in his review of eleven TODs across the United States, although finding that rail services would require a much higher density (20-30 dwellings/acre) than those in the following table.

Table 15: Transit Supportive Residential Density Thresholds (Institute of Transport Engineers, 1989)

Type of Transit Service	Density threshold (dwellings/acre)
Local bus (60 minute frequency)	4-5
Intermediate bus (30 minute frequency)	7
Frequent bus (10 minute frequency)	15
Light rail (5 minute frequency in peak hours)	9
Rapid transit (5 minute frequency in peak hour)	12
Commuter trains (20 trains per day)	1-2

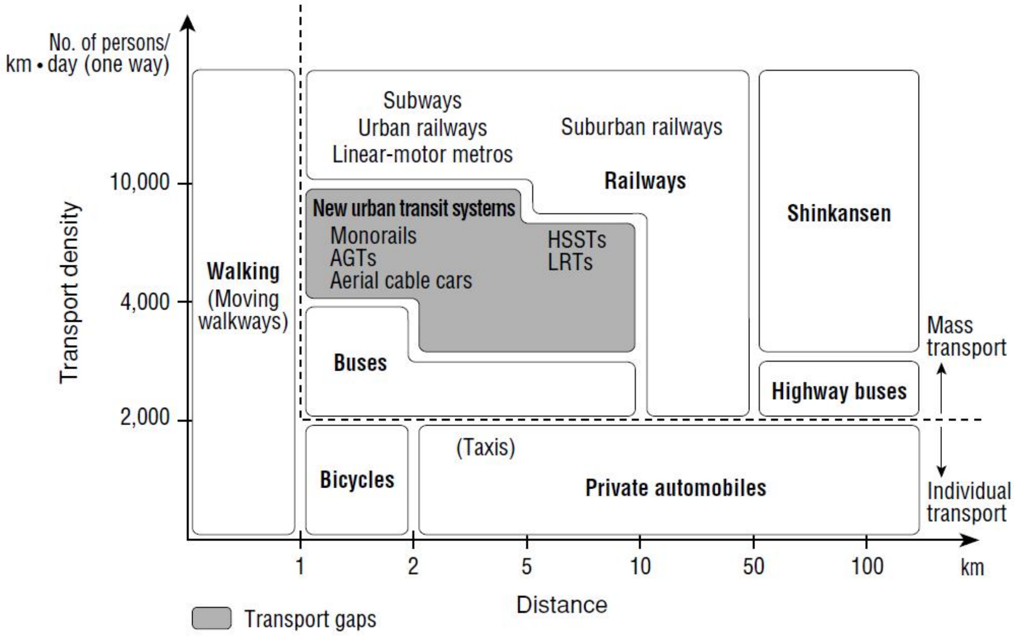
There have also been attempts to standardise the required employment densities that would support passenger transport infrastructure investment and service provisions along corridors. As mentioned previously, Frank and Pivo's (1995) investigation of employment densities found that densities of between 50 to 75 employees per acre tended to equate to significant decreases in private vehicle commuter travel. These figures are in line with some developed by regional councils in Washington State, Seattle. Puget Sound Regional Council (1999) adopted employment thresholds of 25 jobs per acre for frequent transit services, and 50 jobs per acre for light rail infrastructure. Snohomish Transportation Agency (1989) estimated that employment density surrounding local bus service hubs was between 50 to 60 employees per acre.

There have also been attempts to use densities and distance to central areas to determine the optimal mix of transport infrastructure, and identify 'gaps' in the current transport system that need to be filled by transport infrastructure investment. Nehashi (1998) discusses these gaps in her evaluation of transport systems in Japan, looking at the interplay of density of travel patterns and distance travelled. In doing so, she attempts to highlight particular transport situations that may require further investigation as to what investments would help to improve travel outcomes. Her illustration is provided in Figure 9.

Ultimately, all threshold developments have simply been an attempt to accurately project patronage levels to determine whether the costs of infrastructure and service provision improvements are likely to be covered by increases in transit ridership. On balance, while there are general residential and employment density parameters for PT service provisions; these will need to be carefully considered in each circumstance. These are in line with the findings of Demery et al. (2005) who state that site –specific matters should be considered for all transport improvements.

Pushkarev et al. (1982) also note that strategies surrounding passenger transport infrastructure should not only be evaluated in regards to impacts on the transport system, or costs alone. Instead, an understanding and appreciation of the broader impacts such improvements may provide to urban society will be an important path to take. A more robust analysis of land use characteristics including land use mix, distance to city centres and demographic characteristics are likely to provide a better understanding of projected transit patronage in a certain area. This is therefore the approach to be taken by the wider study.

Figure 9: Urban Transport Modes and Gaps in Japan (Nehashi, 1998)



4.5 Literature Review Summary

This literature review begins to explain three key relationships between land use and PT, being:

i) impact of land use patterns on PT demand;

ii) impact of PT infrastructure on land use patterns;

iii) thresholds for provision of PT infrastructure and services.

There are some key findings that can inform later stages of the PTSS, particularly once they have been calibrated to reflect the Wellington context. Observations were made in the literature to the effect that:

- Density of residents and employment, land use mix, distance to the city centre, and street connectivity are seen to have a much greater impact on PT patronage than other variables.
- As residential density increases so too does the number of alternative mode trips. There is a relation between density and increased PT demand that is supported to greater effect by better street connectivity.
- Employment density may affect commuting mode share more than residential density. Private vehicle commuter travel declines significantly when workplace densities reach 50 to 75 employees per gross hectare. This indicates that there may be a threshold at which PT services should be prioritised.
- While good PT service alone is important to attract greater ridership, mixed land uses are important to improve the transit mode share as more destinations are more easily accessible.
- Transit usage is greater in more central areas, decreasing to a city's fringe suburbs. People who live and work farther from regional centres drive more.
- Intersection density and street connectivity of neighbourhoods has the second largest impact on travel activity, behind density levels. Residents of more connected neighbourhoods are more likely to use transit and active modes. Residents who are closer to transit are far more likely to use it. Urban form can have as much of an impact on transit ridership as transit provision itself.
- The provision of additional PT services can support business development through provision of greater access. Street improvements which are often present with good PT provision are valuable to residents, reflected in property values.
- Threshold levels for the provision of PT infrastructure based on travel densities are an effective way to ensure that infrastructure and service provision improvements meet threshold criteria. However, it is important to understand site specific issues when considering transport improvements. While there are general residential and PT service provisions these need to be considered carefully in the context of Wellington.

5.0 KEY RESEARCH FINDINGS

The selection of a passenger transport technology to meet the needs of a complex city like Wellington requires consideration of a range of mode capabilities that affect the performance of the transit system and the ability to meet the needs of travellers. This Chapter summarises findings from the case studies researched to inform the modal parameters and key lessons that can be learnt from passenger transport systems around the world to apply to the PTSS.

5.1 Modal Attributes

A summary of the key findings for each mode researched from the Case Studies is presented in **Table 16**.

5.2 Land Use Transformation and Value Uplift

5.2.1 Land Use Transformation

The review of the case studies highlights that passenger transport systems can shape and influence land uses in the medium to long term. Furthermore, the density of residents and employment, land use mix, distance to the city centre and street connectivity are seen to have a much greater impact on public transport patronage than other variables, as highlighted in the review of land use and public transport trigger points literature.

The oldest systems reviewed were in Hong Kong, Japan and Melbourne. Each has influenced and shaped the travel patterns of residents and visitors within these cities. For Hong Kong Island, the network has been the backbone of its movement system and has supported the financial growth and development of Hong Kong. Cheap fares continue to play a key role in connecting people to places where they work, live and play and will continue to support the Island waterfrontage PT network due to the geographical constraints of the island terrain. In Xiamen, China and Cleveland, USA, BRT systems have been designed and respond to existing transit demand and travel patterns within these cities but are also linked to future revitalisation within and adjoining the BRT corridors.

LRT and MRT have been introduced to either (i) support compact land use development on corridors and around stations e.g. Transit Planning Zones within District Plans (ii) Preserve historical towns and pedestrian “car free” environments (iii) Respond to existing and/or new travel patterns to reduce congestion levels and vehicle kilometre travelled and (iv) Create economic stimulus through new forms of urban development e.g. TOD.

For the case studies reviewed, it is also apparent that they are supported by a number of land use policies and plans. For example, Seattle’s Sound Transit TOD Strategy plan aligns with the Federal Transit Administration and US Department of Housing for joint development and sustainable communities. This strategy aligns with the City of Seattle planning documents which also seek to support mixed use and higher density development around stations.

For densely populated cities like Kagoshima, Japan and Hong Kong, passenger transport is essential to maintain a well connected and accessible place. Long term planning is an on-going function of all government departments which seek to ensure that an integrated passenger transport system of rail, bus, and ferry services, allow it to be possible to live or operate without needing a car. This approach is now being readopted by new world developed nations (Australia, USA and NZ). Examples include, Melbourne’s transport strategy called *Moving People and Freight 2006 – 2020* and Hong Kong 2030: *Planning Vision and Strategy*, Malaysia’s planning document “*The Kuala Lumpur Structure Plan 2020*” which stipulates transit planning zones around stations ensuring that development around stations occurs and therefore also shapes travel behaviour patterns.

5.2.2 Value Uplift

There is a direct correlation between access to passenger transport services and increased property values with several studies identifying the benefits arising from proposed and implemented passenger transport schemes. The following value uplifts have been identified:

- Local bus - the value uplift of property adjacent to or within walking distance (10 minutes) of conventional bus service is not as measurable as seen with other modes of passenger transport. In addition, there is little attraction of new development investment due to availability of bus service, especially on low- to mid-frequency routes.
- BRT – Beijing, Brisbane, Bogota and Curitiba are but a few locations where BRT is having a positive impact on land development. Beijing’s Southern Axis BRT Line 1 opened in 2004 and

is not only more affordable than LRT or MRT but is positively contributing to value uplift. Local real estate agents believe that the introduction of BRT dramatically altered land use and property values in proximity to the BRT Corridor. Estate agents estimated that people would pay a premium of 10% to 25% of rental or capital value near to the corridor. For residential properties, the average increase of 2.3% occurred between 2004 and 2009 within a 500 m radius of a BRT station compared to those not served by BRT. In Bogota, Colombia, the value uplift strongly related to the access on foot with rental properties increasing between 6.8% and 9.3% for every five minutes of walking time to the BRT Station. Properties around the Brisbane BRT have recorded increases of up to 20% when compared to surrounding suburbs. However, the Brisbane BRT is a highly prioritised BRT system that has very high service frequencies.

- LRT and MRT systems have a dramatic effect on property values around stations and the corridor. Both systems are more likely to attract development and increase property values more than conventional bus transit systems. Expected property prices – globally for commercial and residential within 200 m to 500 m of an MRT route can be in the range of 15% to 25% depending on the location of the property to the stations compared to properties 1.5 km away. European cities show that the price premium for office space is 23% higher when compared to 8.9% for residential accommodation in close proximity to stations.

The construction of a dedicated right-of-way can also give the impression of permanency and stimulate confidence for major development around station areas and significantly increases the surrounding property values.

5.3 Key Success Factors

The key success of the passenger transport systems reviewed has been dependent on:

- Setting a long–term strategy which is achievable, realistic and with a political legitimacy, which the public understands to secure a scheme which can survive the political cycle. It is unlikely that a project requiring substantial investment and longer term commitment during the construction period would survive without public and bipartisan political support. The need for transparent understanding of the potential social and economic benefits, through revitalisation and redevelopment of spaces within cities aimed at both the individual and the community, is seen as essential in one's acceptance and investment of passenger transport schemes. The case studies identify that the success of passenger transport systems has often been via a two tier approach with the planning of the route and surrounds the responsibility of planning authorities only and specific transport agencies, e.g. SMART, TRiMetro, established and tasked with day-to-day operations of the system. Transport agencies may also be responsible for the construction of networks and rolling stock.
- The decision on procurement of both infrastructure and land for the corridor and nearby uses is essential if the system developed is to be successful in supporting both existing and future catchments. Inter-government agency cooperation has been seen as a key feature of successful passenger transport schemes providing funding or undertaking redevelopment of land surrounding stations and corridors for mixed use and high density development. For example, the Metropolitan Council, USA promotes medium and higher density housing and mixed use development around several LRT stations on the Hiawatha line. As designated "catalyst" stations for investment and transit oriented development, Council predicted that the sites identified would attract 7,000 new housing units. In Dec 2010, the reality is 8,100 new housing units constructed with another 7,700 proposed by developers. Other case studies indicate that the value uplift resulting from investment in quality passenger transport can be in the order of 10% to 30% dependent on the mode type and coverage.
- The success and protection of land surrounding or near to passenger transport corridors through zoning and development controls. For example, case studies from the USA, Singapore and Hong Kong, Vancouver stipulate and regulate development in corridors and around stations are required to serve existing as well as new urban centres with planning controls designed to enable intensification. A further example is Translink which is required by law to support the Liveable Regional Strategic Plan, which promotes compact and sustainable communities with a diverse transport choice. Higher density development is an instrumental component of the plan with many areas along the Expo and Canada Line redeveloped/earmarked for higher development densities.
- The measure of its performance to address project objectives such as a reduction in congestion; compact land use; is accessible, safe and affordable (to build and operate) meeting the expectations of both the public and customers to service demand, rather than solely a measure on the delivery of infrastructure.

5.4 Design and Operation Considerations

5.4.1 Key Principles

A number of key principles have been established that shape the design of a future passenger transport system for Wellington PT Spine. These are:

- Peak direction carrying capacity – the mode needs to have enough throughput capability to deliver an appropriate level of comfort and crowding to customers. This needs to be related to forecast passenger demand growth (to avoid unnecessary investment today and the need for unplanned future investment). This is discussed further in Section 5.4.2.
- Peak versus off-peak capacity and demand – changes in demand through the day influences the selection of mode by affecting the economics of the line's operation. Bus-based modes, including BRT, are generally best for lines with low daytime traffic when less capacity is needed and a saving can be made in operational costs. Lines serving a diverse mixture of land uses and destinations are likely to have sustained high levels of traffic through the day. Even if peak periods are significantly busier, strong off-peak traffic can strength the case for high capacity rail modes such as LRT and MRT. This is discussed further in Section 5.4.3.
- Station and stop capacity – the mode needs to be appropriate for the volumes and type of passenger traffic expected at stops, because the time spent at stations/stops is a key determinant of both the line's overall capacity and journey time. Lines with very high patronage levels can have excessively long station/stop dwell times if an inappropriate mode with slow boarding times is selected. Depending on the major characteristics of the mode, this can have implications for street space allocation for on-street modes and station design for rail modes.
- Corridor characteristics – the nature of the available transport corridor influences the suitability of mode choice options. Where generous road space is available or can be reallocated with acceptable impacts on the wider transport system, on-road modes such as buses, bus rapid transit, and light rail systems are more feasible. Where existing land uses and road space conditions mean that a dedicated corridor is required, consideration of rail modes such as MRT may be appropriate.
- Catchment – Analysis of international practice suggests that it is reasonable to expect that on average people will walk up to 400 m to ride on a bus or up to 3 km in order to access a station.
- City Centre Coverage – Research indicates that successful cities are walkable cities. Given a walking catchment of 400 m then it is desirable to have a station/stop placement grid within the City Centre that provides for walking access to all major activity nodes.
- Travel Time – The most critical factor associated with attracting commuters away from the use of motor vehicles is comparative travel time. People with long commutes from outer areas are more sensitive to travel time because of the high proportion of their time needed for transportation, whereas people close to the city are less sensitive because of the small differences in travel time. Therefore it is critical that a new passenger transport system provides access to the city via the most direct route and without deviation to link demand nodes close to the city. Reducing interchange penalties between modes, or within the same mode will also be critical.
- Interchange – The development of a transport network with strong and attractive opportunity for interchange provides an enhanced opportunity to effectively serve a wide range of destinations. Interconnection that links the outlying demand nodes will strongly enhance the functionality of the network and use of passenger transport. Lower level forms of PT generally are better at achieving this because of closer stop placements and the ability to more easily establish interconnected networks.

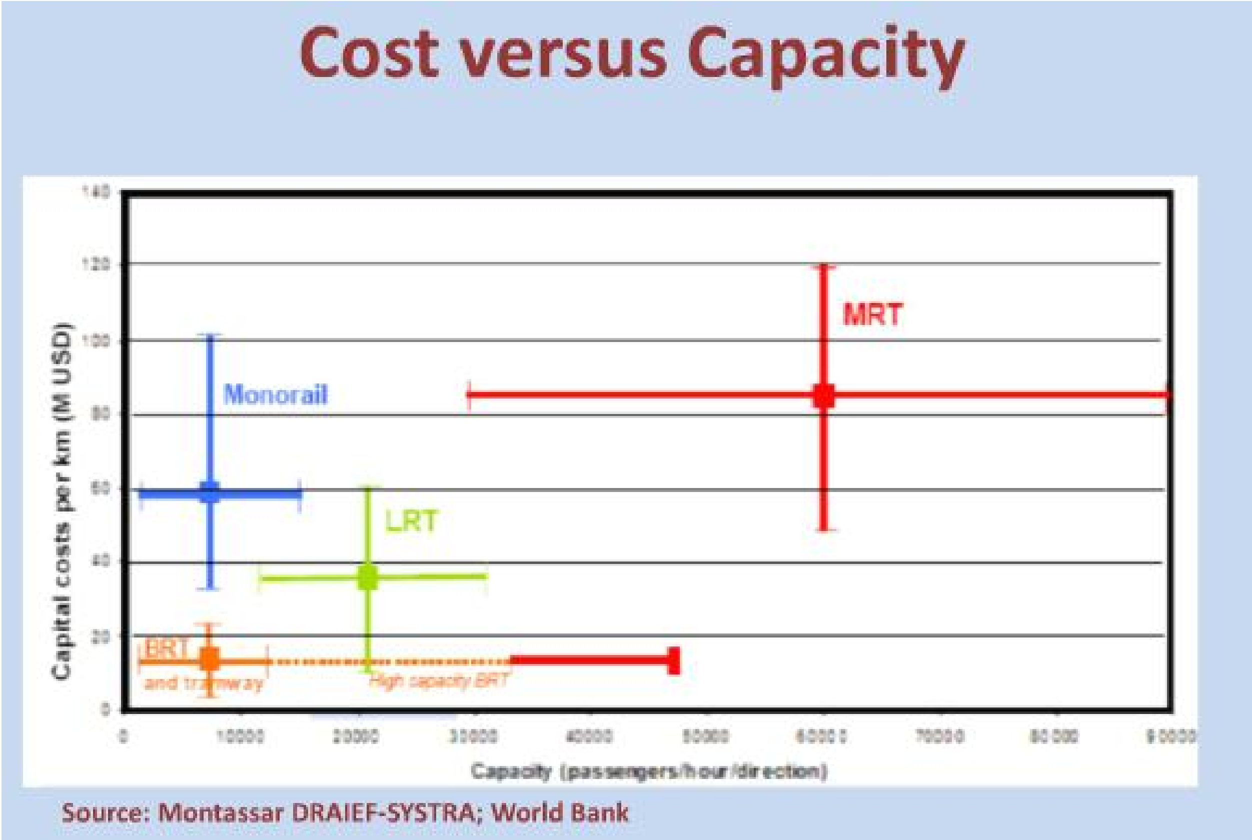
5.4.2 Peak Direction Carrying Capacity

A key driver of the mode choice will be the need to have enough throughput capability to deliver an appropriate level of comfort to customers.

Our research shows that the passenger transport modes can be ordered into a 'spectrum' of capabilities, and costs. Generally, systems range from low cost, low capacity, low performance systems through to higher cost but higher capacity and performance systems. The research from the World Bank (as can be seen on road modes such as buses operating in general traffic are at the low end of the spectrum; automated Mass Rapid Transit on dedicated stand-alone corridors is at the high end of the spectrum). In the middle are the intermediate modes – for example bus rapid transit, and light rail. It is important to note that any assessment of modal capacity will be greatly influenced by local circumstances and generalised comments about mode capacity need to be confirmed by a local assessment relative to the investigation area.

Our findings from case studies are of a similar magnitude to the example published in, except MRT which was based on one case study.

Figure 10: Cost Verses Capacity



5.4.3 Network Coverage

The three main successes to network coverage across all passenger systems is its ability to:

- **Attract passengers** – the higher the passenger-km a network carries on the system, the more likely it is economically to achieve the goals set by the project. The ability to attract passengers is dependent on catchment area coverage[9], directness of travel to and from stations on foot, bike etc, travel speeds and the simplicity and convenience of transfers with other modes (if necessary) and the integration of stations with surrounding land use. For example, BAA Airport Ltd has stated that PRT for London's Heathrow's Terminal 5 has been attributed to a 60% improvement in travel time and 40% operating cost savings. The introduction of BRT in Cleveland, Ohio carries 12,000 passengers per day, a 58% increase in patronage over the local buses it replaced and offers a 25% travel journey saving. Los Angeles BRT service has reduced travel times by as much as 29%, resulting in ridership increases of nearly 40%.
- **Achieve maximum operation efficiency** – the affordability of the system to operate efficiently will be dependent on ridership catchment, travel times, fleet size and vehicle types to accommodate throughput capacities as well as the integration of the total transport system and fare collection. Operating costs must also cover upgrades and future improvements to the system including future extensions and services. Consideration therefore must be given to what a city can realistically afford and maintain. This is illustrated via the Cleveland, Ohio BRT Case Study. The implementation of BRT is the result of numerous planning studies conducted from the 1950s to 1980s identifying and advocating various forms of rapid transit but which were never realised due to costs. It was not until 1995 that BRT was introduced as a scheme which could be realistically funded from available sources and meet demand.

[9] Land use and one's ability to access stops/interchanges will determine ridership catchments and ultimately funding and fare structures. Deng and Nelson (2010) provide evidence "*that accessibility enhancement, rather than the type of transit system, is a far more important reason to influence land development*" and ultimately a trigger in attracting passengers. Even in the most densely populated regions authorities still look to land use activity and population catchments as a key indicator in the financing and timing of large passenger transport projects e.g. Singapore's NEL.

5.4.4 Design and Operational Considerations

The key design and operation considerations that have been drawn from the case studies are:

- Spatial constraints to accommodate either surface at-grade, underground and/or elevated structures, interchanges and stations, etc.
- Funding and Investments of alignment to enable a comprehensive design that can support and is flexible to future changes e.g. growth, technology.
- Location of utilities and opportunity/cost to relocation services e.g. gas, water and communications.
- Access and opportunity to relocate access to buildings, parking, etc.
- Integration with existing historical character, incorporation of art and public spaces for pedestrians.
- Impact of street layouts that can impose constraints on aspects such as LRT vehicle length, or blocking intersections and pedestrian access to platforms/stations.
- Construction – ability to reroute traffic and retain the reliability of existing passenger transport patronage during construction.
- Emergencies/Breakdowns – co-ordination and quick responses especially if tunnels are shared, e.g. bus/rail tunnels.
- Noise – the Norwegian system has laid rubber jackets within selected corridors to reduce noise within the CBD.
- Traffic Signal Priority – to improve reliability of passenger transport and improve safety for all road users.

Table 16: Summary of Investigated Studies

	Personal Rapid Transit	Bus Rapid Transit	Light Rapid Transit	Mass Rapid Transit
Researched studies	ULTRA, Heathrow, UK Masdar City, United Arab Emirates West Virginia, USA	Beijing, China Xiamen, China Brisbane, Australia Adelaide, Australia Auckland, NZ Rouen, France Nantes, France Los Angeles, USA Cleveland, USA Denver, USA Bogota, Colombia Curitiba, Brazil	Gold Coast, Australia Melbourne, Australia Hong Kong Island Kagoshima, Japan Bergen, Norway Frieburg, Germany Karlsruhe, Germany Rouen, France Eidenhoven, Netherlands Minneapolis, USA Portland, USA San Diego, USA San Francisco, USA Seattle, USA Vancouver, Canada	Mumbai, India Hong Kong Republic of Singapore Lyon, France
Vehicle capacity (total – standing + seating)	4 – 6	60 – 150	110 – 350	140 – 280
Typical max passengers (per hour)	500	1,000 – 36,000 (40,000 World Bank estimate)	3,500 – 20,000+	30,000 – 90,000
Service frequency peak (seconds)	< 60	<60 – 600	40 – 90	20 – >40
Capital expenditure per km (NZ$)	$9 million - $20 million	$0.5 million – $75 million	$12 million - $141 million	$105 million
Operating speed (km/h)	40	40 – 100	60 – 120	80 – 120
Turning radii (m)	<10	7 – 13	10 – 25	>250
Power source	Electric, battery	Various (e.g. diesel, natural gas, hybrid, battery, electric)	Overhead, electric, battery underground feed	Electric

	Personal Rapid Transit	Bus Rapid Transit	Light Rapid Transit	Mass Rapid Transit
Station spacing (m)	1,800	500 – 1,000	500 – 1,000	750 – 1,500
Key success factors	Short wait times Point-to-point travel times Completely segregated from other vehicles	Dedicated lanes (reduced conflicts with other vehicles/pedestrians) Good passenger transport vehicles (brand, image) Assist in corridor revitalisation and economic development Design flexibility to convert to LRT later	Fully segregated from traffic / pedestrian environment Topographically suited to hilly terrain Stops can be conveniently placed with short walks	Fully segregated Can help shape and redevelopment urban form around corridors
Key constraints	Low carrying capacity of vehicles Low operating speed, 40 km/h Driverless - only travel on pre-determined routes Must be segregated	Fleet size Lack of priority at signals if re-emerging back to public street	Vehicle length Integration with other traffic at intersections Funding Length of platforms	Large turning radii Larger distance between stops than LRT Potential greater severance Cost
Key operational issues	Large interchanges required for multiple vehicles arrivals. Typically no intermediate stops	Buses queue at bus stations – no overtaking room at stations Traffic signal priority at intersections	Fleet size to cater for peak demand Construction (re-routing traffic) Noise	Geometric curvature and gradient
Key design characteristics	Can integrate easy within existing urban fabric easier than heavier infrastructure	Spatial requirements / buffer zones between adjoining buildings	Integration with existing characteristics of City	