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Bus Rapid Transit system's influence on urban development: An inquiry to Boston and Seoul BRT systems' technical characteristics

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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 of widely acknowledged BRT technical characteristics. It explains the approach taken in understanding the relation between BRT system provision and urban development around the system. Findings regarding 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 technical characteristics of Boston SL4/5 and Seoul BRT systems are provided. This article shows that the two BRT systems that influence urban development around the systems have technical characteristics that enable the BRT systems to have high performance. However, while the quoted BRT systems can influence urban development, they have significantly different performance.

1. Introduction

1.1. Bus rapid transit oriented development

Burchell et al. and Bruegman in Prayogi [1] argued that cities worldwide have been experiencing urban sprawl during the 20th century. Urban sprawl costs significantly to cities' resources: it requires vast amount of land conversion and extensive infrastructure provision and it forces citizens to travel far and spend long hours transporting daily by driving private vehicle. Transit oriented development (TOD) is currently an emerging urban development concept alternative to urban sprawl. Cervero et al. in Prayogi [1] defined that TOD contrasts to urban sprawl by promoting high-density mixed-use built environment around transit hubs. It intends to control the land conversion of cities, provide less extensive infrastructure and help citizens to rely less on driving private vehicle by relying more on taking public transport and walking for daily transportation. Cervero and Suzuki et al. in Prayogi [1] acknowledged that bus rapid transit (BRT) is a mode of transit that is suitable to be built in conjunction with TOD. They noted that the provision of BRT systems in some cities has been triggering urban development around the systems.

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 are the technical characteristics of bus rapid transit system that influence urban development around the system?" This research question is in line with Stokenberga's [1a] 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 research continues Prayogi's [1] work that has partially answer the research question. Prayogi's [1] work shown that the bus rapid transit (BRT)



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system's influence towards urban development around the system is related to the BRT system's performance. As will be elaborated in section 2 and 3, this research intended to explore BRT technical characteristics by paying attention to the BRT performance.

2. Literature Review

2.1. Bus rapid transit technical characteristics

Racehorse et al. [2] provided a concise definition of bus rapid transit (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." Currie and Delbosc in Nikitas and Karlsson [3] provided 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". We may conclude that BRT is bus service that is comparable to rail service. Essential BRT components that are agreed by Deng and Nelson [4], Nikitas and Karlsson [3], Racehorse et al. [2] and Wirasinghe et al. [5] are vehicles, stations, running ways, intelligent transportation system and service.

2.1.1. Vehicles. Hinebaugh [6] and Wright and Hook [7] noted that mini, standard, articulated and bi-articulated buses are some types of bus that may be used for BRT systems. The vehicle length varies from 6 to 24 meters while the capacity varies from 25 to 270 passengers per bus. Bus size and capacity are to be properly chosen by considering the passenger demand and physical route condition. Breipthaupt et al. [8] 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.

2.1.2. Stations. Breipthaupt et al. [8], Hinebaugh [6] and Wright and Hook [7] suggested that BRT stations should be designed in a manner allowing for a swift passenger boarding and alighting process. Overtaking lanes and multiple berths may need to be provided to hinder buses from queuing before boarding/alighting passengers. Off-board ticketing facilities, such as ticket gates or poles, need to be provided. 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. Sufficient passenger information about the BRT systems and services should be provided within the stations.

2.1.3. Running ways. Breipthaupt et al. [8], Hinebaugh [6] and Wright and Hook [7] highlighted the importance of exclusive lane for BRT vehicles. A variety of lane types can be assigned for BRT vehicles, such as painted lane, bridges/tunnels, exclusive lane guarded by officers and lane separated by separators. BRT lanes may need to be complemented by devices and/or traffic signs to prioritise BRT vehicles at traffic intersections.

2.1.4. Services and route structure. Wright and Hook [7] defined the two ends of BRT management scheme spectrum: open and closed scheme. The open scheme refers to the condition where varied bus operators may almost freely use BRT infrastructure. In contrast, closed scheme refers to the condition where only limited bus operators may use BRT infrastructure. They [7] also introduced the two ends of BRT routing options spectrum: trunk-feeder/hub-spoke and direct services. In the former spectrum end, trunk and feeder services are clearly differentiated, while in the later one, trunk and feeder services are not. Breipthaupt et al. [8] and Hinebaugh [6] noted that at least one service on a particular route must be available for a long period every day. The mentioned service must have short headway time, for example, 15 minutes.

2.1.5. Fare collection. Breipthaupt et al. [8] and Wright and Hook [7] noted that the utilisation of an advanced fare collection system and devices is important on making a good BRT system. Fare and financing mechanism between the BRT infrastructure manager and bus operator must be established.

The fare and fare collection system should address inter-route and inter-modal passengers appropriately. They [7] [8] mentioned 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, such as smart card and computer-controlled fare gates/poles, to support the advanced fare collection system.

2.1.6. Intelligent transportation systems. Breipthaupt et al. [8], Hinebaugh [6] and Wright and Hook [7] noted the importance of a control centre for a BRT system. The control centre observes the condition at stations and bus lanes, controls the operation of all buses, controls the bus lanes and relies appropriate information to passengers.

2.1.7. Brand identity. Breipthaupt et al. [8] and Wright and Hook [7] highlighted the importance of brand identity to elevate the positive image of the BRT systems. Increase on the BRT's positive image can be triggered through various ways, such as utilising and advertising a proper name and logo and utilising consistent system's signage visual design at stations and on buses.

2.2. Bus rapid transit performance indicators

Prayogi [1] summed some performance indicators that have been used by some researchers in evaluating bus rapid transit systems. 'Passengers per route km' (PRK) and 'passenger per vehicle km' (PVK) are two performance indicators that have been used by Currie and Delbosc [9]. They [9] argued that bus services with higher PRK and PVK figures are better performing bus services. The PRK figure is obtained by dividing the bus route's total patronage figure with route length, while the PVK figure is obtained by dividing the bus route's total patronage figure with total distance travelled by the buses of the route.

'Passengers per hour per direction' (PPHPD) is a performance indicator that has been introduced by Wright and Hook [7]. The figure is obtained by multiplying buses capacity or occupancy with their one direction trip frequency within a specified time, for instance, one hour. Babalik-Sutcliffe and Cengiz [10], Deng et al. [11], Hensher and Golob [12], Hidalgo and Graftieaux [13], Wright and Hook [7] and Zhang et al. [14] suggested to pay attention to BRT maximum PPHPD figure to understand its capacity. Other performance indicators that have been paid attention by researchers are bus average speed, frequency and headway time.

2.3. Relation between BRT technical characteristics and performance

2.3.1. Passengers per route km (PRK) and passengers per vehicle km (PVK) figures. Currie and Delbosc [9] [15] and Hensher and Golob [12] pointed out that some bus rapid transit (BRT) technical characteristics are associated with BRT PRK and PVK figures. They found that higher PRK and PVK figures are associated with shorter station spacing, utilisation of accessible buses, utilisation of higher capacity buses, higher share of segregated right of way, availability of wide and integrated transit network and utilisation of off-board ticketing.

2.3.2. Passengers per hour per direction (PPHPD) figure. Deng et al. [11] pointed out that some BRT technical characteristics are associated with BRT PPHPD figure. They found that that higher PPHPD figure is associated with provision of overtaking lanes at stations and integration of BRT system with non-motorised transportation. They also found that PPHPD figure is associated dynamically with station spacing.

2.3.3. Frequency and headway time. Currie and Delbosc [9] and Hensher and Golob [12] found frequency and headway time influence PRK and PVK figures. Currie and Delbosc [15] found higher frequency and lower headway time associated with higher PVK figure. Deng et al. [11] found higher frequency and lower headway time associated with higher PPHPD figure.

3. Methodology

The research question is as follow: "What are the technical characteristics of bus rapid transit system that influence urban development around the system?" The qualitative research approach was chosen to answer the question, considering that it helps provide detailed and orderly information leading to the answers for the research question. A multi-staged comprehensive literature review was used to answer the research question. Findings of the first literature review have been provided in sub-section 2.1., 2.2. and 2.3. The mentioned findings serve as the base for further investigation, in which its findings will be discussed in section 4.

Researches on Boston SL 4/5's and Seoul BRT systems' influence on urban development, maximum PPHPD figure, bus average speed, maximum frequency and minimum headway time that have been summed by Prayogi [1] will be quoted and utilised for further investigation on the BRT systems' technical characteristics. The hypothesis of this research was that BRT systems that influence urban development around the systems have technical characteristics that make them able to have high performance. It was hypothesised that the BRT systems, for instance, have high share of segregated right of way, are integrated with wide transit network and utilise off-board ticketing.

4. Findings

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

Prayogi [1] summarised Perk's et al. research on the influence of Boston SL4/5 on urban development along Washington Street. Prayogi [1] quoted that Boston SL4/5 brought a premium at 7.6% for condo units located at the mean distance to Washington Street. He [1] also quoted that Boston SL4/5 have a maximum passengers per hour per direction (PPHPD) figure at 1,236. The systems' buses on average run at 12.1 km/h. The systems' maximum frequency is six trips/hour and minimum headway time is 10 minutes.

4.1.1. Station configuration and accessibility. Schimek et al. [16] noted that Boston SL4/5 have 14 stations and distanced on average at 320 m. Stations are located on the curb side and adjacent to sidewalks. Stations are utilising standard curb at 15cm high, leaving 20 cm 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. Figure 1 shows the typical appearance of Boston SL4/5 stations.



Figure 1. Boston SL4/5 typical station. Source: Schimek *et al.* [16]

4.1.2. Vehicle capacity and accessibility. Schimek et al. [16] noted that Boston SL4/5 utilise 18.3m long and 2.6m wide articulated bus able to carry 79 passengers. The buses are partial low-floor buses and have three 1.2m-wide doors. The buses also have a wheelchair-loading facility at the front door. Figure 2 shows the vehicle used by Boston SL4/5.



Figure 2. Boston SL4/5 articulated bus. Source: Schimek *et al.* [16]

4.1.3. Segregated right of way. 2.7km out of 3.86km of SL4/5 route length is curbside bus lanes. The curbside bus lanes are painted continuously in red and given 'bus lane' mark. 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 [16].

4.1.4. Off-board ticketing. Boston SL4/5 utilise on-board ticketing. Passengers interact with an electronic fare box that recognises payment with notes and coins (without change), magnetic stripe cards and contactless smart cards.

4.1.5. Network width and transit network integration. Massachusetts Bay Transportation Authority (MBTA) [17] noted that SL4/5 connect with other Boston rapid transit services that have a total length of 112.6km of route network. They also connect with nine Massachusetts Bay commuter rail, Amtrak and intercity bus services. SL4/5 also connect with more than 15 conventional bus services. Figure 3 shows the connections between Boston SL4/5 and other Boston rapid transit services. Passengers transfer between SL4/5 and other transport services at transfer stations mostly by walking along standard sidewalks, semi-sheltered walkways and sometimes crossing roads through signalised pedestrian crossings. Transferring information is provided through maps and signs. 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. To implement the integrated fare system, electronic fare boxes are utilised at stations and inside vehicles.

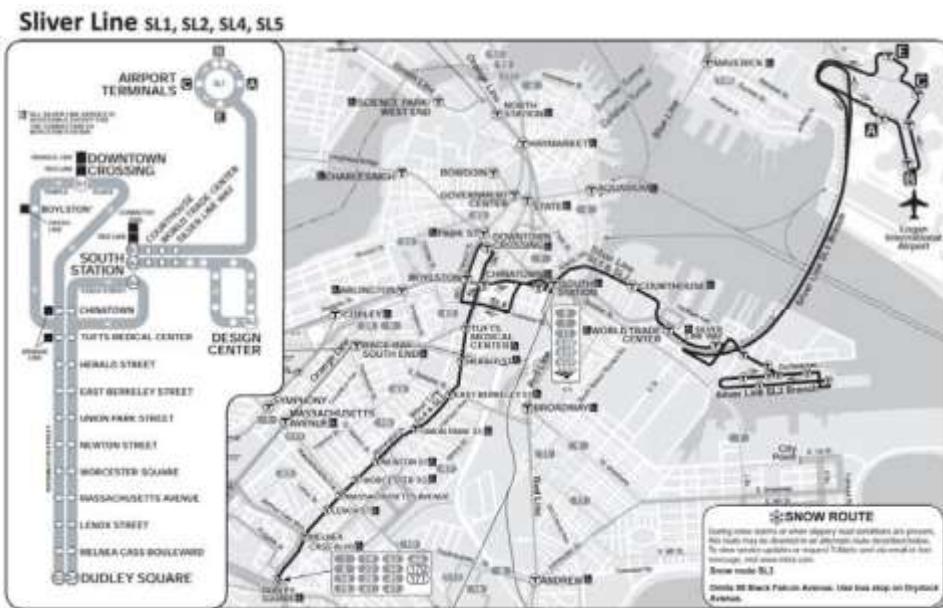


Figure 3. Boston SL4/5 within Boston rapid transit network. Source: Schimek *et al.* [16]

4.2. Seoul BRT systems, South Korea

Prayogi [1] summarised Cervero and Kang's research on the influence of Seoul BRT systems on urban development around the systems. Prayogi [1] quoted that the systems brought a premium at 5%-10% for residential properties within 300m of a BRT station and 3%-26% for non-residential properties within 150m of a BRT station. He [1] also quoted that Seoul BRT systems have maximum passengers per hour per direction (PPHPD) figure at 12,000. The systems' buses on average run at 22 km/h. The systems' maximum frequency is 60 trips/hour and minimum headway time is 1 minute.

4.2.1. Station configuration and accessibility. Hensher and Golob [12] noted that as of 2006 Seoul BRT systems have 75 median-lane stations. The average distance between stations is 780m. Other than some interchange stations that are located at the curb side, stations are located at the median side. Median-lane stations are connected to sidewalks by signalised pedestrian crossings. On average, stations accommodate three vehicles. Some stations have overtaking lanes. Figure 4, 5 and 6 show Seoul BRT stations' typical layout and appearance. Major interchange stations have multiple paralleled berths. 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, route maps, neighbourhood map and transferring information.

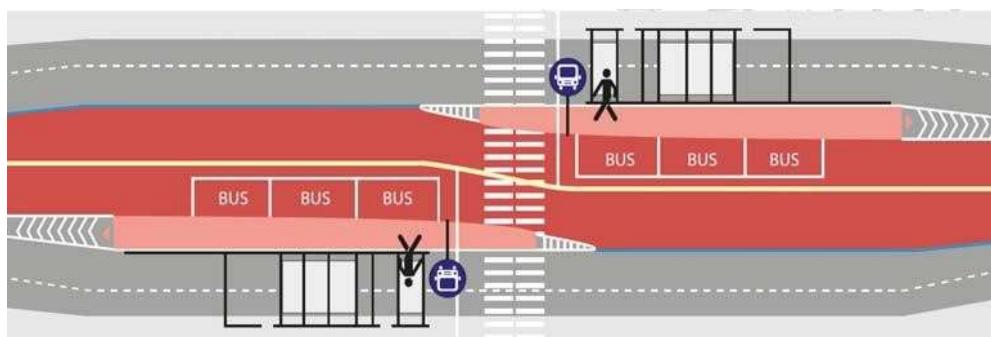


Figure 4. Seoul BRT stations typical layout. Source: Seoul Metropolitan Government. [17]



Figure 5. A Seoul BRT station with overtaking lanes. Source: Seoul Metropolitan Government. [17]



Figure 6. Seoul BRT typical median lane stop. Source: Park Young Wook.

4.2.2. Vehicle capacity and accessibility. Seoul Metropolitan Government (SMG) [17] mentioned that Seoul BRT systems utilise various types of buses for various types of services, that are 8 to 15m long single buses and 18m long articulated buses. Some buses introduced after 2004 are low-floor buses with 20cm height gap between buses door floor and curb, have two to three 1.2m-wide doors and have wheelchair-loading facilities.

4.2.3. Segregated right of way. Almost all of Seoul BRT right of ways are exclusive bus lanes that no vehicle other than buses allowed to use the lanes [17]. The bus lanes are painted continuously in red and given 'bus lane' mark.

4.2.4. Off-board ticketing. Seoul BRT systems utilise on-board ticketing. Passengers can pay with contactless smart card, named T-Money, when boarding and alighting buses [17]. Figure 7 shows the T-Money and on-board device used to validate payment by using T-Money.



Figure 7. Electronic fare box for T-Money at Seoul BRT vehicles. Source: Seoul Metropolitan Government [17].

4.2.5. Network width and transit network integration. As of 2008, Seoul BRT systems are about 74km long spanning eight corridors. They connect with eight Seoul Metropolitan Area rail transit services as well as regional and national rail services. The systems are connected to some major bus and train interchanges. At interchange facilities, passengers transfer between BRT services and other transport services by walking along standard sidewalks, semi-sheltered walkways and sometimes crossing roads through signalised pedestrian crossings. Transferring information is provided through maps and signs. Seoul Metropolitan Government [17] imposes an integrated fare system for all public transport services within Seoul Metropolitan Area. Under the fare system, a passenger is charged based on the total distance travelled by taking the consecutive services. The system is applied through the use of contactless smart card for payment that is recognised on all BRT vehicles as well as on other conventional buses and inner city trains.

5. Conclusion and Discussion

In line with the hypothesis of this research, it was found that BRT systems that influence urban development around the systems have technical characteristics that make them able to have high performance. Both Boston SL4/5 and Seoul BRT systems have some technical characteristics that contribute positively to the possible increase of the systems' passengers per hour per direction (PPHPD) figures.

Stations of the mentioned systems are averagely distanced on ideal distance suggested by Wright and Hook [7], making the stations conveniently reached by walking passengers. Stations are conveniently accessible by passengers walking along sidewalks. Stations that are located on median-side are connected to sidewalks by signalised pedestrian crossing, in which is a convenient pedestrian crossing according to Wright and Hook [7]. Boston SL4/5 and Seoul BRT systems utilise high capacity buses that clearly contribute positively to the possible high patronage of the system. The mentioned systems utilise buses that offer convenient access to various types of passengers, attracting potential passengers to use 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 well-designed transfer facilities, including the availability of transferring information, increase the connectivity. The integrated public transport fare systems imposed by Massachusetts Bay Transportation Authority (MBTA) and Seoul Metropolitan Government (SMG) also increase the connectivity. The mentioned features encouraged passengers of other modes of transport to use the BRT systems when starting and finishing their trip.

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. Boston SL4/5 utilise bus-priority traffic signals that reduce the queuing time for buses at traffic intersections. Seoul BRT systems utilise median lanes that are very unlikely used by vehicles parking or pulling over. All the mentioned systems utilise buses that are not required to dwell too long at stations when picking up and dropping

off passengers. The low floor, multiple wide doors and electronic fare box for contactless smart cards help fasten the passengers boarding and alighting process. All the mentioned technical characteristics make the BRT systems able to usher a significant number of people rapidly, thus making the BRT systems able to have high passengers per hour per direction (PPHPD) figure.

Table 1. Summary of the BRT systems technical characteristics that make the BRT systems able to have high passengers per hour per direction (PPHPD) figure.

Boston SL4/5		Seoul BRT systems
Station configuration and accessibility		
Average distance between stations		780m
Location	Curb side	Median line
Connectivity to sidewalks	Located adjacent to sidewalks	Connected by signalised pedestrian crossing
Vehicle capacity and accessibility		
Bus size and type	18m articulated	Various sizes and types including 18m articulated
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
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 includes 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	Contactless smart card	Contactless smart card
Fare collection device	On-board electronic fare box for contactless smart card	On-board electronic fare box for contactless smart card
Segregated right of way		
Location	Curb side	Median lane
Share of segregated right of way	70%	90%
Right of way exclusivity	May only be used by buses, 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

Prayogi's [1] article and this article bring interesting summary of two BRT systems. Seoul BRT systems bring premium for properties around the system, have technical characteristics that make the systems able to have high PPHPD figure and *do have* high PPHPD figure. Meanwhile, Boston SL4/5 bring premium for properties around the system, have technical characteristics that make the system able to have high PPHPD figure but *don't have* high PPHPD figure. I argue that both articles haven't been able to properly relate the BRT influence towards urban development and BRT technical characteristics, though the articles have been able to show that the two things are related through BRT performance. I argue that a new approach is needed to properly relate the two things.

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