International Journal of Built Environment and Scientific Research Volume 01 Number 01 | June 2017
e-issn: 2580-2607 | Pg. 1-8

The Influence of Bus Rapid Transit System on Urban Development: An Inquiry to Boston and Seoul BRT Systems' Performance Indicators

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ABSTRACT

This article explores the relation between bus rapid transit (BRT) system and urban development. This article was written through a multi-staged comprehensive literature review. It includes a general overview on widely observed BRT performance indicators. Findings in terms of the influence of Boston Silver Line 4 and 5 and Seoul BRT systems on urban development around the systems are quoted and used as case studies. Investigation on the performance of Boston SL 4/5 and Seoul BRT systems are provided. This article shows that two BRT systems of different performance are able to influence urban development around the systems in varying degrees. Further investigation is needed to explain the nature of the relation between BRT performance and influence towards urban development.

Keywords: Bus rapid transit, performance, urban development

1. Introduction

1.1. Bus rapid transit oriented development

Burchell et al.[1] and Bruegman[2] recorded that cities in the United States have been experiencing urban sprawl during the 20th century. Ewing in Burchell et al. (p.1)[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.[3] 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[1][3]. 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. In contemporary discourse, the term 'transit oriented development' was first popularised by Calthorpe[4]. 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[5]. 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[6] and Curtis et al.[10] 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[6][7], Ottawa, Canada[6][7] and Brisbane, Australia[8]. In those cities, provision of BRT systems triggered urban development around their surrounding areas as TOD intended to. The provision of BRT systems in Curitiba, Brazil, triggered the development of a notable high density built environment along the BRT systems corridors[6].

Racehorse et al. (p.175)[7a] 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[20] 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 (p.1)[7b] 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". In short, BRT can be described as a bus service comparable to rail transit service. That is, a bus service with higher performance.

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), a bus service with higher performance, is a potentially significant component of TOD.

1.2. Purpose and relevance of this research

This research intended to answer the following question in regards to bus rapid transit oriented development: "What kind of bus rapid transit system that influence urban development around the system?" This research question is in line with Stokenberga's (p.291)[9] argument towards the end of her article, 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".

This article contributes to the topic of integrated transit and physical development planning. Current knowledge on this topic has been compiled by Curtis et al.[10] in Transit Oriented Development: Making it happen, Suzuki et al.[7] in Transforming cities with transit: Transit and land-use integration for sustainable urban development and Suzuki et al.[11] 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.

2. Literature Review

2.1. Influence of BRT system on urban development

Stokenberga[9] provided a literature review on the influence of bus rapid transit (BRT) systems on urban development. She reviewed the methods, 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. Considering that physical urban development takes significant time to be observable, Stokenberga[9] found that so far researchers have been unable to properly observe BRT-related physical urban development. She found most researchers including Cervero and Kang[12], Hidalgo et al.[13], Rodriguez and Mojica[14] and Zhang et al.[15] 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.

2.2. Bus rapid transit performance indicators and measurements

Currie[16] is among the first of the researchers to write about the performance of bus rapid transit (BRT). In his work 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. In the following years, a number of researchers including Babalik-Sutcliffe and Cengiz[17], Currie and Delbosc[18][19], Deng and Nelson[20], Deng et al.[21], Godavarthi et al.[22], Hensher and Golob[23], Hidalgo and Graftieaux[24], Hidalgo et al.[13], Wright and Hook[25] and Zhang et al.[15] developed BRT performance indicators on patronage aspect. They also used BRT patronage performance indicators to evaluate various BRT systems worldwide. Currie and Delbosc[19], Deng et al.[21] and Zhang et al.[15] are some researchers who developed and used BRT operational performance indicators. It is worth to be highlighted that there is a growing tendency to integrate the BRT operational performance indicators with BRT patronage performance indicators.

Currie and Delbosc[18][19] 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). When comparing bus services of different route lengths, bus services with higher PRK and PVK figures are considered as those with better patronage performance.

The PRK figure is obtained by dividing the bus route's 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 bus route's total patronage figure with total distance travelled by the buses of the route. 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.

Wright and Hook[25] 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 or occupancy 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[17], Deng et al.[21], Hensher and Golob[23], Hidalgo and Graftieaux[24], Wright and Hook[25] and Zhang et al.[15] 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.

Aside from operational performance indicators that have been integrated with patronage performance indicators, there are a couple of purely operational performance indicators. One of them is bus average speed; Babalik-Sutcliffe and Cengiz[17], Currie and Delbosc[18][19], Deng and Nelson[20], Deng et al.[21], Godavarthi et al.[22], Hensher and Golob[23], Hensher and Li[26], Hidalgo and Graftieaux[24], and Zhang et al.[15] paid attention to it. Another ones are bus frequency and headway time; Babalik-Sutcliffe and Cengiz[17], Currie and Delbosc[18][19], Deng and Nelson[20], Deng et al.[21], Hensher and Golob[23], Hensher and Li[26] and Wright and Hook[25] paid attention to them.

Following are calculation examples of bus average speed, frequency, headway time and passengers per hour per direction (pphpd) figures. 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.

It can be concluded from this section that passengers per route km (PRK), passengers per vehicle km (PVK) and passengers per hour per direction (pphpd) are some indicators that are widely concerned by researchers when evaluating bus rapid transit (BRT) systems' performance. Bus average speed, frequency and headway time are some other indicators that are also concerned by them.

3. Methodology

As previously mentioned in sub-section 1.2, the research question is as follow: "What kind of bus rapid transit system that influence urban development around the system?" In order to answer it, qualitative research approach was chosen. Qualitative research approach was chosen considering that it helps provide detailed and orderly information leading to answers for the research question. Literature review was the method used in all stages of this research. Findings of the first literature review have been discussed in sub-section 2.1 and 2.2. Findings discussed in sub-section 2.1 and 2.2 triggered further investigation on the performance of BRT systems that have been found influencing urban development around the systems. Findings of such investigation will be discussed in section 4.

The 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[18][19], Deng et al.[21] and Hensher and Golob[23], it was hypothesised that BRT systems which has been found influencing urban development around the systems and investigated in this research 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.

Perk's et al.[27] research on Boston SL 4/5 and Cervero and Kang's[12] research on Seoul BRT systems' influence on urban development around the systems were quoted and utilised for further investigation on the BRT systems' performance. However, by so doing 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.

4. Findings

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

Boston Silver Line 4 and 5 (SL 4/5) 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 SL 4/5' or 'SL 4/5' in this research. As exhibited in figure 1, Boston SL 4/5 routes only slightly differ in the CBD area after passing Chinatown: SL 4 loops clockwise passing South Station while SL 5 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. SL 4/5 operate 7 days a week from 6:00am to 12:20am. SL 4/5 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[27][28].

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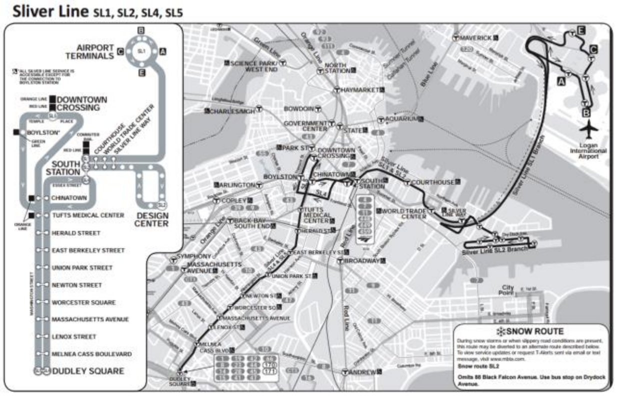
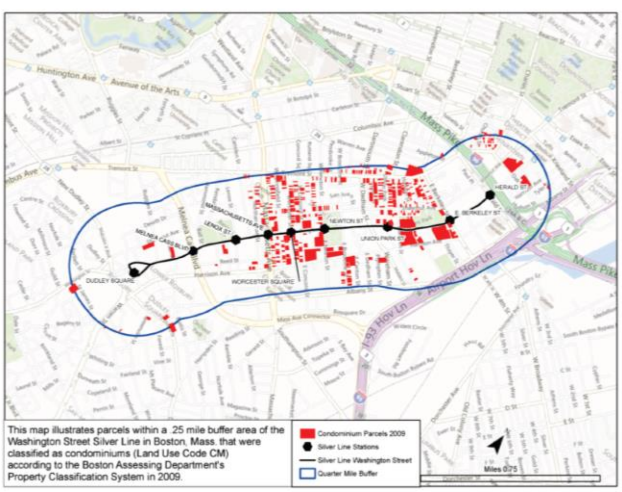


Source: Massachusetts Bay Transportation Authority, http://www.mbta.com/uploadedFiles/Documents/Schedules_and_Maps/Bus/silverwatermap.pdf, retrieved on 17/09/2015 1:20pm
Figure 1: Boston Silver Line map

Perk et al.[27] investigated the influence of Boston SL 4 and SL 5 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 SL 4/5 stations. As exhibited in figure 2, 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.



Source: (Perk et al., 2013)[27]
Figure 2: Perk's et al. (2013) study area

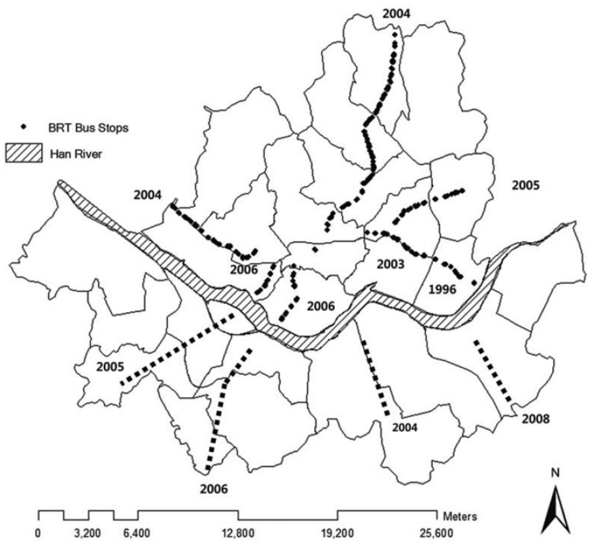
The research calculated the marginal effects of the sale prices of the condo units differed by the location of the units, before and after the start of SL 4/5 services along Washington Street. The research found that between 2000 and 2001, before the start of SL 4/5 services along Washington Street, 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 SL 4/5 services along Washington Street.

On the contrary, the research also found that between 2007 and 2009, after the start of SL 4/5 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 SL 4/5 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.

Schimek et al.[29] recorded that on spring 2005, the SL 4/5 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[29].

4.2. Seoul BRT systems, South Korea

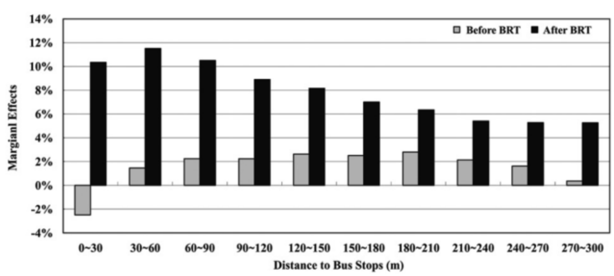
Different from Boston SL4 and SL5 services which are finely defined and easily differentiated from conventional bus services, Seoul BRT systems were indefinitely described by Cervero and Kang[12] as bus services operating using advanced bus infrastructure built after the 2000s in Seoul, South Korea. They described that the Seoul BRT systems include all bus services running along dedicated median-lanes and some other bus services running along curbside bus lanes and mixed traffic roads. Having said that, 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 3. 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.



Source: (Cervero and Kang, 2011)[12]
Figure 3: Seoul BRT corridors investigated by Cervero and Kang (2011)

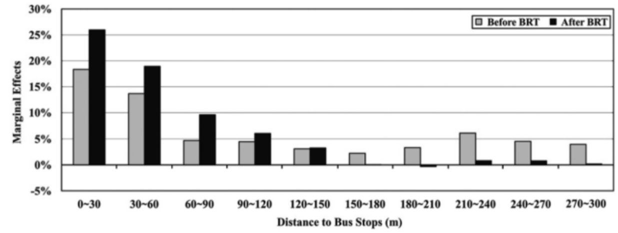
Cervero and Kang[12] investigated the Seoul BRT systems influence on urban development on areas around the dedicated median-lane BRT corridors. They investigated the values of land parcels around the new median-lane stations before and after the construction of dedicated median-lanes. The land parcels evaluated are land parcels whose nearest bus stop transformed into a median-lane station. All parcels were within 2.15km and the vast majorities 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 4 while findings of the marginal effects of non-residential properties are exhibited in figure 5.



Source: (Cervero and Kang, 2011)[12]

Figure 4: Marginal effects of residential properties in relation to distance to bus stops, before and after the BRT project



Source: (Cervero and Kang, 2011)[12]
Figure 5: Marginal effects of non-residential properties in relation to distance to bus stops, before and after the BRT project

Figure 4 shows that between 2001 and 2004, the price of residential properties located within 300m of a bus stop were having premium compared 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 5 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.

Seoul Development Institute in Cervero and Kang[12] 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 is 11.4km/h. As of 2006, the maximum capacity of the systems is around 12,000 pphpd[23]. 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.

5. Conclusion and discussion

This research found that the hypothesis mentioned in section 3 is partially correct. Boston SL 4/5 have a very low maximum passengers per hour per direction (pphpd) figure at 1,236, while Seoul BRT systems have a very high pphpd figure at 12,000. Boston SL 4/5 have a pphpd figure far below the hypothesised figure, while Seoul BRT systems have a pphpd figure far above the hypothesised figure.

Boston SL 4/5'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[23] research. Wright and Hook[25] recorded that by ushering

1,236 passengers per hour per direction, Boston SL 4/5 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[22]. It is only lower to the figures of the BRT systems in Bogota, Colombia and Sao Paulo, Porto Alegre and Curitiba, Brazil. World Bank in Lloyd[30] 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 hypothesis.

Table 1: Summary of the investigated BRT systems: performance and urban development around the system

	Boston SL4/5	**Seoul BRT systems**
Maximum passengers per hour per direction (pphpd) figure	1,236	12,000
Average speed	12.1 km/h	22 km/h
Maximum frequency and minimum headway time	6 trips/hour, 10 minutes headway time	60 trips/hour, 1 minute headway time
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

As summarised in table 1, 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[12]. Meanwhile, Boston SL 4/5 maximum pphpd figure is only 1,236. By ushering only 1,236 passengers per hour per direction, it is not expected that Boston SL 4/5 would influence urban development around them. Nevertheless, Boston SL 4/5 brought a premium at 7.6% for the condo units located at the mean distance to Washington Street[27].

Considering that Boston SL 4/5 and Seoul BRT systems have highly different passengers per hour per direction (pphpd) figures, it is unexpected that the two systems would bring a premium for residential units at about the same level. This unexpected finding brings up a further question regarding the relation of BRT system's performance with premium on properties around the BRT systems. How is it possible that a BRT system with low performance bring a level of premium similar to the level brought by a BRT system with high performance?

Acknowledgement

This research was funded by Indonesia Education Endowment Fund (Lembaga Pengelola Dana Pendidikan Kementerian Keuangan Republik Indonesia) through its Indonesia Education Scholarship (Beasiswa Pendidikan Indonesia) program.

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