Technical characteristics of bus rapid transit (BRT) systems that influence urban development

Lutfi Prayogi

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Abstract

This dissertation explores the relation between bus rapid transit (BRT) technical characteristics and influence on urban development. It includes a comprehensive knowledge in terms of BRT technical characteristics and performance. Explanation in terms of the influence of Boston Silver Line 4 and 5 and Seoul BRT systems on urban development around the systems is used as case studies. Analysis on the technical characteristics of and investigation on the performance of Boston Silver Line 4 and 5 and Seoul BRT systems are provided.

The analysis on the technical characteristics of the BRT systems includes analysis in terms of the station configuration and accessibility, vehicle capacity and accessibility, segregated right of way, off-board ticketing and network width and transit network integration. The technical characteristics of the BRT systems are analysed in regard to their positive contribution towards the patronage, vehicle average speed and passengers per hour per direction (pphpd) figure of the BRT systems. The investigation on the performance of the BRT systems includes investigation in terms of the maximum and average pphpd figure of the BRT systems.

This dissertation shows that BRT systems that influence urban development have technical characteristics which enable the BRT systems to have high performance. However, it is unclear whether or not these technical characteristics make BRT systems influence urban development by making the systems have high performance.

Keywords: bus rapid transit, technical characteristics, performance, urban development

Dedication

This research is dedicated to the people of the Republic of Indonesia. You, through Lembaga Pengelola Dana Pendidikan, Kementerian Keuangan Republik Indonesia (Indonesia Endowment Fund for Education, Ministry of Finance Republic of Indonesia), have made me able to attain a world-class education that is far from affordable by me.

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My greatest thanks is for my parents who have their great trust on me and taught me to persevere on pursuing my dreams.

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List of abbreviations and terms

BRT	Bus rapid transit
BRT system	The manifestation of BRT concept
BRT vehicles	Buses that are part of the BRT system
Frequency	The amount of trips within a certain time, usually within one hour
Headway time	The time gap between each consecutive trip
MBTA	Massachusetts Bay Transportation Authority
Off-board ticketing	Fare collection and ticketing facilities that are located outside the bus
On-board ticketing	Fare collection and ticketing facilities that are located inside the bus
Overtaking lane	A lane that can be used by a bus to overtake the buses in front of it
Patronage	The use of a certain mode of transport by its users/passengers, usually in numerical dimension
Pphpd	Passengers per hour per direction
Premium	Margin between higher and lower price
PRK	Passengers per route km
PVK	Passengers per vehicle km
Right of way	The legal right for a certain mode of transport to pass along a route
SL4/5	Boston Silver Line 4 and Silver Line 5
SMG	Seoul Metropolitan Government
TOD	Transit oriented development
Transit	A mode of transport that only stop at certain locations and always stop at those locations
Urban sprawl	The spread-out and skipped-over urban development

Chapter 1
Introduction

Bus rapid transit (BRT) is an emerging mode of transit worldwide. After the first modern project being initiated in Curitiba, Brazil, in the 1970s, the concept has been spreading and various BRT projects have been carried out worldwide. The BRT systems created are physically varied, ranging from having simple painted road-median lanes as in Seoul, South Korea, to exclusive elevated lanes as in Kuala Lumpur, Malaysia. The characteristics of cities having BRT systems are also varied, ranging from developed countries cities such as Brisbane, Australia, to developing countries cities such as Ahmedabad, India. Some BRT systems are complemented by significant urban development around the systems and some are not.

This research intended to explore the relation between BRT technical characteristics and influence on urban development by answering the following questions:

1. What are the technical characteristics of BRT systems that influence urban development around the systems?
2. How does having those technical characteristics make the BRT systems influence urban development around them?

This research will contribute to the field of urban transport planning. To certain extent it will also contribute to the field of urban economic planning. It will specifically contribute to the topic of integrated transit and physical development planning. Current knowledge on this topic has been compiled by Curtis et al. (2009) in *Transit oriented development: Making it happen*, Suzuki et al. (2013) in *Transforming cities with transit: Transit and land-use integration for sustainable urban development* and Suzuki et al. (2015) in *Financing transit-oriented development with land values: Adapting land value capture in developing countries*.

Within the topic of integrated transit and physical development planning, this research will add knowledge about a relatively new mode of transit. It will add knowledge about an alternate transit component, in which the current dominant transit component is rail transit. Better knowledge in terms of available transit components will help cities to plan integrated transit and physical development while having difficulties to plan and carry out rail transit project.

The next chapter will discuss the literature that has been reviewed and served as the basis for answering the research questions. Towards the end of the next chapter, the knowledge gap and the research assumption will be discussed. Chapter 3 will discuss the research methods and present the research hypotheses. Chapter 4 will introduce the case studies that were analysed. Chapter 5 will analyse the case studies and present the findings. Chapter 6 will present the result on the examination of the hypotheses as well as provide discussions and suggestions that might be useful for future researches.

Chapter 2
Literature Review

This chapter will discuss the current knowledge related to bus rapid transit (BRT) with particular foci on its influence to urban development, its technical characteristics and its performance. Section a will briefly introduce the role of BRT in transit oriented development (TOD). Section b will discuss the influence of BRT system provision on urban development. Section c will briefly discuss the definition of BRT, BRT essential components and development history and context of BRT. Section d will discuss BRT technical characteristics. Section e will discuss some BRT performance indicators and measurements. Section f will discuss the relation between the technical characteristics and performance of BRT. Section g will summarise the discussions in this chapter. The last section will discuss the knowledge gap and research assumption.

a) Transit oriented development and bus rapid transit

Burchell et al. (1998) and Bruegman (2005) recorded that cities in United States have been experiencing urban sprawl during the 20th century. Ewing in Burchell et al. (1998, pg. 1) defined urban sprawl as "the spread-out, skipped-over development" that is observable on the non-central city metropolitan areas and non-metropolitan areas of the United States. They also argued that to a certain extent urban sprawl has also been experienced by cities in Western and Eastern Europe, Australia, Latin America and Asia. Burchell et al. in Neuman (2005) set three, along with some others, characteristics of cities experiencing urban sprawl: they have low density and heterogeneous built environment, have transportation dominated by privately owned motor vehicles and have widespread commercial strips along major roadways. Urban sprawl costs significantly to cities' resources (Burchell et al., 1998, 2000). It requires vast amount of land conversion and extensive infrastructure provision. It also forces people who reside in the cities to travel far and spend long hours transporting daily by driving car.

Transit oriented development (TOD) has been emerging as an urban development concept alternative to urban sprawl. It intends to be a type of urban development not having the drawbacks owned by sprawl. Urban development that is tied to transit development has occurred since the 19th century in accordance with the development of trams in various cities. During the 20th century, various cities also had similar development, utilising various modes of transit (Cervero et al., 2002). Even so, the term ‘transit oriented development’ was first popularised by Calthorpe (1993). The urban development concept at the time was developed as an antithesis of and to counteract urban sprawl. TOD is in contrast to urban sprawl by promoting high density mixed-use built environment around transit hubs (Cervero et al., 2002). In so doing, it intends to control the land conversion of the cities and provide less extensive infrastructure. It intends to help residents of the cities rely less on driving car and rely more on taking public transport (including rapid transit systems), cycling and walking for daily transportation.

Bus rapid transit (BRT) systems have been built in many cities around the world, some of them were built in conjunction with TOD. Cervero (1998) and Curtis et al. (2009) acknowledged BRT as one mode of transit that is suitable to be built in conjunction with TOD, the other mode of transit is rail transit. Furthermore, utilisation of BRT in TOD has been found successful in several cities, such as in Curitiba, Brazil (Cervero, 1998; Suzuki et al., 2013), Ottawa, Canada (Cervero, 1998; Suzuki et al., 2013) and Brisbane, Australia (Kamruzzaman et al. 2014). In those cities, provision of BRT systems triggered urban development around its surrounding areas as TOD intended to. Lindao et al. (2010) noted that the provision of BRT systems in Curitiba, Brazil, triggered the development of a notable high density built environment along the BRT systems corridors. Figure 1 depicts the designed and realised built environment along a BRT system corridor in Curitiba, Brazil.

Figure 1 - Designed (below) and realised (top) built environment along a BRT corridor in Curitiba, Brazil

Source: Lindao et al., 2010

Apart from the previously mentioned cities, some other cities including Ahmedabad, India; Bogota, Colombia; Kent Thameside, United Kingdom and Seoul, South Korea recently integrated BRT projects as part of their development plans (Cervero and Kang, 2009; Deng and Nelson, 2011; DFT, 2008; Rodriguez and Targa, 2004; Cervero et al., 2013). Cervero and Dai (2014) and Stojanovski (2013) have specifically explored the issues regarding utilisation of BRT in TOD.

While transit service, including bus rapid transit (BRT) service, provision is an essential component of transit oriented development (TOD), it is not the only component of TOD. Cervero and Kang (2011) argued that within TOD, transit service provision is necessary but may not be sufficient by itself to influence urban development. Cervero (1998), Curtis et al. (2009) and Suzuki et al. (2013, 2015) have explored a range of TOD components in addition to transit service provision. Some of those other components are related to yet are separate from transit service provision. For instance, land use intensification policy on areas within the transit service catchment area is critical to ensure the transit service is able to operate properly, while it is a policy separate from transit service provision. Cervero (1998) recorded that the provision of BRT services in Curitiba, Brazil, was complemented by land use intensification, social housing provision and commercial centre construction policies on areas around the BRT corridors. Suzuki et al. (2013) recorded that the provision of BRT services in Ottawa, Canada, was complemented by the provision of regional jobs and car use reduction policies in areas around the BRT corridors.

It can be concluded from this section that transit oriented development (TOD) is an emerging type of urban development that intends not to have the drawbacks of urban sprawl. It promotes the development of high-density built environment around transit hubs. Bus rapid transit (BRT) is a potentially significant component of TOD. While the provision of transit service, including BRT service, is an essential component of TOD, it is not the only component of TOD. It is common for the provision of BRT service to be complemented by other policies that related to yet are separate from BRT provision policy. The next section will further discuss the influence of BRT system provision on urban development.

b) Influence of BRT system on urban development

Stokenberga (2014) provided a literature review on the influence of bus rapid transit (BRT) systems provision on urban development. She reviewed the methodologies, underlying theories and findings presented in the literature on the theme, mostly drawing on

Latin American and Asian systems. Some of the BRT systems reviewed in her work include Bogota TransMilenio, Beijing Southern Axis BRT Line 1, Seoul BRT systems, Pittsburgh MLK Jr. East Busway, Eugene Emerald Express, Boston Silver Line and Los Angeles Metro Rapid. As a preface to reviewing the influence of BRT on urban development, Stokenberga reviewed the literature related to BRT technical characteristics and operational performance. When summarising the findings of the researches on the theme, she highlighted BRT key technical characteristics and operational performance indicators.

Considering that physical urban development takes significant time to be observable, Stokenberga (2014) found that so far researchers have been unable to properly observe BRT-related physical urban development. She found most researchers including Bocarejo et al. (2013), Cervero and Kang (2011), Dube et al. (2011), Hidalgo et al. (2013), Jun (2012), Mulley (2014), Raskin (2010), Rodriguez and Mojica (2009) and Zhang et al. (2014) carried out their researchers on the theme by converging their observation to the influence of BRT system provision on land use and property price change.

Stokenberga (2014) noted that the land rent theory, advanced in the urban context by Alonso (1964) and Muth (1969), is the core theory used by those researchers. The researchers used the theory in modelling the relation between accessibility and property values. The theory suggests that the implicit prices of the different attributes of heterogeneous goods (including property) can be inferred by observing the willingness of consumers to pay for each unique set of those attributes. Transit accessibility is one of the attributes of property commonly considered by customers. Furthermore, Debrezion in Stokenberga (2014) argued that investments in transport infrastructure may alter the properties' implicit price by altering the transit accessibility of the properties. The alteration is observed on the change of land use demand of and the willingness of consumers to pay for the land use of properties close to transit stations.

Stokenberga (2014) found cross-sectional approaches as the most frequently used approaches in the researches, followed by before-after approaches. She found before-after approaches were commonly complemented by hedonic price regression models. Considering the difficulty of obtaining actual property transaction price, Stokenberga (2014) found researchers commonly observed and analysed 'asking price' in their researches.

Among the BRT systems analysed in the literature, Stokenberga (2014) found their influence on land-use and property price change have been less uniform compared to the BRT operational performance indicators. A summary of the findings of her research is provided in table 1.

Table 1 - Operational performance and property value impacts of select BRT systems.

Source: Stokenberga, 2014

BRT system	**Type**	**Operational performance**	**Property value impacts**
Bogota TransMilenio	Median-lane exclusive busway	Hidalgo et al. (2010): 1.6 million daily passengers, peak loads at 43,000 pphpd; bus average speed at 28km/h	Rodriguez and Mojica (2009): Property asking prices 13-14% higher near BRT corridor compared to control areas Perdomo-Calvo et al. (2007): Residential properties located near BRT corridor valued by between 5.8% and 17% higher
Beijing Southern Axis BRT Line 1	Median-lane exclusive busway	Deng and Nelson (2010): 120,000 daily passengers; bus speed up to 22km/h	Deng and Nelson (2010): asking prices of apartments in the BRT catchment area 11% higher than in control areas
Seoul BRT	Median-lane exclusive busway and curbside lanes	Cervero and Kang (2011): over 100,000 daily passengers, bus average speed at 22km/h	Cervero and Kang (2011): land price premiums up to 10% for residences within 300m of stations and more than 25% for non-residential uses within 150m
Pittsburgh MLK Jr. East Busway	At-grade dedicated busway, signal priority for buses	Hinebaugh (2009): 30,000 daily passengers, 12-minute peak headway time	Perk and Catala (2009): property values increase by $2.75 when moving from 1001 to 1000 feet away from a station

Eugene Emerald Express	Median-lane exclusive busway for 60% of the route	Community Planning Workshop (2009): 2,700 daily passengers	Hodel and Ickler (2012): 0.18% price increase for residential properties within one minute of walking distance to a station
Boston Silver Line	Bus-only lane for much of the route, signal priority for buses	Hinebaugh (2009): 14,105 daily passengers, 4-minute peak headway time	Perk et al. (2012): premium at 7.6% for condo sales near BRT
Los Angeles Metro Rapid	Operates in mixed-traffic conditions along freeways, signal priority for buses	Hinebaugh (2009): >265,000 daily passengers, 4-30 minutes peak headway time	FTA (2009): residential properties within 0.5 mile from stops sold for less, while commercial properties sold for more, relative to the rest of the city

It can be concluded from this section that the provision of some bus rapid transit (BRT) systems have been found influencing urban development around the systems. The influence has been less uniform compared to the BRT operational performance indicators. In regard to that, Stokeberga (2014) suggested that further research be carried out on exploring the influence of BRT particular technical characteristics on land-use and property price change. An overview of BRT, a discussion on BRT technical characteristics and a discussion on BRT performance indicators will be carried out in the following sections.

c) Overview of bus rapid transit

An overview of worldwide bus rapid transit (BRT) systems and projects has been provided by a number of researchers, including Deng and Nelson (2011), Hensher and Golob (2008), Maeso-Gonzales and Perez-Ceron (2013), Nikitas and Karlsson (2015) and Racehorse et al. (2014). Meanwhile, a review of literature related to BRT has been provided by Wirasinghe et al. (2013). Their works summarised knowledge on BRT definition, development history and context, technical characteristics, performance, strengths and weaknesses, financing and impacts. Their works also included lists of operating BRT systems. The most recurring issues explored in their researches include the development context, technical characteristics and performance of BRT.

Racehorse et al. (2014, pg. 175) provided an overarching and simple definition of BRT, "an improvement to the current bus situation making a convenient alternative to the cost of constructing a rail transit system approximately up to one-third of the cost". Similarly, Deng and Nelson (2011) described BRT as a form of mass rapid transit that combines the speed and reliability of a rail service with the operating flexibility and lower cost of conventional bus service. Currie and Delbosc in Nikitas and Karlsson (2015, pg. 1) set a sharper definition of BRT, "schemes that apply rail-like infrastructure and operations to bus systems in expectations of offerings that can include high service levels, segregated rights-of-way, station-like platforms, high-quality amenities and intelligent transport systems for a fraction of the cost of fixed rail". While the previously mentioned researchers tied the BRT definition to the concept of general 'rail transit', Maeso-Gonzales and Perez-Ceron (2013) specifically tied BRT's definition to the concept of light rail transit (LRT). They (pg. 149) defined the BRT as "a collective way of land transportation based on the functional features of LRT that benefits from the economic advantages and flexibility of the bus".

From the above information, it can be concluded that BRT definitions lie on its service condition rather than on its physical being/technical characteristics. All researchers described BRT as bus service comparable to rail transit service. Consequently, discussion on BRT technical characteristics should depart from BRT service condition, which is commonly measured by a number of performance indicators. Some researchers also tied the BRT's cheaper cost compared to rail transit's cost as part of the BRT definition. Thus, it can be concluded that BRT is bus service which is less costly than rail transit service.

Deng and Nelson (2011), Nikitas and Karlsson (2015), Racehorse et al. (2014) and Wirasinghe et al. (2013) mentioned the components of BRT in their works. It can be concluded from their works that BRT components include at least vehicles, stations, running ways, intelligent transportation system and service. It is implied in their works that a comprehensive analysis of any BRT system should at least include an analysis of those components. Similarly, a BRT planning should at least include planning on those components.

Weinstock et al. in Wirasinghe et al. (2013) and Deng and Nelson (2011) argued that the modern concept of BRT was first implemented in Curitiba, Brazil, in 1974, taking name as Rede Integrada de Transporte/Integrated Transportation Network (RIT). Jaime Lerner, the then Mayor of Curitiba, initiated the project. He carried out the project as part of a city-wide transport plan named Trinary Road System. Architect Rafael Dely was the principal designer of the transport plan (Terezinha Vaz in Racehorse, 2014). The publicly perceived success and low cost of the initial project led to the development of the RIT in tandem with the city's expansion (Smith and Ramakers in Deng and Nelson, 2011). The success of the project inspired implementation of other BRT projects worldwide (Wirasinghe et al., 2013). Hensher and Canadian Urban Transit Association and Federal Transit Administration in Hensher and Golob (2008) noted that there is a growing worldwide interest in enhancing and utilising bus as a primary mode of public transport through BRT projects. Global BRT Data in Wirasinghe (2013) noted that currently there are 146 cities which have BRT systems of a certain extent and collectively these BRT systems serve approximately 24 million passengers per day.

It can be concluded from this section that BRT is bus service which is comparable to rail transit service. Its investment and operational cost are usually less costly than rail transit's ones. It is a mode of transit that has been growing popular since the 1970s. BRT components include at least vehicles, stations, running ways, intelligent transportation system and service. The following section will further discuss these components and their technical characteristics.

d) Bus rapid transit technical characteristics

Some researchers have evaluated the performance of various bus rapid transit (BRT) systems and relate the evaluation with their technical characteristics. While the relation will be discussed in section f, this section will introduce the BRT technical characteristics. Some professional publications from Hinebaugh (2009), published by Federal Transit Administration/FTA, Wright and Hook (2007) and Breithaupt (2014), published by Institute for Transportation and Development Policy/ITDP and Levinson et al. (2003a, 2003b) and Danaher et al. (2007), published by Transportation Research Board/TRB have summarised the discussions of the BRT technical characteristics.

Levinson's et al. (2003a, 2003b), Danaher's et al. (2007) and Hinebaugh's (2009) publications are related publications. Levinson et al. (2003a, 2003b) provided a comprehensive overview of BRT theories and select practices. Danaher (2007) enhanced the previous publications with comprehensive empirical data of select practices. Hinebaugh (2009) redelivered the BRT theories and provided practical and applicable advice deduced from the empirical data published by Danaher et al. (2007). Their publications provided comprehensive information on North American BRT systems and some information about BRT systems elsewhere.

Wright and Hook (2007) provided a comprehensive overview of BRT theories and worldwide practices. Breithaupt (2014) provided information on the essential and non-essential components of BRT. Their publications provided general information on worldwide BRT systems.

a. Vehicles

i. Size and passenger capacity

Mini, standard, articulated and bi-articulated buses are some types of bus that may be used for BRT system (Hinebaugh, 2009; Wright and Hook, 2007). The vehicle length varies from 6 to 24 meters, while the capacity varies from 25 to 270 passengers per bus. Some considerations on choosing bus of the proper size and capacity include the passenger demand and physical route condition.

ii. Passenger boarding and alighting speed

Breithaupt (2014) suggested the BRT vehicles to have swift passenger boarding and alighting process to reduce the buses' dwelling time at stations. Buses may trigger swift passenger boarding and alighting process by having platform-level boarding, multiple wide doors, off-board fare collection and proper vehicle acceleration capability (Hinebaugh, 2009; Wright and Hook, 2007; Breithaupt, 2014).

iii. Other issues

Breithaupt (2014) suggested the BRT vehicles to provide appropriate passenger information. Passenger information may be delivered through the use of various media, such as route map sticker, digital information panel and verbal announcements (Hinebaugh, 2009; Wright and Hook, 2007). They also suggested to increase the personal safety and convenience of passengers as appropriate by installing closed-circuit television (CCTV), stationing officer, providing space for wheelchair user, providing gender-separated spaces, and so forth. It is also necessary for buses to be universally accessible (Breithaupt, 2014). The use of low-emission buses, such as biodiesel and compressed natural gas (CNG) buses is also suggested (Hinebaugh, 2009; Breithaupt, 2014).

b. Stations

i. Passenger boarding and alighting speed

Stations should be designed in a manner allowing for a swift passengers boarding and alighting process (Breithaupt, 2014). Overtaking lanes and multiple berths/bays may need to be provided to hinder buses from queueing before boarding/alighting passengers (Hinebaugh, 2009; Wright and Hook, 2007; Breithaupt, 2014). Passenger queueing, boarding and alighting space need to be designed properly. Off-board ticketing facilities, such as ticket gates or poles, also need to be provided (Breithaupt, 2014). Stations also need to be distanced from traffic intersections to hinder a traffic-queueing bus from blocking buses approaching stations (Breithaupt, 2014).

ii. Intermodal integration and transferring facilities

Stations should also be designed to ease passengers on transferring between buses of different routes as well as transferring between buses and other modes of transport (Hinebaugh, 2009; Wright and Hook, 2007; Breithaupt, 2014). Walkways, bridges and/or tunnels integrated with the stations may need to be provided to let passengers transfer to other modes of transport without the need to experience the situations happening outside the stations, such as crossing wide roads.

iii. Passenger information

Sufficient passenger information about the BRT systems and services should be provided within the stations (Hinebaugh, 2009; Wright and Hook, 2007; Breithaupt, 2014). Information can be provided through route map stickers, buses' location digital panels, verbal announcements, officers' assignment, and so forth.

iv. Architectural design

Stations need to be responsive to the local climate (Wright and Hook, 2007; Breithaupt, 2014). It may need to be enclosed and air conditioned. They need to provide sufficient facilities for passengers waiting for bus, varying from sufficient queueing space and benches to restrooms and convenience stores. They also need to be universally accessible as well as provide convenient pedestrian and cyclist access from their surroundings.

v. Other issues

Stations need to be properly distanced between each other (Hinebaugh, 2009; Wright and Hook, 2007; Breithaupt, 2014). They may be located on the curb sides of, median of or separated from existing roads. Stations may need to be complemented with a park-and-ride facility and secure bicycle parking (Hinebaugh, 2009; Breithaupt, 2014).

c. Running ways

Hinebaugh (2009), Wright and Hook (2007) and Breithaupt (2014) highlighted the importance of exclusive lane for BRT buses. They recorded a variety of lane types that may be assigned for BRT buses, including painted lane, bridges/tunnels, exclusive lane guarded by officers and lane separated by separators. The separators can take form as raised lane delineators, separator blocks, curbs, bollards, fences and green reserve lane. Hinebaugh (2009) noted that lane guidance may be needed on BRT lanes. Lane guidance devices include curb, single rail and optical guidance. BRT lanes may be located on the curb sides of, median of or separated from existing roads.

Breithaupt (2014) highlighted the importance of intervention towards traffic signals and rules on traffic intersections along BRT lanes. BRT lanes may need to be complemented with devices and/or traffic signs to prioritise BRT buses on traffic intersections. Hinebaugh (2009), Wright and Hook (2007) and Breithaupt (2014) also highlighted that pavement of BRT lanes should be strong enough to be used exclusively by buses.

d. Services and route structure

Wright and Hook (2007) defined the two ends of BRT management scheme spectrum: open and closed scheme. The open scheme refers to the condition where BRT infrastructure, such as lanes and stations, may be used almost freely by varied bus operators. There is a limited agreement and contract between infrastructure provider and bus operators. Closed scheme refers to the condition where BRT infrastructure may only be used by limited bus operators. There is an extensive agreement and contract between infrastructure provider and bus operators.

Wright and Hook (2007) and Breithaupt (2014) argued that BRT systems utilising closed scheme are better than the ones utilising open scheme. They claimed that BRT systems utilising closed scheme have better operational performance than BRT systems utilising open scheme. Wright and Hook (2007) briefly described that the BRT systems utilising closed scheme have a more efficient infrastructure and vehicle utilisation. Nevertheless, they suggested to consider local context when selecting open or closed scheme to be applied on BRT system. They pointed out that existing bus network and institutional capabilities of the infrastructure provider and bus operators are two main issues that should be considered when choosing the appropriate BRT management scheme.

Wright and Hook (2007) also introduced the two ends of BRT routing options spectrum: trunk-feeder/hub-spoke and direct services. Figure 2 depicts the differences between trunk-feeder services and direct services routing. The two routing options are to address the varied passenger demands of the BRT routes. They are utilising a different composition of infrastructures and vehicles. They are affecting and differing the BRT system's management scheme (open or closed scheme), infrastructure and vehicle provision costs, operational efficiency and passengers' convenience. Wright and Hook (2007) acknowledged the advantages and disadvantages of the two BRT routing options and did not specifically promote one or the other.

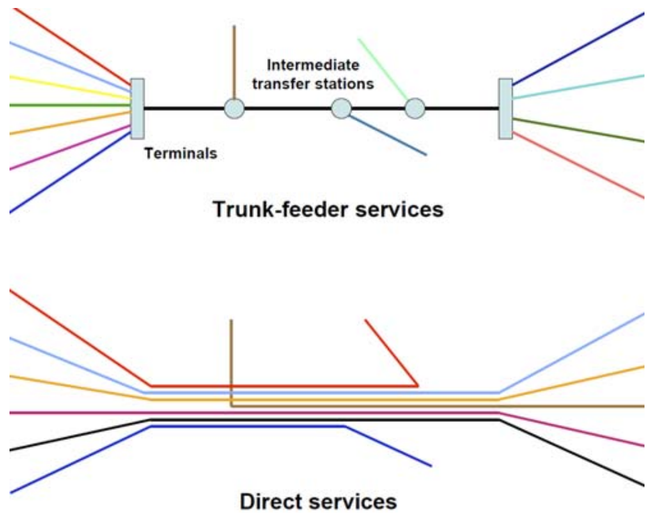

Figure 2 - Trunk-feeder services and directs services routing diagram

Source: Wright and Hook, 2007

However, Wright and Hook (2007) specifically paid attention to direct services routing in a closed BRT scheme. They argued that many urban bus networks are currently operating direct services with open scheme. They suggested that the provision of BRT infrastructure complemented by rearrangement of management into a closed scheme will make a good BRT system. They also argued that direct services better utilise the flexibility of buses, thus current direct services don't need to be radically altered. They suggested that trunk and feeder services need to be introduced only as appropriate. They noted that the introduction of an advanced fare collection system and devices are important for a successful direct services with a closed scheme. The left side of figure 3 depicts Curitiba BRT trunk services. The right side of figure 3 depicts Curitiba BRT feeder services that intersect with trunk services. The right side of figure 3 depicts that Curitiba BRT utilises a hybrid routing which combines trunk-feeder services with direct services.

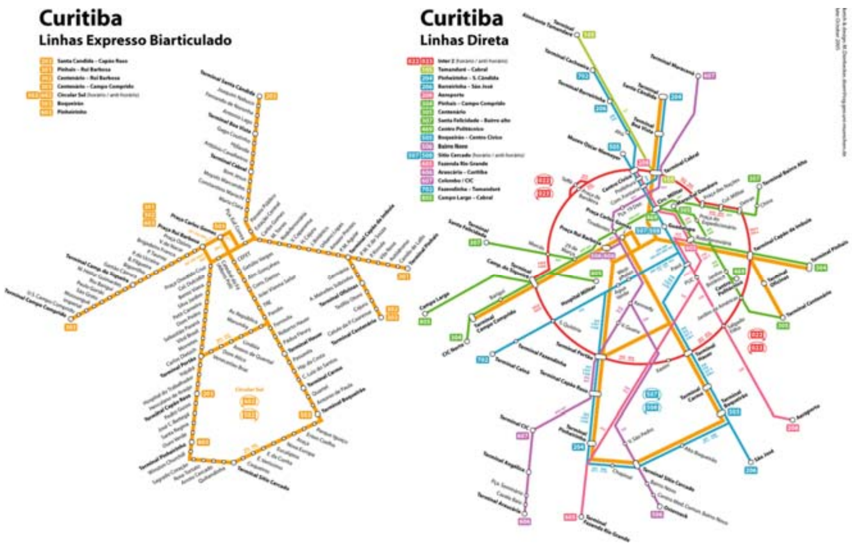

Figure 3 - Left: Curitiba BRT trunk services, Right: Curitiba BRT direct-feeder and trunk services
Source: Wikipedia "Rede Integrada de Transporte", https://en.wikipedia.org/wiki/Rede_Integrada_de_Transporte, retrieved on 17/08/2015 3:20pm

Hinebaugh (2009) noted the importance of routing BRT services by connecting areas of high job availability and areas of high residential density. The new BRT route may make use of the existing bus route with high passenger demand (Breithaupt, 2014). Wright and Hook (2007) also pointed out the importance of considering passengers' inter-route transferring experience when choosing appropriate routing option and designing routes. Routes of high passenger demands should have fewer transferring points.

Wright and Hook (2007) and Breithaupt (2014) also pointed out that BRT systems should be able to address hourly-fluctuating passenger demands. They introduced the possibility of providing local/main services, limited-stop services, express services and shortened services as appropriate. Figure 4 depicts the schematic difference of local/main, limited-stop and express services. Hinebaugh (2009) and Breithaupt (2014) noted that at least one service, that is local or main service, on a particular route must be available for a long period of time every day. One service must be available, for example, during late night on weekends. The headway time of local/main services should be short, for example, below 15 minutes (Hinebaugh, 2009). Figure 5 depicts the example of a BRT route-building process by considering transferring passengers demand and providing limited-stop and express services.

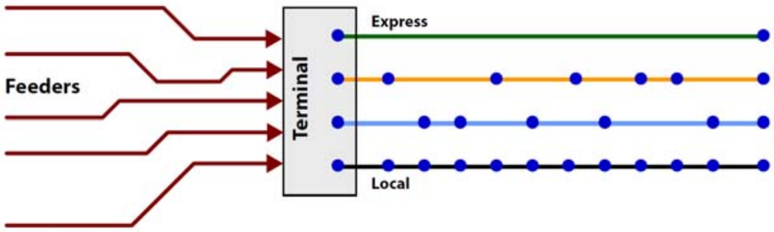

Figure 4 - Schematic of local, limited stop and express services in a trunk-feeder BRT routing system

Source: Wright and Hook, 2007

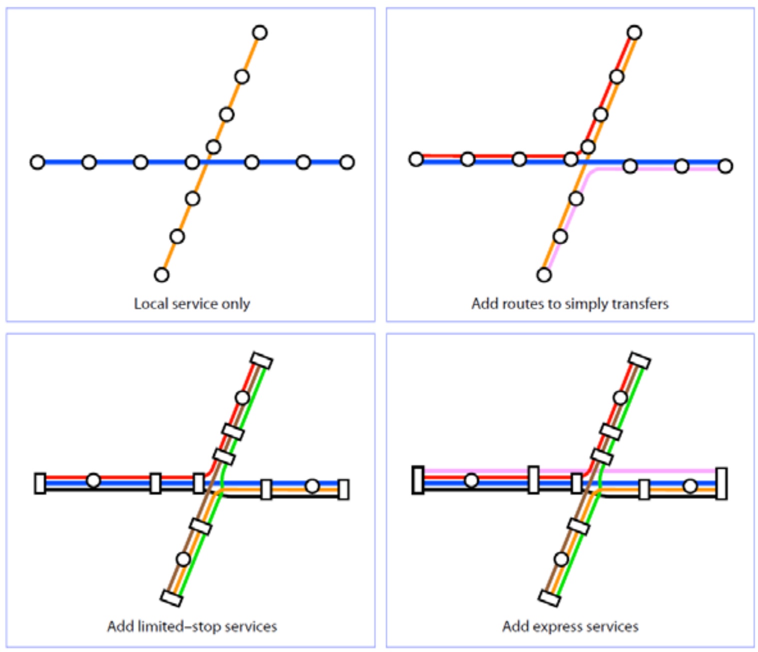

Figure 5 - Example of BRT route-building process

Source: Wright and Hook, 2007

e. Fare collection

Contracts between infrastructure provider and bus operators of BRT systems usually with closed scheme include agreements on fare collection and operational financing (Wright and Hook, 2007). Bus operators usually do not handle fare collection; the infrastructure provider or a third party does. Bus operators finance the operation of their buses and are usually paid by the infrastructure provider on an agreed upon basis, such as on 'per kilometre travelled' basis. As for BRT systems with open scheme, bus operators usually handle fare collection and finance the operation of their buses independently (Wright and Hook, 2007). They may need to pay a small fee to the infrastructure provider for using BRT infrastructures.

Wright and Hook (2007) and Breithaupt (2014) noted that the utilisation of an advanced fare collection system and devices is important on making a good BRT system. The fare and fare collection system should address inter-route passengers appropriately. The need to pay separately for each route should be hindered. The fare system may also need to address inter-modal passengers. Hinebaugh (2009) and Wright and Hook (2007) introduced flat, distance-based, zone-based and time-based fare systems to address inter-route and inter-modal passengers. They noted the importance of utilising advanced fare collection devices, including smart card and computer-controlled fare gates/poles, to support the advanced fare collection system.

f. Intelligent transportation systems

Hinebaugh (2009), Wright and Hook (2007) and Breithaupt (2014) noted the importance of a control centre for a BRT system. The control centre tracks the operation of all buses as well as observes the condition at all stations. Furthermore, the control centre may modify the normal operation of buses to address the fluctuating number of passengers waiting at stations. The control centre need to rely information on the location of the buses to passengers. Buses' location need to be informed to passengers waiting in stations through real-life digital panels and/or verbal announcements. Buses' location may also need to be informed to passengers through mobile phone softwares. Traffic signals along BRT routes may need to be modified in order to give priority to buses. Priority may be given through intervention from control centre or automated intervention by utilising devices on traffic signals, buses and/or pavement.

g. Brand identity

Wright and Hook (2007) and Breithaupt (2014) highlighted the importance of brand identity in order to elevate the positive image of the BRT system. The BRT system's positive image, one of which, is important to increase its ridership. Increase on the BRT's positive image can be triggered through various ways, varying from utilising a proper name and logo, advertising the name and logo properly, utilising consistent system's signage visual design and utilising consistent stations' architecture design and buses' livery. BRT system operators may also assertively advertise themselves through exhibitions and launch events.

Figure 6 - Utilisation of consistent signage visual design and stations' architectural design on Brisbane BRT
Source: Wright and Hook, 2007

It can be concluded from this section that bus rapid transit (BRT) system has technical characteristics that make its service unique, different from conventional bus service and comparable to rail transit service. The following section will introduce BRT performance indicators and measurements, while section f will discuss the relation between BRT performance and technical characteristics.

e) Bus rapid transit performance indicators and measurements

Currie is among the first of the researchers to write about the performance of bus rapid transit (BRT). In his work (2006) on evaluating BRT systems in Australasia, he proposed four aspects to be concerned about when evaluating BRT system's performance: patronage, operation, market and urban development. The 'patronage' aspect refers to the number of people using the BRT system. The 'operation' aspect refers to buses' operational performance, such as speed, travel time, frequency and headway. The 'market' aspect refers to modal share change triggered by BRT system provision, such as the number of people who take the bus of the BRT system to work and used to drive to work prior to the provision of the BRT system. The 'urban development' aspect refers to urban developments that are triggered by, or associated with, the provision of the BRT system.

In the following years, a number of researchers including Babalik-Sutcliffe and Cengiz (2015), Currie and Delbosc (2011, 2014), Deng and Nelson (2011), Deng et al. (2013), Godavarthi et al. (2014), Hensher and Golob (2008), Hidalgo and Graftieaux (2008), Hidalgo et al. (2013), Wright and Hook (2007) and Zhang et al. (2013) developed BRT performance indicators on patronage aspect. They also used BRT patronage performance indicators to evaluate various BRT systems worldwide. As will be discussed in sub-section a and d, these researchers have been able to conceptualise the BRT patronage performance indicators including forming the indicators' solid formula.

Meanwhile, BRT performance indicators on operation, market and urban development aspects have been less developed and used compared to BRT patronage performance indicators. Currie and Delbosc (2014), Deng et al. (2013) and Zhang et al. (2013) are some researchers who developed and used BRT operational performance indicators. However, as will be discussed in sub-section d, there is a tendency to integrate the BRT operational performance indicators to BRT patronage performance indicators. As discussed in section b, a number of researchers have tried to relate BRT systems with urban development. However, they have not been able to conceptualise a solid formula for BRT urban development performance indicators.

BRT performance on market aspect seems to get the least attention from researchers. Currie (2006) and Currie and Delbosc (2014) paid limited attention to the percentage of Australasian BRT passengers who previously drive. Ernst (2005) briefly mentioned Jakarta BRT passengers who previously drive. This section will introduce some BRT patronage and operation performance indicators and measurements while section d will discuss the relation between BRT performance and technical characteristics.

a. Passengers per route km (PRK) and passengers per vehicle km (PVK) figures

The rationale of using BRT system's patronage in measuring its performance is derived from the assumption that buses cannot transport as many people as trains can do. Meanwhile, many urban authorities are in an urgent situation to provide a mode of transport that can transport a massive number people while not having sufficient money to invest in rail-based transport. Hence, BRT projects are initiated to enable buses transport a massive number of people while not costing as much as rail-based transport costs (Deng and Nelson 2011; Deng et al., 2013; Wright and Hook, 2007; Maeso-Gonzalez and Perez-Ceron, 2014; Nikitas and Karlsson, 2015; Racehorse et al., 2014).

The total patronage figure is one of the key figures of concern when evaluating BRT patronage performance. The total patronage figure refers to the total number of people boarding buses of the BRT system on particular corridor/s. The measurement can be done on any time basis including daily, weekly, monthly or annually). Currie and Delbosc

(2011, 2014) developed 'passengers per route km' (PRK) and 'passengers per vehicle km' (PVK) figures as two BRT patronage performance indicators derived from the total patronage figure. They developed PRK and PVK figures when comparing the performance of BRT and non-BRT services of different route length in Australasian (Australia and New Zealand) cities. PRK is also known as boardings per route km (BRK) and PVK is also known as boardings per vehicle km (BVK).

The PRK figure is obtained by dividing the total patronage figure with route length. The inclusion of 'per route km' component to PRK enables the PRK figure to be used as a patronage performance indicator of bus services (including BRT and non-BRT services) of different route lengths. Vehicle km, as in PVK, refers to the distance travelled by buses within a specified time. The PVK figure is obtained by dividing the total patronage figure of the buses with total distance travelled by the buses. The total patronage and buses' total distance travelled figures must be of the same time unit, for example, day, week, month or year). Similar to PRK, the inclusion of 'vehicle km' component to PVK enables the PVK figure to be used as a patronage performance indicator of bus services (including BRT and non-BRT services) of different route lengths. PRK and PVK figures can be used to evaluate patronage performance of BRT systems of both single corridor and multiple corridors. Total patronage, route length and vehicle km travelled figures certainly need to be the appropriately paired ones.

Following are examples of PRK and PVK measurements of a single corridor BRT system. The BRT system is 10 km long. It is served by 10 buses, each travels 10 return trips per day. The daily total patronage figure is 10,000 passengers. The BRT system's passengers per route km (PRK) figure is 10,000 passengers : 10 km = 1,000. The BRT systems passenger per vehicle km (PVK) figure is 10,000 passengers : [10 buses x 10 trips x (1 outbound trip + 1 outbound trip) x 10 km] = 5. When comparing bus services of different route lengths, bus services with higher PRK and PVK figures are considered as those with better patronage performance.

b. Bus average speed

The rationale of using bus average speed in measuring BRT system's performance is derived from one commonly shared background of BRT projects: urban buses prior to BRT project are used to be impeded by traffic congestion, thus cannot rapidly usher their passengers. Responding to that background, BRT projects are usually carried out by including actions and interventions enabling buses to move rapidly (Cervero and Kang, 2011; Ernst, 2005; Wright and Hook, 2007). Hence, bus average speed is used as a BRT performance indicator. It is expected that bus average speed preceding to BRT project be higher than the one prior to BRT project. It is also expected that BRT vehicle average speed be higher than conventional bus average speed.

Bus average speed figure is obtained by dividing bus trip length (in spatial unit, for example, km, mile) with bus trip time (in time unit, for example, minute, hour). BRT vehicle average speed is obtained by averaging all the average speed of buses operating within a particular BRT corridor/s. Babalik-Sutcliffe and Cengiz (2015), Deng and Nelson (2011), Godavarthi et al. (2014), Hensher and Golob (2008), Hensher and Li (2012) and Hidalgi and Graftieaux (2008) paid attention to bus average speed during their whole operating time. Currie and Delbosc (2011, 2014), Deng et al. (2013), Hensher et al. (2014) and Zhang et al. (2013) preferred paying attention to bus average speed only during a certain time when traffic demand peaks (during peak hours).

c. Frequency and headway time

Babalik-Sutcliffe and Cengiz (2015), Currie and Delbosc (2011, 2014), Deng and Nelson (2011), Deng et al. (2013), Hensher and Golob (2008), Hensher and Li (2012) and Wright and Hook (2007) paid attention to frequency and headway time when evaluating performance of various BRT systems. Frequency refers to quantity of bus trips in a specified BRT route within a specified time, for example, one hour. Headway time refers to the time gap between each consecutive trip.

Considering that frequency and headway are functions of speed, I argue that using them as BRT performance indicator is not necessary as long as the bus average speed indicator is being used. However, understanding frequency and headway time will help understanding the 'passengers per hour per direction' (pphpd) indicator that will be discussed in the following sub-section. Understanding them will also help understanding the relation between BRT technical characteristics and performance that will be discussed in section d.

d. Passengers per hour per direction (pphpd) figure

Wright and Hook (2007) introduced passengers per hour per direction (pphpd) as a BRT patronage performance indicator that takes BRT operational performance into account. The figure is obtained by multiplying buses capacity with their one direction trip frequency within a specified time, for example, one hour. Bus occupancy assumption (as percentage of bus capacity) may be used as appropriate. Considering that the trip frequency of buses is affected by their average travelling speed, pphpd figure is affected by the average speed of buses. It is suggested that the figure is obtained in hourly basis to obtain figures that respond to the hourly fluctuating bus average speed. Babalik-Sutcliffe and Cengiz (2015), Deng et al. (2013), Hensher and Golob (2008), Hidalgo and Graftieaux (2008), Wright and Hook (2007) and Zhang et al. (2013) suggested to pay attention to BRT maximum pphpd figure in order to understand its *capacity*. BRT maximum pphpd figure is usually reached when passenger demand peaks (during peak hours). BRT systems with higher pphpd figure are considered performing better that the ones with lower pphpd figure.

Following are calculation examples of average speed, frequency, headway and passengers per hour per direction (pphpd) figures. Prior to the BRT project, a bus service of 10 km route-length is served by 2 buses of 40 passenger-capacity, named bus X and bus Y. The buses on average travel 20 km/h and their average occupancy rate is 75 percent. The bus service maximum pphpd figure is 2 buses x 40 passengers x 20 km/h : (10 km outbound trip + 10 km inbound trip) = 80 passengers/hour/direction. The bus service average pphpd figure is 75% x 80 = 60 passengers/hour/direction. The bus service frequency (per direction) is 2 buses x 20 km/h : (10 km outbound trip + 10 km inbound trip) = 2 trips/hour. Bus X is scheduled to depart every minute 0 and bus Z is scheduled to depart every minute 30, hence the headway time is 30 minutes.

Preceding to the BRT project, the same bus service is served by 2 buses of 80 passenger-capacity, named bus P and Q. The buses on average travel 40 km/h and their occupancy rate is 75 percent. The bus service maximum pphpd figure is 2 buses x 80 passengers x 40 km/h : (10 km outbound trip + 10 km inbound trip) = 320 passengers/hour/direction. The bus service average pphpd figure is 75% x 320 = 240 passengers/hour/direction. The bus service frequency (per direction) is 2 buses x 40 km/h : (10 km outbound trip + 10 km inbound trip) = 4 trips/hour. Bus P is scheduled to depart every minute 0 and 30 and bus Q is scheduled to depart every minute 15 and 45, hence the headway time is 15 minutes. The BRT project quadrupled the bus service pphpd figure, doubled its frequency and halved its headway time.

It is worth to note that the pphpd figure is not exclusively used as a BRT performance indicator. The pphpd figure can be used to evaluate performance of various modes of transport, ranging from car to heavy rail/MRT. Thus, the pphpd figure can be used to compare the performance of BRT system with the other modes of transport, as have been done by Babalik-Sutcliffe and Cengiz (2015) and Wright and Hook (2007). I consider the pphpd figure's compatibility in comparing various modes of transport's performance as its advantage.

It can be concluded from this section that the performance of BRT system is commonly measured in terms of their patronage and operational aspects. Some of the widely used performance indicators include passengers per route km (PRK) figure, passengers per vehicle km (PVK) figure, bus average speed, bus frequency and headway time and passengers per hour per direction (pphpd) figure. The following section will discuss the relation between BRT technical characteristics and performance.

f) Relation between BRT technical characteristics and performance

a. Passengers per route km (PRK) and passengers per vehicle km (PVK) figures

Currie and Delbosc (2011, 2014) and Hensher and Golob (2008) evaluated the PRK and PVK figures for various bus rapid transit (BRT) systems around the world. They also relate the varied BRT systems' PRK and PVK figures with their varied technical characteristics. Currie and Delbosc (2014) evaluated 10 BRT systems in five Australasian (Australia and New Zealand) cities, reviewing their key technical characteristics as well as patronage and operational performance indicators. Each BRT system may consist of more than one BRT corridors. They analysed the data and created the relational patterns (in Cartesian diagram) of variable combinations.

Currie and Delbosc (2011) evaluated 77 Australian BRT and conventional bus (non-BRT) services. The explanatory variables they explored in their research include service level, frequency, average speed, station spacing, share of segregated right of way, vehicle accessibility, employment and residential density, car ownership levels and BRT infrastructure. Currie and Delbosc relate those variables with BRT systems' PRK and PVK figures by using five regression models. Similarly, Hensher and Golob (2008) evaluated 44 worldwide BRTs. The explanatory variables they explored in their research include fares, number of stations, average distance between stations, average all day commercial speed, average peak headway, average non-peak headway and vehicle capacity. Hensher and Golob relate those variables with BRT systems' PRK figures by using one regression model.

Currie and Delbosc (2011, 20014) and Hensher and Golob (2008) pointed out a number of technical characteristics issues associated with BRT PRK and PVK figures:

i. Station spacing

All researchers found higher PRK and PVK figures are associated with shorter stop spacing. Currie and Delbosc (2014) argued that the phenomenon is likely because BRT systems having shorter stop spacing are located in areas of high density and high transit demand. In addition, all researchers also noted that shorter stop spacing is associated positively with lower bus speed. Lower bus speed, in turn, is associated with lower passengers per hour per direction (pphpd) figure.

ii. Accessible bus

Currie and Delbosc (2011, 2014) found BRT systems utilising accessible buses have higher PRK and PVK figures. They described accessible buses as better-designed, better-branded and newer vehicles. They mentioned low floor buses, platform level buses and wheelchair accessible buses as examples of accessible buses.

iii. Bus capacity

Hensher and Golob (2008) found BRT systems utilising higher capacity buses have higher PRK figures.

iv. Segregated right of way

Currie and Delbosc (2011, 2014) found BRT systems having a higher share of segregated right of way have higher PRK and PVK figures.

v. Network width, transit network integration and transferring distances at stations

All researchers found BRT systems that have wide network and BRT systems that are integrated with other transit services have higher PRK and PVK figures. They also found inter-route and inter-modal transferring distance at stations influence PRK and PVK figures.

vi. Off-board ticketing

Currie and Delbosc (2014) found BRT systems having off-board ticketing have higher PRK and PVK figures.

b. Passengers per hour per direction (pphpd) figure

Deng et al. (2013) evaluated the pphpd figures of bus rapid transits (BRT) systems in 13 Chinese cities. They relate the varied BRT systems' pphpd figures with their varied technical characteristics as well as the Chinese cities' context. The explanatory variables they explored in their research include network length, share of segregated right of way, station spacing, passing lanes, vehicle length, off-board ticketing, signal priority, routes, population, population density and GDP per capita. Deng et al. relate those variables with BRT systems' pphpd figures by using one regression model.

Deng et al. pointed out a number of technical characteristics issues associated with BRT pphpd figure:

i. Overtaking lanes

Provision of overtaking lanes is found to have a significant impact on the pphpd figure.

ii. Station spacing

Distance of station spacing is found having significant impact on bus average speed and pedestrian coverage. Bus average speed and pedestrian coverage in turn have significant impact on pphpd figure.

iii. Integration with non-motorised transportation

Integration of BRT system with non-motorised transportation is found to have a significant impact on the pphpd figure. Deng et al. noted that bicycle facilities should be integrated to BRT systems in Chinese cities.

c. Frequency and headway time

Currie and Delbosc (2011, 2014), Deng et al. (2013) and Hensher and Golob (2008) related BRT technical characteristics with BRT patronage performance indicators, including the PRK, PVK and pphpd figures. They didn't specifically relate BRT technical characteristics with BRT operational performance indicators, such as frequency and headway time. However, they related BRT operational performance indicators with BRT patronage performance indicators. Currie and Delbosc (2011) and Hensher and Golob (2008) found frequency and headway influence PRK and PVK figures. Currie and Delbosc (2014) found BRT systems of higher frequency and lower headway time have higher PVK figures. Deng et al. (2013) found frequency and headway time are associated with pphpd figure.

It can be concluded from this section that BRT performance is related to BRT technical characteristics. The BRT system's passengers per route km (PRK) and passengers per vehicle km (PVK) figures are related to its station spacing, vehicle accessibility, vehicle capacity, share of segregated right of way, network width, integration with wider transit network and availability of off-board ticketing. The BRT system's passengers per hour per direction (pphpd) figure is related to its availability of overtaking lanes, station spacing and integration with non-motorised transportation. The following section will summarise all of the discussions in this chapter.

g) Summary

Transit oriented development (TOD) is an emerging type of urban development that intends not to have the drawbacks of urban sprawl. It promotes the development of a high-density built environment around transit hubs. Bus rapid transit (BRT) is a potentially significant component of TOD. While the provision of transit service, including BRT service, is an essential component of TOD, it is not the only component of TOD. It is common for the provision of BRT service to be complemented by other policies that related to yet are separate from BRT provision policy.

The provision of some bus rapid transit (BRT) systems have been influencing urban development around the systems. The influence have been less uniform compared to the BRT operational performance indicators. In regard to that, Stokeberga (2014) suggested that further research be carried out on exploring the influence of BRT particular technical characteristics on land-use and property price.

In a glance, BRT is bus service which is comparable to rail transit service. Its investment and operational cost are usually less costly than rail transit's ones. It is a mode of transit that has been growing popular since the 1970s. BRT components include at least vehicles, stations, running ways, intelligent transportation system and service. Technical characteristics of those components make BRT service unique, different from conventional bus service and comparable to rail transit service.

The performance of BRT system performance is commonly measured in terms of their patronage and operational aspects. Some of the widely used performance indicators include passengers per route km (PRK) figure, passengers per vehicle km (PVK) figure, bus average speed, bus frequency and headway time and passengers per hour per direction (pphpd) figure. BRT performance is related to BRT technical characteristics. The BRT system's passengers per route km (PRK) and passengers per vehicle km (PVK) figures are related to its station spacing, vehicle accessibility, vehicle capacity, share of segregated right of way, network width, integration with wider transit network and availability of off-board ticketing. The BRT system's passengers per hour per direction (pphpd) figure is related to its availability of overtaking lanes, station spacing and integration with non-motorised transportation. The following section will discuss the knowledge gap I found exist and the assumptions I will use when trying to fill the knowledge gap.

h) Knowledge gap and research assumptions

Recent researches have explained the influence of BRT system on urban development. Bocarejo et al. (2013), Cervero and Kang (2011), Deng and Nelson (2013), Dube et al. (2011), Hidalgo et al. (2013), Jun (2012), Mulley (2014), Munoz-Raskin (2010), Perk et al. (2012), Rodriguez and Mojica (2009) and Zhang et al. (2014) are some of the researchers who had conducted the researches. Stokenberga (2014) provided a literature review on the issue.

However, these researches mainly regard each BRT system as a 'system' instead of a working combination of several components. They barely explained the technical characteristics of the BRT systems analysed. For instance, the works of Bocarejo et al. (2013), Hidalgo et al. (2013) and Munoz-Raskin (2010) only briefly explained that BRT systems in Bogota, Colombia, operate in trunk-and-feeder system, use articulated and bi-articulated buses, operate in both exclusive and mixed-traffic lanes, utilise integrated fare system and off-board fare collection, have bus-priority traffic signals, utilise real-time passenger information systems and are integrated with the pedestrian and bicycle infrastructure. Hidalgo's et al. work (2013) added that BRT systems in Bogota, Colombia, have level boarding at stations, have centralised control systems and operate under a public-private mechanism. The works of Cervero and Kang (2011) and Jun (2012) only stated that BRT systems in Seoul, South Korea, have dedicated lanes, bus-priority traffic signals, real-time passenger information systems and attractively designed bus stops. Jun's work (2012) added that BRT systems in Seoul, South Korea, operate in a 'semi-public' operation system and utilise state-of-the-art buses. Mulley's work (2014) only stated that the Liverpool Parramatta Transitway in South-west Sydney, Australia, has infrastructure that is designed similar to rail transit infrastructure. Deng and Nelson's work (2013) that discuss a BRT system in Beijing, China and Dube's et al. work (2011) that analyse a BRT system in Quebec City, Canada, did not explicitly state the technical characteristics of the BRT systems analysed.

Meanwhile, separate recent researches have described and evaluated the technical characteristics of BRT systems. Babalik-Sutcliffe and Cengiz (2015), Currie and Delbosc (2011, 2014), Deng and Nelson (2011), Deng et al. (2013), Hensher and Golob (2008), Hensher and Li (2012), Hinebaugh (2009) and Wright and Hook (2007) are some of the researchers who had conducted the researches. The mentioned recent researches dissected various BRT systems and described them as working combinations of several components.

However, those researches did not explain the influence of the analysed BRT systems on urban development.

Stokenberga's work (2014) is currently the only research that paid attention to both the technical characteristics BRT systems and the influence of the BRT systems on urban development. However, as table 1 illustrates, the description on the technical characteristics of the BRT systems only slightly cover the right of way/pavement of the BRT systems. There is no sufficient description on the other technical characteristics of the BRT systems. Furthermore, the work did not exhibit a reliable method to relate the BRT technical characteristics with the BRT influence on urban development.

Little if any reliable knowledge exists in regard to the relation between the BRT technical characteristics and the BRT influence on urban development. This argument is shared by Stokenberga (2014, p.291) who suggested that "future research should more thoroughly explore the question of which of the physical characteristics of BRT corridors and not just the systems themselves induce the price premiums found in the reviewed studies". Consistent with Stokenberga's suggestion, I assume that there is a relation between the BRT technical characteristics and the BRT influence on urban development. Moreover, I assume that certain BRT technical characteristics contribute positively to the BRT influence on urban development. In other words, I consider that a BRT system may influence urban development by having certain technical characteristics.

In their analysis on the influence of BRT systems on urban development in Seoul, South Korea, Cervero and Kang (2011) and Perk et al. (2013) had a conclusion that refine my assumption. They argued that it is the BRT quality of service instead of the BRT system "hardware" that influence urban development. In addition, they argued that, in regard to the Seoul BRT systems, it is the comparative travel-time savings of taking buses of BRT system vis-à-vis driving car that influence urban development. They claimed that their opinion is consistent with the findings of previous researches on the influence of rail-transit improvements on urban development. I found that their opinion is consistent with the theoretical framework that has been employed by various researchers when evaluating the influence of BRT systems on urban development, referred to as the land rent theory that is advanced in urban context by Alonso (1964) and Muth (1969). Debrezion in Stokenberga (2014) developed the theory in regard to investment in transport infrastructure and argued that investment in transport infrastructure may alter the properties' implicit price by altering the transit accessibility of the properties.

Cervero and Kang (2011) argued that it is the quality of service of BRT instead of BRT system "hardware" that influences urban development. Meanwhile, recent researchers (Babalik-Sutcliffe and Cengiz, 2015; Currie and Delbosc, 2011, 2014; Deng and Nelson, 2011; Deng et al., 2013; Hensher and Golob, 2008 and Hensher and Li, 2012) found that a number of BRT technical characteristics influence BRT performance. Based on Cervero and Kang's (2011) argument and the findings of the mentioned researches, I assume that BRT technical characteristics influence BRT performance and in turn influence urban development. In other words, I assume that a BRT system may influence urban development by having certain technical characteristics that influence its performance.

As has been suggested towards the end of section a, it is common for BRT service provision to be complemented by other policies related to yet separate from BRT provision policy. Cervero (1998) and Suzuki et al. (2013) explained that the complementary policies may include transport and land-use policies. Accordingly, I argue that research on the influence of BRT system on urban development must pay attention to the BRT complementary policies whenever available.

It can be concluded from this section that currently little if any reliable knowledge exists in regard to the relation between the technical characteristics of BRT and the influence of BRT on urban development. It is assumed that BRT technical characteristics influence BRT performance and in turn influence urban development. It is necessary to note that research involving the mentioned assumption needs to notice the BRT complementary policies whenever available.

Chapter 3
Methodology

This chapter will discuss the methodology of this research. Section a will briefly describe the research strategy and general method. Section b will discuss the selection of case studies that were analysed in this research. Section c will discuss the object and the knowledge base of the analysis carried out in this research. Section d will discuss the hypotheses of this research. The last section will discuss the limitations of the methods employed in this research.

a) Research strategy and general method

This research was carried out following the assumption that has been constructed in section h of chapter 2. It was carried out following the assumption that "BRT technical characteristics influence BRT performance and in turn influence urban development". This research employs the qualitative research approach. Qualitative research approach was chosen considering that it helps provide detailed and orderly information leading to the answers for the research questions. As previously mentioned in chapter 1, the research questions as follows:

1. What are the technical characteristics of BRT systems that influence urban development around the systems?
2. How does having those technical characteristics make the BRT systems influence urban development around them?

Literature review was the method used in all stages of this research. In addition to providing the research assumption, the literature review presented in the previous chapter also provided the case studies and the knowledge base for the analysis of the case studies in order to answer the research questions. Researches on the influence of BRT systems on urban development were quoted as case studies. A further literature review was carried out when analysing the quoted BRT systems. The analysis of the case studies included analysis on the BRT systems' technical characteristics and investigation on the performance of the BRT systems. Figure 7 depicts the strategy of this research.

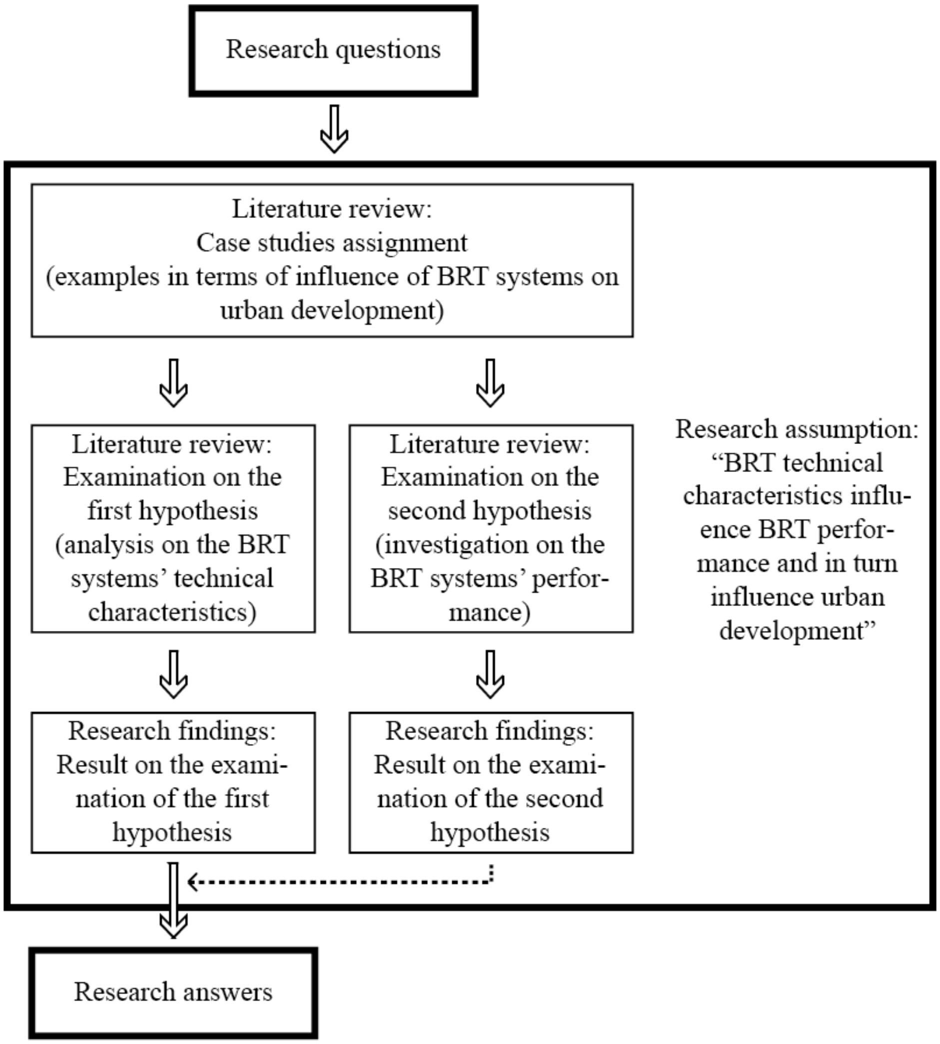

Figure 7 – The research strategy

b) Case studies selection

In order to provide answer with wider perspective for the research questions, two different bus rapid transit (BRT) systems were assigned as case studies and analysed through the further literature review. Due to time limitations of this research, I was not able to carry out my own research on the influence of BRT systems on urban development. Instead, I quoted and utilised two researches on the issue for the case studies. The two case studies had the same urban development indicator, enabling this research to be able to provide a comparable analysis. Furthermore, the two quoted researches on the influence of BRT systems on urban development observed the similar object and utilised the same method. Further information on the similarity of the two quoted researches will be presented on section c of chapter 4.

The two BRT systems utilised as case studies have different complementary policies in regard to transit oriented development (TOD). The differentiation was intended to help understanding the BRT systems as part of TOD policy package. The information on the TOD policies was intended to help understanding the different findings of the two case studies, if the findings are different. The differentiation was also intended to help future researches that will analyse bus rapid transit (BRT) in the context of transit oriented development (TOD).

c) Analysis

This research analysed the BRT technical characteristics that were found to influence BRT performance by Currie and Delbosc (2011, 2014), Deng et al. (2013) and Hensher and Golob (2008), of the BRT systems assigned as the case studies. The analysis of the technical characteristics were grouped into several issues. The issues include:

- Station configuration and accessibility
- Vehicle capacity and accessibility
- Segregated right of way
- Off-board ticketing
- Network width and transit network integration

The BRT performance, as discussed by Currie and Delbosc (2011, 2014), Deng et al. (2013) and Hensher and Golob (2008), are measured by passengers per hour per direction (pphpd), passenger per route km (PRK) and passenger per vehicle km (PVK) figures. Consistent with that, this research also investigated the BRT systems pphpd, PRK and PVK figures. This research also paid attention to BRT patronage and vehicle average speed that constitute the pphpd figure.

The BRT technical characteristics were analysed based on their contribution towards the BRT performance. Extensive knowledge on BRT technical characteristics provided by Breithaupt (2014), Danaher et al. (2007), Hinebaugh (2009) and Levinson et al. (2003a, 2003b) that has been discussed in section d of the previous chapter was used as the base for the analysis. Whenever available, technical characteristics of the predecessor modes of transport to the BRT systems were presented. The presenting of the technical characteristics of the predecessor modes of transport reinforced the explanation regarding the way technical characteristics of the BRT systems influence the BRT systems performance.

d) Hypotheses

Following the assumption that "BRT technical characteristics influence BRT performance and in turn influence urban development", this research adopted two hypotheses. The first hypothesis of this research was that BRT systems influence urban development by having technical characteristics which make the BRT systems have high performance, as measured by pphpd, PRK and PVK figures. By considering the works of Currie and Delbosc (2011, 2014), Deng et al. (2013) and Hensher and Golob (2008) that has been discussed in section f of the previous chapter, I proposed that the BRT systems assigned as the case studies have the following technical characteristics:

- On station configuration and accessibility: stations are distanced in a way that all areas adjacent to the BRT corridor are within 10 minutes walking
- On vehicle capacity and accessibility: buses are of low floor or platform level and wheelchair accessible, buses are articulated or bi-articulated
- On segregated right of way: 80% of BRT right of way is segregated right of way
- On off-board ticketing: off-board ticketing facilities are utilised
- On network width and transit network integration: BRT systems are well connected to other modes of transport.

This hypothesis was the main hypothesis examined in this research. Examination of the first hypothesis led to the answer for the research questions.

The second hypothesis of this research was that BRT systems influence urban development by having high performance, as measured by pphpd, PRK and PVK figures. By considering the works of Currie and Delbosc (2011, 2014), Deng et al. (2013) and Hensher and Golob (2008) that has been discussed in section f of the previous chapter, I proposed that the BRT systems assigned as the case studies have:

- Passengers per hour per direction (pphpd) figure at above 5,000
- Passengers per route km (PRK) figure at above 40,000
- Passenger per vehicle km (PVK) figure at above 1.75.

Though it was not the main hypothesis, this hypothesis was also examined in this research. This hypothesis was examined to strengthen the first hypothesis. This hypothesis was examined to strengthen the hypothesis that having several technical characteristics, as mentioned in the bullet points of the first paragraph, makes BRT systems have high performance, thus making the BRT systems influence urban development around them.

Examination of this hypothesis was intended to strengthen the examination of the first hypothesis.

e) Limitation

By quoting and utilising other researches on BRT systems influence on urban development, I couldn't pay attention to the type of urban development that I think appropriate to pay attention to. I was restricted to paying attention to the observed object of the quoted researches regardless of the observed object's relevance to this research. Second topic on section c of the next chapter will further discuss this limitation. Meanwhile, the inappropriateness of the observing the object, as observed in the quoted researches, may contribute to the unclear conclusion of this research as will be presented in chapter 6.

Chapter 4
Case Studies

This chapter will introduce the case studies that will be analysed in the next chapter. Section a and b will introduce the BRT systems including their general system overview, influence on urban development and complementary policies if available. Section c will discuss the limitations in terms of selecting and analysing the chosen BRT systems for this research. The last section will briefly summarise information on the two case studies.

a) Boston Silver Line 4 and 5 (Washington Street), United States

a. General systems overview

Boston Silver Line 4 and 5 (SL4 and SL5) are BRT systems operating along Washington Street, Boston, United States, connecting Dudley Square to Chinatown in Boston CBD. The two BRT systems will be referred as 'Boston SL4/5' or 'SL4/5' in this research. Boston SL4/5 routes only slightly differ in the CBD area after passing Chinatown: SL4 loops clockwise passing South Station while SL5 loops anti-clockwise passing Downtown Crossing. The total route length of the two systems is 3.86km. The services were started on 2002 and the latest route extension was carried out on 2009. SL4/5 operate 7 days a week from 6:00am to 12:20am. As exhibited in figure 8, SL4/5 connect with other Boston rapid transit services, named Blue Line, Green Lines, Orange Line, Green Lines, Red Lines and other Silver Lines, at a number of stations within Boston CBD (Perk et al., 2012; MBTA, 2015).

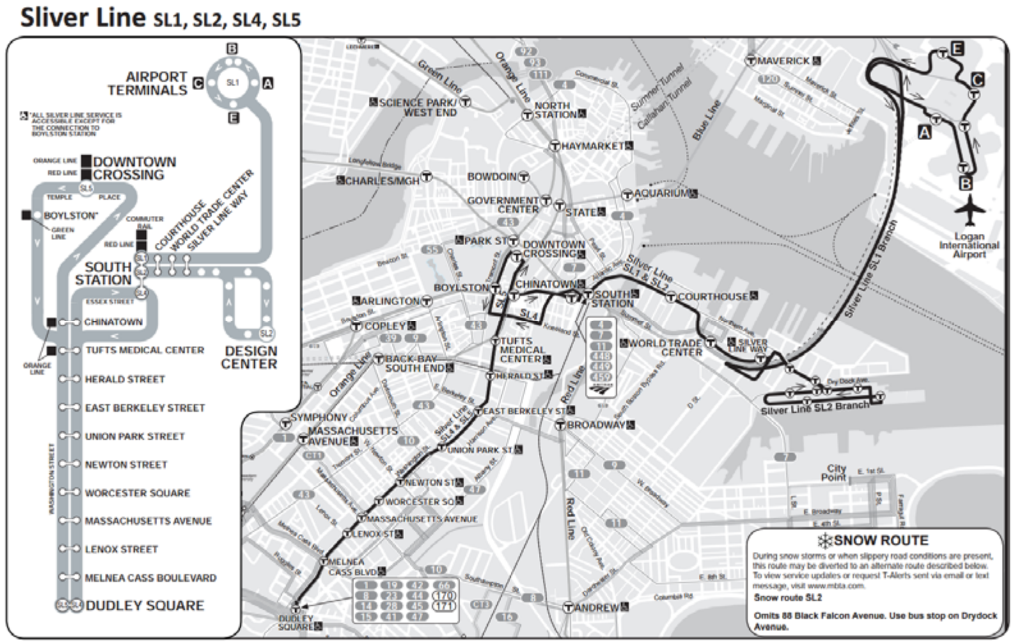

Figure 8 - Boston Silver Line map

Source: Massachusetts Bay Transportation Authority, http://www.mbta.com/uploadedFiles/Documents/Schedules_and_Maps/Bus/silverwatermap.pdf, retrieved on 17/09/2015 1:20pm

b. Influence on urban development

Perk et al. (2013) investigated the influence of Boston SL4 and SL5 on urban development along Washington Street. They investigated the sale prices of condominium units around BRT stations along Washington Street before and after the start of the services. 9 BRT stations are located along Washington Street out of 14 SL4/5 stations. As exhibited in figure 9, the data used for their study consists of all condominium units within 0.4km of the Washington Street corridor. Condominium units were selected as the focus of their research considering that a relatively large amount of condominium units are located along the corridor. The City of Boston provided parcel data for the years 2003 to 2009 and the sales data for the years 2000 to 2009.

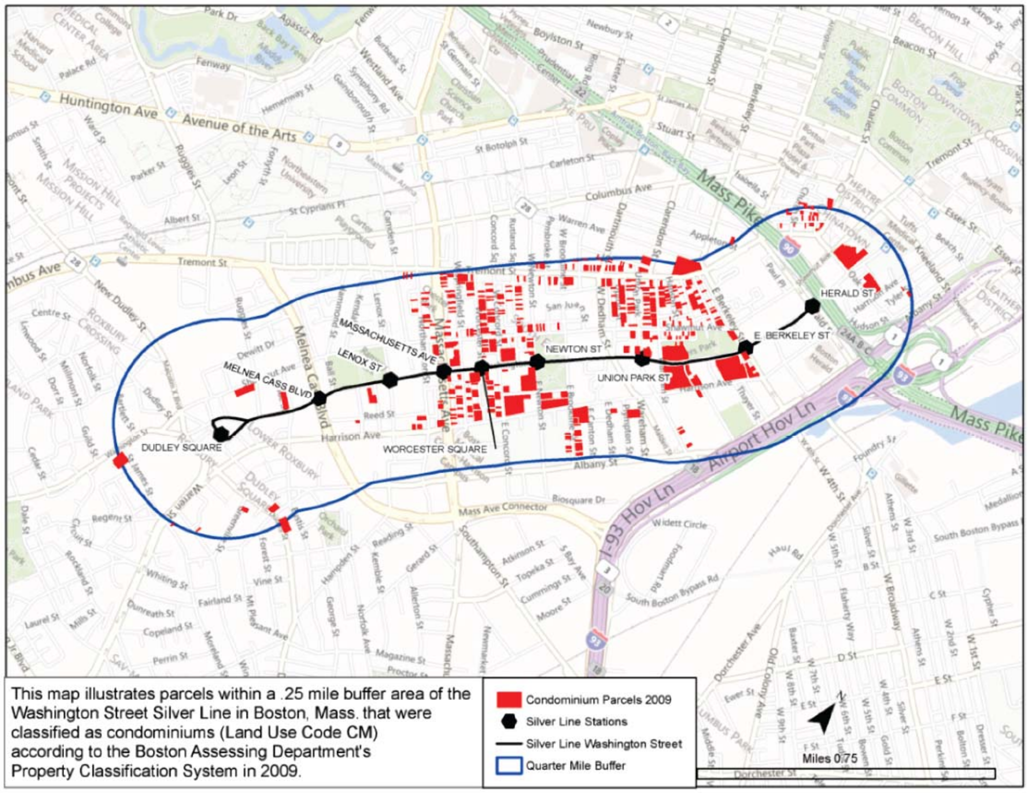

Figure 9 - Perk's et al. (2013) study area

Source: Perk et al., 2013

The research calculated the marginal effects of the sale prices of the condo units differed by the location of the units, before and after the starting of SL4/5 services along Washington Street. The research found that between 2000 and 2001, before the start of SL4/5 services along Washington Street, condo units closer to the corridor had a *lower* per square meter sale price than the ones farther away. For example, the per square meter sale price of a condo unit located 30.5m from the corridor was 1.3$ lower than the per square meter sale price of a condo unit located 30.8m from the corridor. The per square meter sale price of a condo unit located 292.6m from the corridor was 0.67$ lower than the per square meter sale price of a condo unit located 292.9m from the corridor. By summing these marginal effects of various distances, the research found that there was a premium at approximately 988.9$ per square meter for a condo unit at the mean distance from the corridor compared to the one adjacent to the corridor, all else constant, for the time period before the start of SL4/5 services along Washington Street.

On the contrary, the research also found that between 2007 and 2009, after the starting of SL4/5 services along Washington Street, condo units closer to the corridor had a *higher* per square meter sale price than the ones farther away. The per square meter sale price of a condo unit located 30.5m from the corridor was 0.67$ higher than the one located 30.8m from the corridor. The per square meter sale price of a condo unit located 265.2m from the corridor was 0.44$ higher than the one located 265.5m from the corridor. By summing these marginal effects of various distances, the research found that there was a premium at approximately 509.1$ per square meter for a condo unit adjacent to the corridor compared to the one located at the mean distance from the corridor, all else constant, after the start of SL4/5 services along Washington Street. The research found the BRT premium was approximately 7.6%. These results are statistically significant at the 5% level of significance using robust standard errors.

c. Complementary policies

Hinebaugh (2009) and Perk et al. (2013) had written about Boston SL4 and SL5. None of them stated that the SL4/5 projects were complemented by significant transport or land-use policies. For instance, none of them stated that the projects were complemented by traffic rearrangement or floor area ratio (FAR) allowance increase around the corridor. Perk et al. (2013) only noted that the projects were complemented by sidewalk renovation and pavement resurfacing along Washington Street. Sidewalk renovation included widening, ramp making and tree planting. It can be assumed that the SL4/5 projects were isolated transit projects. Thus, the property price change along Washington Street was influenced almost exclusively by the projects.

b) Seoul BRT systems, South Korea

a. General systems overview

Differeent from Boston SL4 and SL5 services which are finely defined and easily differentiated from conventional bus services, Seoul BRT systems were defined by Cervero and Kang (2011) as bus services operating using advanced bus infrastructure built after the 2000s in Seoul, South Korea. They specifically stated that the bus services running along dedicated median-lanes are the Seoul BRT systems and acknowledged that some other bus services running along curbside bus lanes and mixed traffic roads are also part of the Seoul BRT systems. The dedicated median-lanes were firstly built on 2004. However, the Seoul BRT systems analysed in their research are the bus services running along the dedicated median-lanes as indicated by continuous dots in figure 10. The numbers located close to the continuous dots refer to the year the dedicated median-lanes were constructed. As of 2008, Seoul had built 74km of dedicated median-lanes spanning 8 corridors. The corridors connect with many Seoul inner city, regional and national train stations: underground, at grade and elevated ones.

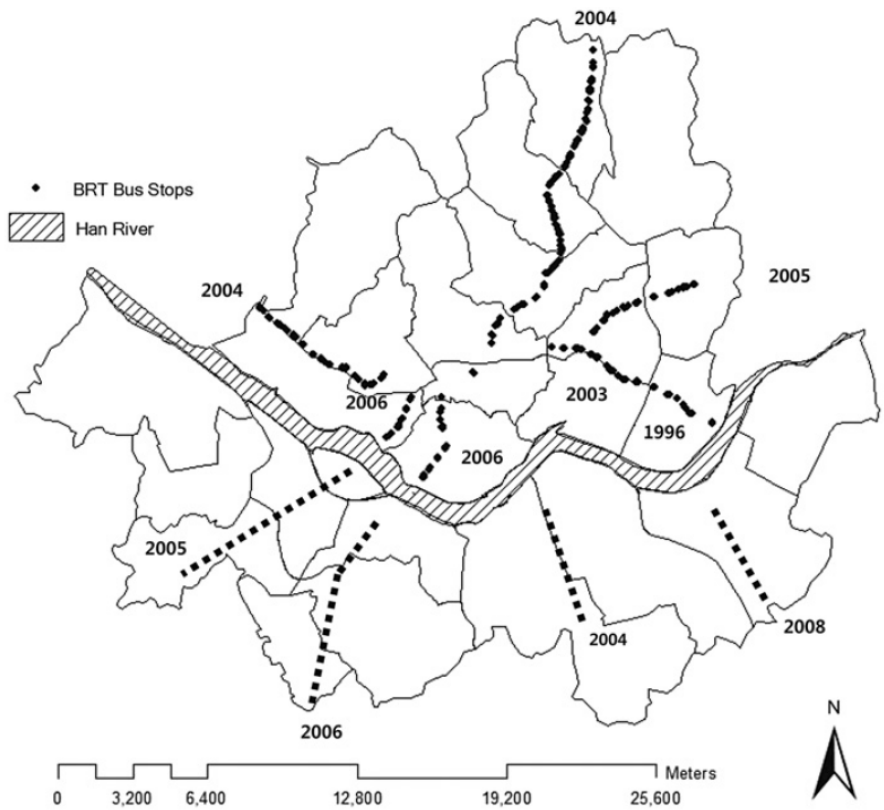

Figure 10 - Seoul BRT corridors investigated by Cervero and Kang (2011)
Source: Cervero and Kang, 2011

b. Influence on urban development

Cervero and Kang (2011) investigated the Seoul BRT systems influence on urban development on areas around the dedicated median-lane BRT corridors. They investigated the values of land parcels around the new median-lane stations before and after the construction of dedicated median-lanes. The land parcels evaluated are land parcels whose nearest bus stop transformed into a median-lane station. All parcels were within 2.15km and the vast majority were within 0.5km of a BRT station. Seoul's Assessor's Office provided land parcel and value data for the years 2001-2007.

Through multiple regression models, the research calculated the marginal effects of residential and non-residential properties that differed by their locations. The research calculated the marginal effects over two time periods: 2001-2004 (before the construction of dedicated median-lanes) and 2005-2007 (after the construction of dedicated median-lanes and operation of BRT services along the lanes). The findings related to the marginal effects of residential properties are exhibited in figure 11 while findings of the marginal effects of non-residential properties are exhibited in figure 12.

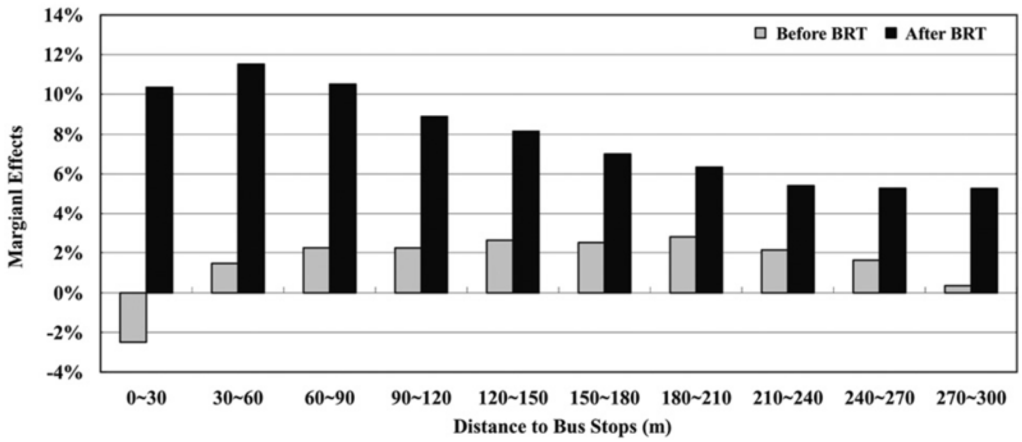

Figure 11 - Marginal effects of residential properties in relation to distance to bus stops, before and after the BRT project

Source: Cervero and Kang, 2011

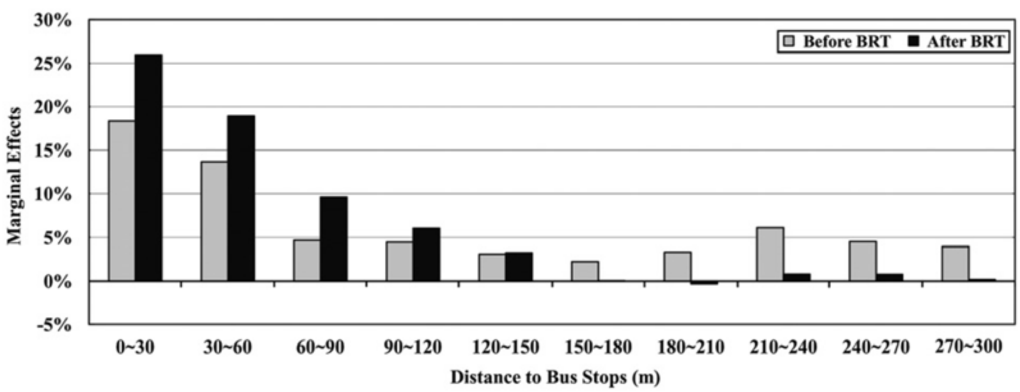

Figure 12 - Marginal effects of non-residential properties in relation to distance to bus stops, before and after the BRT project

Source: Cervero and Kang, 2011

Figure 11 shows that between 2001 and 2004, the price of residential properties located within 300m of a bus stop were having premium compare to the ones located beyond. Between 2005 and 2007, the premium was noticeably bigger. The negative premium of residential properties located within 30m of a bus stop between 2001 and

2004 was also diminished between 2005 and 2007. The BRT premium for residential properties located within 300m of a BRT stop ranged from 5% to 10%. Figure 12 shows that between 2001 and 2004, the price of non-residential properties located within 300m of a bus stop were also having premium compared to the ones located beyond. Between 2005 and 2007, the premium was increased and shifted to within 150m of a bus stop. The BRT premium for non-residential properties within 150m of a BRT stop ranged from 3% to 26%. These results are statistically significant at the 5% probability level.

c. Complementary policies

Cervero and Kang (2011), Jun (2012) and Stokenberga (2014) argued that Seoul BRT projects were part of a large scale urban renewal project carried out since early 2000s. Jun (2012) argued that Cheonggye elevated highway removal is the project most related to Seoul BRT projects. On 2003, Cheonggye elevated highway that used to connect the Gwanghamun area with Naebu motorway (Seoul eastern inner ring motorway) was demolished. The 4-lane Cheonggye at-grade road was also reduced into 2-lanes road. The BRT projects were then carried out thoroughly to redirect the commuters who used to drive along Cheonggye elevated highway and at-grade road into taking buses. I argue that the mobility redirection modify the accessibility of some areas in the city, thus modifying the property value of those areas.

Cervero and Kang (2011) and Stokenberga (2014) also noted that there were some direct interventions carried out on areas around the BRT corridors. Cervero and Kang (2011) and Kim and Choe (2010) recorded that Seoul local government carried out New Town-In Town (NIT) program between 2000 and 2008. The program was intended to intensify developments/redevelopments in inner Seoul by providing various public amenities, such as green space, and expanding infrastructure and public services at designated areas. By 2005, there were 23 NIT designated areas within the city (Kim and Choe, 2010). Some of these designated areas were located close to the BRT corridors, as exhibited in figure 13.

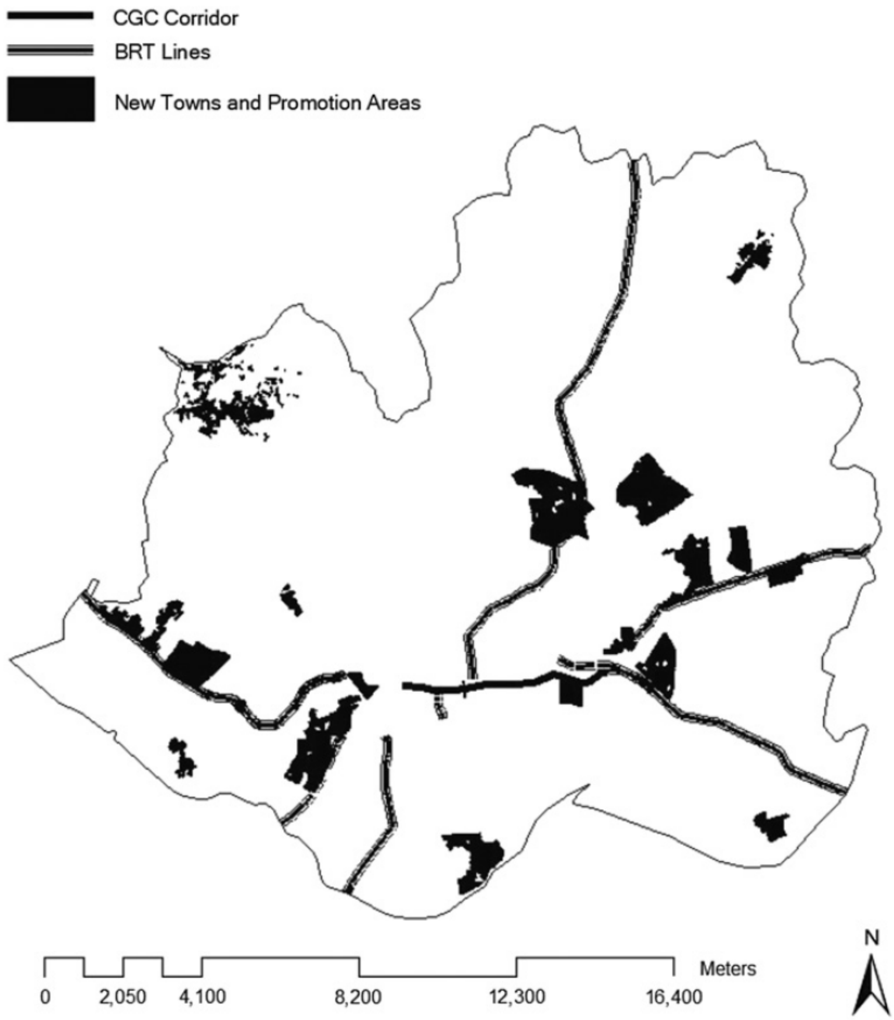

Figure 13 - Seoul BRT corridors in relation to New Town-In Town designated areas and Cheonggyecheon

Source: Cervero and Kang, 2011

Besides carrying out the NIT program, Seoul local government also redesigned the ex-Cheonggye elevated highway area into a public park along a stream, named Cheonggyecheon (CGC). As exhibited in figure 13, some areas around Cheonggyecheon are also located around BRT corridors. While those areas were areas under investigation in Cervero and Kang's (2011) research, some other researchers (Cho, 2010; Lim et al., 2013, Ursik and Kriznik, 2012) noted that those areas may also had been affected by the Cheonggyecheon project. Ursik and Kriznik (2012) and Lim et al. (2013) argued that the Cheonggyecheon project increased the land value of areas along the stream.

It can be concluded that the Seoul BRT project was not an isolated project. It was complemented by Cheonggye elevated highway removal, Cheonggye at-grade road lane reduction, New Town-In Town program and Cheonggyecheon project. Consistent with Cervero and Kang's (2011) argument, the property price change around Seoul BRT systems was influenced significantly, but not exclusively, by the provision of the BRT systems.

c) Limitations

Relevancy of the complementary policies to transit oriented development

As previously discussed in section b of the previous chapter, the two case studies have the same urban development indicator. The two quoted researches on the influence of BRT systems on urban development observed the similar object, utilised the same method and used the same indicator for the research finding. Both of the researches quoted in this chapter observed property price, utilised before-after method and used BRT premium as the indicator for the research finding.

The two BRT systems used as case studies have different complementary policies in regard to transit oriented development (TOD). Compilation of recent knowledge on TOD has been provided by Cervero (1998), Curtis et al. (2009) and Suzuki et al. (2013, 2015). Unfortunately, the assignment of the two different BRT systems as cases studies was not based on that current knowledge. For instance, the assignment of Seoul BRT systems and their complementary policies as the case study was not based on solid knowledge that the complementary policies are relevant to transit oriented development (TOD). I assume that those complementary policies are relevant to TOD while I don't have solid knowledge to support my assumption.

The mentioned limitation was inevitable due to the limited availability of two similar researches as previously discussed in the first paragraph. Considering the limited availability of the two similar researches, it is complicating to ensure the relevancy of the BRT complementary policies to TOD. Nevertheless, I argue that future researches exploring bus rapid transit (BRT) in the context of transit oriented development (TOD) should select case studies based on a solid knowledge of TOD.

BRT premium on non-residential properties

Cervero and Kang (2011) found the Seoul BRT systems premium on non-residential properties was higher than the premium on residential properties. They found the premium on non-residential properties ranged from 3% to 26% while the premium on residential properties ranged from 5% to 10%. Considering the significant difference between the two levels of premium, I assume that the influence of property accessibility on property price is stronger on non-residential properties than on residential properties. This assumption is consistent with common knowledge that, for instance, commercial activities require good accessibility to occur more so than residential activities.

Perhaps, it is more appropriate to observe premium on non-residential properties when investigating BRT systems influence on urban development around the systems. Unfortunately, it is not possible to focus on premium on non-residential properties in this research. Differed from Cervero and Kang (2011) who investigated the Seoul BRT systems premium on non-residential properties around the systems, Perk et al. (2012) did not investigate the Boston SL4/ premium on non-residential properties around the systems.

d) Summary

It can be concluded from this chapter that the provision of Boston SL4 and SL5 and Seoul BRT systems have influenced urban development around the systems. The BRT systems brought a premium to the properties located around them. Boston SL4/5 premium for condo units located at the mean distance to Washington Street is 7.6%. Seoul BRT systems premium for the residential properties within 300m of a BRT station ranged from 5% to 10%, while the premium for non-residential properties within 150m of a BRT station ranged from 3% to 26%. SL4/5 projects were isolated transit projects, while Seoul BRT project was complemented by a number of policies.

Chapter 5
Analysis and findings

This chapter will analyse the case studies, present the findings from the analysis and discuss the findings. Section a and b will present the technical characteristics of the two case studies. Section c will discuss how having those technical characteristics make the BRT systems influencing urban development around them.

a) Boston Silver Line 4 and 5 (Washington Steet), United States

a. Technical characteristics

i. Station configuration and accessibility

Boston SL4/5 have 14 stations. Distance between stations ranged from 160m to 550m and averaging at 320m. Besides Dudley Square, all SL4/5 stations are located at the curb side. The curbside stations are essentially expanded sidewalks. Sidewalk at stations area are expanded into parking lane and transformed into passengers waiting space. SL4/5 have their own berth at Dudley Square terminal (Schimek et al., 2005).

All SL4/5 stations can only accommodate one vehicle at a time and have no dedicated overtaking lane. Most stations along Washington Street are located at the far side of the next traffic intersection within the route. Figure 14 shows the configuration of SL4/5 far-side stations. Stations are utilising standard curb at 15cm high, leaving 20cm height gap between curb and bus door floor. Stations are equipped with station name and direction, a route map, a transit network map and a neighbourhood map. Some stations are equipped with transferring information. Stations also have bike racks (Schimek et al., 2005).

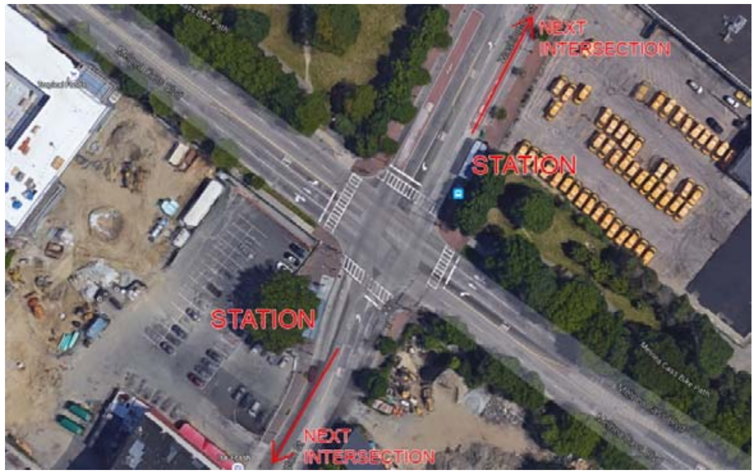

Figure 14 - Configuration of SL4/5 far-side stations

Source: Google Maps, edited by Lutfi Prayogi

The previous Route 49 stops are much simpler than SL4/5 stations. Route 49 stops only include bus stop signs and do not include route information. Figure 15 shows the previous Route 49 and current SL4/5 station located at the same location. Figure 16 shows the SL4/5 typical station.

Figure 15 - Previous Route 49 stop (left) and current SL4/5 stop (right) near Massachusetts Avenue

Source: Schimek et al., 2005

Figure 16 – Boston SL4/5 typical station

Source: Schimek et al., 2005

ii. Vehicle capacity and accessibility

Boston SL4/5 utilise 18.3m long and 2.6m wide articulated buses. The bus capacity is 79 passengers and has 57 seats with 2+2 seating configuration. The buses are partial low-floor buses and have a 20cm height gap between the door floor and curb. The buses have three 1.2m wide doors. The buses also have a wheelchair loading facility at the front door. The previous Route 49 buses are 12m long buses (Schimek et al., 2005). Figure 17 shows the SL4/5 articulated bus.

Figure 17 – Boston SL4/5 articulated bus

Source: Schimek et al., 2005

iii. Segregated right of way

2.7km out of 3.86km of SL4/5 route length is curbside bus lanes. The curbside bus lanes make 70% of the total route length. The rest of the route is mixed traffic lanes.

The curbside bus lanes are painted continuously in red, given 'bus lane' mark and intermittently cut at intersections. At some sections, parking lanes are located adjacent to the bus lanes, closer towards curb. The lanes also serve as right turning-only lane for mixed traffic at intersections where right turns are allowed. Figure 18 shows the SL4/5 lanes near a traffic intersection. Bicycles are allowed to use the lanes. SL4/5 utilise bus-priority traffic signals at some traffic intersections that give priority to SL4/5 buses that are late according to the schedule (Schimek et al., 2005).

Figure 18 – Boston SL4/5 lanes at Washington Street-West Dedham Street intersection

Source: Google StreetView, retrieved on 21/09/2015 1:22pm

iv. Off-board ticketing

Boston SL4/5 utilise on-board ticketing. Passengers interact with an electronic farebox instead of a driver. The electronic farebox recognises payment with notes and coins (without change), magnetic stripe cards and contactless smart cards. During the early operation days of SL4/5 services, the use of contactless smart cards as a common mean of payment is still at the introductory stage (Schimek et al., 2005). As of 2009, SL4/5 still recognise the three means of payment (Hinebaugh et al., 2009). Figure 19 shows the SL4/5 buses' multi mode-of-payment electronic farebox.

Figure 19 - SL4/5 buses' multi mode-of-payment electronic farebox

Source: Schimek et al., 2005

v. Network width and transit network integration

SL4/5 connect with other Boston rapid transit services, named Blue Line, Green Lines, Orange Line, Green Lines, Red Lines and Silver Lines, at five stations within Boston CBD. They connect with 112.6km of other rapid transit services. They also connect with nine Massachusetts Bay commuter rail, Amtrak and intercity bus services at South Station. SL4/5 also connect with more than 15 bus services at Dudley Square (MBTA, 2015b).

Passengers transfer between SL4/5 and other transport services at Boston CBD stations mostly by walking along standard sidewalks and sometimes crossing roads through signalised pedestrian crossings. Transferring information is provided through maps at Boston CBD stations. Passengers transfer between SL4/5 and other bus services at Dudley Square by crossing through berths in a semi-sheltered bus interchange. Transferring information is also provided through maps and signs.

Massachusetts Bay Transportation Authority (MBTA) imposes an integrated fare system for all public transport services within Greater Boston. The fare system permits passengers who take and have already paid the fare for the SL4/5 bus to take other rapid transit or bus services free of charge or at reduced fare. Passengers who use the contactless smart card, named CharlieCard, for payment obtain the biggest integrated fare benefit. The smart card is recognised for all public transport services fare payment within Greater Boston. Passengers who use the single trip ticket, referred to as the

CharlieTicket, or pay by cash for payment obtain a less integrated fare benefit (MBTA, 2015a). To implement the integrated fare system, electronic fareboxes are utilised at stations and inside vehicles.

b. Performance data

Schimek et al. (2005) recorded that on spring 2005, the SL4/5 vehicles all-day average speed is 12.1km/h. The previous Route 49 buses' all-day average speed is 11.4km/h. The maximum capacity of the systems is 1,264 passengers per hour per direction (pphpd). In the spring of 2005, the average usage of the systems was only 415 pphpd, which is 32% of the systems capacity (Schimek et al., 2005). There is currently no reliable data on the passengers per route km (PRK) and passengers per vehicle km (PVK) figures of the systems. The scheduled headway between buses is 10 minutes during the peak and 15 minutes outside the peak hours (Schimek et al., 2005).

b) Seoul BRT systems, South Korea

a. Technical characteristics

i. Station configuration and accessibility

As of 2006, Seoul BRT systems have 75 median-lane stations. The average distance between stations is 780m (Hensher and Golob, 2008). Considering that Seoul BRT systems have been continuously expanding, the mentioned figures might be different during the time Cervero and Kang (2011) carried out their research. Hensher and Golob (2008) investigated Seoul BRT systems spanning 57.7km, while Cervero and Kang (2011) investigated 74km. Thus, I argue that the difference might not be significant. Other than some interchange stations, stations are located at the median side. Some interchange stations are located at the curb side. Median-lane stations are connected to sidewalks by signalised pedestrian crossings.

Most stations accommodate more than one vehicles. On average, stations accommodate three vehicles. Some stations have overtaking lanes. Figure 20 shows the Seoul BRT stations typical layout and figure 21 shows a Seoul BRT station that has overtaking lanes. Major interchange stations have multiple paralleled berths. Some stations are located close to intersections and utilise pedestrian signalised crossings that also serve as crossings for pedestrian who intend to cross the roads. Stations are utilising standard curb at 15cm high, leaving at least 20cm height gap between curb and bus door floor. Stations are equipped with station name and direction as well as route maps. Some stations are equipped with a neighbourhood map and transferring information. Figure 22 shows the Seoul BRT typical median lane stop.

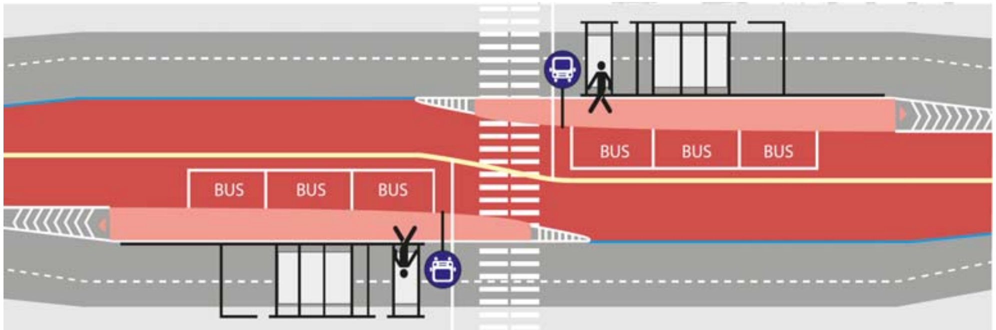

Figure 20 - Seoul BRT stations typical layout

Source: Seoul Metropolitan Government, 2009

Figure 21 – A Seoul BRT station with overtaking lanes

Source: Seoul Metropolitan Government, 2009

Figure 22 - Seoul BRT typical median lane stop

Source: Park Young Wook

ii. Vehicle capacity and accessibility

Seoul BRT systems utilise various types of buses for various type of services. Feeder and local-circular services utilise 8-12m long single buses with 1+2 seating configuration. Trunk services utilise 12-15m long single and 18m long articulated buses with 1+2 seating configuration. Inter-regional services utilise 12-15m long single buses with 2+2 seating configuration. Buses introduced after 2004 are low-floor buses and have 20cm height gap between buses door floor and curb. Buses introduced after 2004 for trunk and feeder services have two to three 1.2m wide doors and wheelchair loading facilities (Seoul Metropolitan Government, 2009).

iii. Segregated right of way

Almost all Seoul BRT right of ways under Cervero and Kang's (2011) investigation are exclusive bus lanes. The bus lanes are painted continuously in red, given 'bus lane' mark and intermittently cut at intersections. In normal conditions, no other vehicle other than buses allowed to use the lanes (Seoul Metropolitan Government, 2009). Figure 23 shows the Seoul BRT median lanes near a traffic intersection.

Figure 23 - Seoul BRT median lanes at Hangang Avenue-Baekbeom Road intersection

Source: Google StreetView, retrieved on 22/09/2015 2:32pm

iv. Off-board ticketing

Seoul BRT systems utilise on-board ticketing. Passengers can pay with contactless smart card, named T-Money, or by exact change cash. Passengers tap the smart card when boarding and alighting buses (Seoul Metropolitan Government, 2009). Figure 24 shows the electronic farebox for T-Money inside Seoul BRT vehicles.

Figure 24 - Electronic farebox for T-Money at Seoul BRT vehicles

Source: Seoul Metropolitan Government, 2009

v. Network width and transit network integration

As of 2008, Seoul BRT systems are about 74km long spanning eight corridors. The systems are connected to a number of major bus and train interchanges, including Seoul Digital Media City, Seoul Station, Cheongnyangni, Jamsil and Gangnam. Seoul BRT systems connect with eight Seoul Metropolitan Area rail transit services. Seoul BRT systems also connect with Korea regional and national rail services at Seoul

Station. At the mentioned interchanges, passengers transfer between different bus services by crossing through berths in a semi-sheltered bus interchange. Passengers transfer between modes of transit by walking along standard sidewalks and sometimes by crossing roads through signalised pedestrian crossings. Transferring information is provided through maps and signs. Figure 25 shows the Cheongnyangi bus and train interchange before and after the BRT project.

Figure 25 - Cheongnyangni bus and train interchange before (left) and after (right) the BRT project

Source: Seoul Metropolitan Government, 2009

Seoul Metropolitan Government (SMG) imposes an integrated fare system for all public transport services within Seoul Metropolitan Area (SMG, 2009). Under the fare system, a passenger is not charged for using each service when taking consecutive public transport services. Instead, a passenger is charged based on the total distance travelled by taking the consecutive services. Under the system, a consecutive multi-modal trip is charged lower than separate standalone trips. Illustration of the fare charging is shown on table 2. The system is applied through the use of contactless smart card, named T-Money, for payment. The smart card is recognised for payment at all BRT vehicles as well as at other conventional buses and inner city trains.

Table 2 - Seoul Metropolitan Area public transport fare charging example

Trip length and mode of transport	**Individual fares**				**Integrated fare**			
	Components		Flat fare***	Total	Components		Flat fare***	Total
	Basic fare*	Extra fare**			Basic fare*	Extra fare**		
First trip: 44km of	W1,050	W700	-	W1,750	W1,050	W700	-	W1,750

subway trip								
Second trip: 18km of bus trip	-	-	W1050	W1,050	-	W400	-	W400
Last trip: 14km of subway trip	W1,050	W100		W1,150	-	W300	-	W300
Total				**W3,950**				**W2,450**

*Basic fare: W1,050/first 10km

**Extra fare: W100/additional 5km

***Flat fare: W1,050/trip, regardless of the distance travelled

b. Performance data

Seoul Development Institute in Cervero and Kang (2011) recorded that on 2005, the Seoul BRT vehicles all-day average speed is 22km/h. The all-day average speed of buses that used to operate on the corridors prior to the BRT project 11.4km/h. As of 2006, the maximum capacity of the systems is around 12,000 pphpd (Hensher and Golob, 2008). There is currently no reliable data on the average usage, passengers per route km (PRK) and passengers per vehicle km (PVK) figures of the systems. There is currently also no reliable data on the average headway time of buses operating along the BRT corridors. Nevertheless, Google Maps shows that the headway can be up to less than one minute at a BRT corridor adjacent to Seoul Station interchange.

c) Technical specifications' positive contribution towards performance and influence on urban development

Positive contribution towards patronage

Both Boston SL4/5 and Seoul BRT systems have a number of technical characteristics that contribute positively to the patronage of the systems. Both systems have stations distanced in a way that all areas along the corridors are within a short walking to a station. As presented previously, average distance between Boston SL4/5 stations is 320m while between Seoul BRT stations is 780m. At those average distances, all areas adjacent to the corridors are within 500m or 6 minutes walking to a station. Those average distances are within the average distance suggested by Wright and Hook (2007), which is between 300m and 1000m. Boston SL4/5 stations also have bike racks that encourage cyclists to take the SL4/5 bus.

Both systems also have stations that are easily accessed by pedestrian from sidewalks. Most Boston SL4/5 stations are located at the curb side while most Seoul BRT stations are located at the median side and connected to the sidewalks by signalised pedestrian crossings. Boston SL4/5 stations are located directly adjacent to sidewalks. While Seoul BRT median-lane stations are a bit far from sidewalks, they are connected to sidewalks by signalised pedestrian crossings. I argue that signalised pedestrian crossing is the most convenient pedestrian crossing. I argue that signalised pedestrian crossing is, for instance, more convenient than overhead/underground pedestrian crossing that forces pedestrians to walk up and down to cross the road. My argument in terms of the convenience of signalised pedestrian crossing is consistent with Wright and Hook's (2007) study. I argue that Boston SL4/5 and Seoul BRT stations offer convenient access for passengers. The convenient access for passengers contributes positively to the patronage of the systems.

Boston SL4/5 and Seoul BRT systems utilise high capacity buses, including 18m articulated buses. The utilised 1+2 seating configuration buses provide more standing space for passengers. The utilisation of high capacity buses clearly contribute positively to the patronage of the systems. Both systems also utilise buses that offer convenient access to various types of passengers. I argue that the 20cm height gap between curb and bus floor is less an obstacle for passengers when boarding and alighting the buses. Thus, I argue that buses are easily accessible by kids, aged people, people using crutches, people carrying lot of items and so forth. The availability of wheelchair loading facilities permits the buses to be also accessible for passengers on wheelchairs. I argue that Boston SL4/5 and Seoul BRT vehicles offer convenient access for passengers. The convenient access for passengers contributes positively to the patronage of the systems.

Boston SL4/5 and Seoul BRT systems are highly connected to the local, regional and national modes of public transport of the respective cities. The systems offer first-mile and last-mile services for passengers. The integrated public transport fare systems imposed by Massachusetts Bay Transportation Authority (MBTA) and Seoul Metropolitan Government (SMG) increase the connectivity. The fare systems encouraged passengers to use combined modes of public transport for their first-mile, main-mile and last-mile trips. In other words, passengers of other modes of transport are encouraged to use Boston SL4/5 and Seoul BRT services when starting or finishing their trip. Wright and Hook (2007) acknowledged the combined distance- and time-based public transport fare system imposed by Seoul Metropolitan Government (SMG) as an advanced fare system. SMG in Wright and Hook (2007) and SMG (2009) claimed that the fare system was able to increase the total patronage figure of buses within Seoul Metropolitan Area (SMA). Table 3 shows an example of a trip that include the uses of Seoul BRT services upon starting and finishing the trip.

The compact and well-designed interchanges also increase the connectivity. They increase the connectivity of the different BRT services as well as between a BRT service and other public transport services. The utilisation of signalised pedestrian crossings near Boston SL4/5 and Seoul BRT interchanges help passengers cross the roads conveniently. The provision of transferring maps and signs help passengers navigate their transferring direction. Seoul Metropolitan Government (2009) claimed that the average transferring time between buses at Seoul Station interchange is 3 minutes and the average transferring distance between buses in Cheongnyangni interchange is 50m.

Table 3 - A trip example that include the uses of Seoul BRT services, data obtained from Google Maps

	First-mile	**Main-mile**	**Last-mile**
Origin and destination	Home (2 Cheongnyangri-dong) – Cheongnyangni interchange	Cheongnyangni interchange - Seoul Station interchange	Seoul station interchange – Work (Millennium Seoul Hilton)
Mode	Route 51 bus*	Line 1 subway	Route 402 bus*
Trip length	9 minutes	17 minutes	4 minutes
Trip fare	W1,050	W200	W100

*bus service running along BRT median-lanes

Positive contribution towards bus average speed

Both Boston SL4/5 and Seoul BRT systems have a number of technical characteristics that contribute positively to the BRT vehicles average speed. Boston SL4/5 stations expand towards the road from the sidewalks. The expanded stations reduce the pulling over time for the buses. The stations are also positioned at the far-side of the next traffic intersection within the route. The positioning prevents the bus queueing at the traffic intersection from blocking the next bus to pick up and drop off passengers at stations. Thus, the positioning prevents the next bus from losing time due to waiting for clearance at stations.

Boston SL4/5 and Seoul BRT systems utilise exclusive bus lanes that prevent buses from losing time by slowing or stopping unintentionally due to congestion. Seoul BRT systems utilise median lanes instead of curb side lanes as bus lanes. The utilisation prevents the bus lanes from being obstructed by vehicles parking or pulling over, thus preventing the buses from wasting time slowing or stopping due to those vehicles. Boston SL4/5 utilise bus-priority traffic signals that reduce the queueing time for buses at traffic intersections.

Boston SL4/5 and Seoul BRT systems utilise buses that are not required to dwell too long at stations when picking up and dropping off passengers. The 20cm height gap between buses door floor and curb reduces buses dwelling time by not requiring passengers to take multiple steps up or down when boarding and alighting buses. Hinebaugh (2009) found that low floor buses are the buses with second fastest passenger boarding and alighting process. Platform-level buses are the only buses that have higher passenger boarding and alighting process than low floor buses. The multiple wide doors allow passengers to board and alight swiftly. The electronic farebox for contactless smart card saves time for the collection of fares. All of the mentioned time saving features make BRT vehicles able to complete their trip faster, thus contributing positively towards the BRT vehicles average speed.

Summative positive contribution towards passengers per hour per direction (pphpd) figure and influence on urban development

By contributing positively towards the systems patronage and bus average speed, Boston SL4/5 and Seoul BRT systems technical characteristics contribute positively towards the passengers per hour per direction (pphpd) figure of the systems. They make the systems usher a significant number of people rapidly. By ushering a significant number of people rapidly, the systems increase the accessibility of the properties around the systems. More people can access the properties around the systems more quickly. Consistent with Debrezion's argument in Stokenberga (2014), the increase of accessibility of the properties increases the properties' price. Therefore, Boston SL4/5 and Seoul BRT systems influence urban development around them by having the technical characteristics that contribute positively towards the systems patronage and bus average speed. Figure 26 depicts the contribution of the BRT systems' technical characteristics towards the passengers per hour per directions (pphpd) figure of the systems and the influence of the systems on urban development.

Chapter 6
Conclusion

Result on the examination of the first hypothesis, "BRT systems influence urban development by having technical characteristics which make the BRT systems have high performance, as measured by pphpd, PRK and PVK figures"

This research found that the first hypothesis is mostly correct. As summarised in table 5 and 6, BRT systems analysed in this research have technical characteristics which make them have high performance. The only hypothesised technical characteristics that the analysed BRT systems clearly do not have is the utilisation of off-board ticketing facilities. The BRT systems utilise on-board ticketing facilities that allow for a swift passengers boarding, alighting and fare collection, though not as swift as off-board ticketing facilities. The analysed BRT systems also do not utilise platform level buses. However, they utilise low floor buses that allow for passengers boarding and alighting almost as swift as platform level buses allow for.

Result on the examination of the second hypothesis, "BRT systems influence urban development by having high performance, as measured by pphpd, PRK and PVK figures"

This research found that the second hypothesis is partially correct. As shown in table 7, Boston SL4/5 have a very low maximum passengers per hour per direction (pphpd) figure, while Seoul BRT systems have very high pphpd figure. Boston SL4/5 have a pphpd figure far below the hypothesised figure, while Seoul BRT systems have a pphpd figure far above the hypothesised figure.

Boston SL4/5's maximum pphpd figure is about the same as the figure of the BRT system with the lowest pphpd figure in Hensher and Golob's (2008) research. Wright and Hook (2007) recorded that by ushering 1,236 passengers per hour per direction, Boston SL4/5 performance is not much different from the performance of conventional bus systems. Meanwhile, Seoul BRT systems' maximum pphpd figure is ranked the fourth highest among 44 BRT systems in 26 cities analysed by Hensher and Golob (2008). It is only lower compared with the figures of the BRT systems in Bogota, Colombia and Sao Paulo, Porto Alegre and Curitiba, Brazil. World Bank in Lloyd and Karl (2002) recorded that by ushering 12,000 passengers per hour per direction, Seoul BRT systems performance is comparable to the performance of light rail transit (LRT) systems in Kuala Lumpur, Malaysia, Tunis, Tunisia and Recife, Brazil.

Furthermore, it is unfortunate that the BRT systems' passengers per route km (PRK) and passengers per vehicle km (PVK) figures couldn't be obtained. Investigation on the BRT systems' PRK and PVK figures might lead to different result on the examination of the second hypothesis.

Summary of case studies and findings of the analysis

Table 4 - Summary of BRT systems influence on urban development

	Boston SL4/5	**Seoul BRT systems**
Influence on urban development	Premium at 7.6% for condo units located at the mean distance to Washington Street	Premium at 5%-10% for residential properties within 300m of a BRT station Premium at 3%-26% for non-residential properties within 150m of a BRT station

Table 5 - Summary of the BRT systems technical characteristics that contribute positively to BRT systems patronage

	Boston SL4/5	**Seoul BRT systems**
Station configuration and accessibility		
Average distance between stations	320m	780m
Location	Curb side	Median lane
Connectivity to sidewalks	Located adjacent to sidewalks	Connected by signalised pedestrian crossing
Vehicle capacity and accessibility		
Bus size	18m articulated	Various sizes, including 18m articulated
Seating configuration	2+2	Various seating configurations, including 1+2

Height gap between curb and bus doors floor	20cm (low floor buses)	20cm (low floor buses)
Door quantity and size	Three 1.2m wide doors	Two to three 1.2m wide doors on some post-2004 buses
Wheelchair loading facility	Available	Available on some post-2004 buses
Network width and transit network integration		
Connected modes of transport	Inner city, regional and national train services, inner city and intercity bus services	Inner city, regional and national train services, inner city bus services
Transit interchanges	Six interchanges	At least five major interchanges
Transferring facilities	Short walking distance, signalised pedestrian crossings, semi-sheltered berths, maps and signs	Short walking distance, signalised pedestrian crossings, semi-sheltered berths, maps and signs
Transit fare system	SL4/5 ticket include free or reduced fare for other modes of public transport	Summative distance based fare charging for consecutive use of various modes of public transport
Mode of payment integration	Cash (notes and coins), magnetic strip card and contactless smart card	Cash and contactless smart card

Table 6 - Summary of the BRT systems technical characteristics that contribute positively to BRT systems average vehicle speed

	Boston SL4/5	**Seoul BRT systems**
Station configuration and accessibility		
Station design	Expanded sidewalks, mixed traffic road can be used as overtaking lane	Some stations have overtaking lanes

Vehicle capacity	One	Three at average
Location to next intersection within the route	Far side	Varied
Vehicle capacity and accessibility		
Door quantity and size	Three 1.2m wide doors	Two to three 1.2m wide doors for some post-2004 buses
Height gap between bus door floor and curb	20cm (low floor buses)	20cm (low floor buses)
Segregated right of way		
Location	Curb side	Median lane
Share of segregated right of way	70%	90%
Right of way exclusivity	May be used by bicycles and right-turning vehicles	Exclusive for buses at certain hours
Bus-priority traffic signals	At some intersections for buses that are late from schedule	None
Off-board ticketing		
Fare collection device	On-board electronic farebox for contactless smart card and other payment methods	On-board electronic farebox for contactless smart card

Table 7 - Summary of the performance of BRT systems that influence urban development around the systems

	Boston SL4/5	**Seoul BRT systems**
Maximum passengers per hour per direction (pphpd) figure	1,236	12,000

Further discussion: Understanding the strikingly different passengers per hour per direction (pphpd) figures of BRT systems having similar technical characteristics by investigating the BRT systems' vehicle frequency and headway

Examination on the two hypotheses found that BRT systems having similar technical characteristics can have different passengers per hour per direction (pphpd) figures. This implies that technical characteristics is not the only factor that influence BRT systems pphpd figure. This also implies that there are things separate from technical characteristics that influence BRT systems pphpd figure.

I assume that the strikingly different Boston SL4/5 and Seoul BRT systems pphpd figures could be resulting from the different vehicle frequency and headway of the two BRT systems. Though both BRT systems have technical characteristics that *can* make them have high pphpd figure, they operate vehicles at different frequency, making them have different pphpd figure. Also, though both BRT systems have technical characteristics that enable the vehicles to operate at high frequency, they do not operate vehicles at equally high frequency. I assume that Seoul BRT systems optimise their technical characteristics by operating vehicles at high frequency, making them have high pphpd figure. Meanwhile, Boston SL4/5 don't optimise their technical characteristics by operating vehicles at low frequency, making them have low pphpd figure. This assumption cannot be validated due to the lack of valid data on the average frequency/headway data of vehicles operating along Seoul BRT corridors.

Further discussion: Inadequately answered question on how having several technical characteristics make BRT systems influence urban development around the systems

Towards the end of section c on chapter 5, it has been argued that several technical characteristics contribute positively to the BRT systems patronage, average vehicle speed and passengers per hour per direction (pphpd) figure. By having a high pphpd figure and ushering a significant number of people rapidly, the BRT systems increase the accessibility of properties and bring a premium to properties' price around the systems. The increase of accessibility and the premium brought are considered as the influence on urban development.

However, examination on the two hypotheses, involving two case studies, found that the causative phenomena described in the previous paragraph is not fully correct. In the case of Seoul BRT systems, all the mentioned phenomena are present. Seoul BRT systems have the referred technical characteristics (as summarised in table 5 and 6), have high passengers per hour per direction (pphpd) figure and bring a premium to properties' price around the systems. On the other hand, Boston SL4/5 have the referred technical characteristics, have low pphpd figure and bring a premium to properties' price around the systems.

The imprecision of the causative phenomena described in the first paragraph leaves the second research question inadequately answered. Is it true that the referred technical characteristics make BRT systems influence urban development around the systems *by* making the systems have high patronage, high average vehicle speed and high passengers per hour per direction (pphpd) figure? Do the referred technical characteristics make BRT systems influence urban development around the systems *by* something else?

Further discussion: Question on BRT systems performance, as measured by passengers per hour per direction (pphpd) figure, influence on premium on properties around the systems

As previously mentioned towards the end of section a of chapter 4, the Seoul BRT systems' maximum pphpd figure is 12,000. By ushering 12,000 passengers per hour per direction, it is well understood that Seoul BRT systems influence urban development around them. Seoul BRT systems brought a premium ranged between 5% and 10% for the residential properties within 300m of a station and a premium ranged between 3% and 26% for the non-residential properties within 150m of a station (Cervero and Kang, 2011). Meanwhile, Boston SL4/5 maximum pphpd figure is only 1,236. By ushering only 1,236 passengers per hour per direction, it is not expected that Boston SL4/5 would influence urban development around them. Nevertheless, Boston SL4/5 brought a premium at 7.6% for the condo units located at the mean distance to Washington Street (Perk et al., 2013).

Considering that Boston SL4/5 and Seoul BRT systems have highly different passengers per hour per direction (pphpd) figure, it is unexpected that the two systems would bring a premium for residential units at about the same level. Remembering that Seoul BRT systems have complementary policies while Boston SL4/5 do not, it is more unexpected that the systems would bring a premium for residential units at about the same level. In short, it is unexpected that Seoul BRT systems that are able to usher 12,000 pphpd and complemented by a number of policies brought a level of premium which is not much different from the level brought by Boston SL4/5 that are only able to usher 1,236 pphpd and not complemented by any policy.

This unexpected finding brings up a further question regarding the influence of BRT system's performance on premium on properties around the BRT systems. This question complements the questions raised towards the end of the previous discussion topic. How is it possible that BRT systems with low performance and no complementary policy bring a level of premium similar to the level brought by BRT systems with high performance and a number of complementary policies?

Research suggestion: Quantitative research on the influence of BRT technical characteristics on BRT premium

As this research has revealed some technical characteristics which are owned by BRT systems that bring premium to properties around the systems and also has partially explained how having those technical characteristics make BRT systems bringing premium to properties around the systems, it is interesting to know how influential those technical characteristics are on the BRT premium. Quantitative research utilising a series of regression model could quantify the influence. The revealed technical characteristics could be used as the explanatory variables. The explanatory variables could be analysed through a series of regression model against the BRT premium.

Findings of this research may be compared with findings of the quantitative researches on the influence of BRT technical characteristics on BRT performance that have been conducted by Currie and Delbosc (2011, 2014), Deng et al. (2013) and Hensher and Golob (2008). Congruency/in-congruency of findings of the researches on the two topics may better explain the relation between BRT technical characteristics, performance and premium.

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