BRT OMNIBUS: HOW BUS RAPID TRANSIT ENHANCES MOBILITY

by

Michael Niezgoda
Bachelor of Arts, Ryerson University, 2017

A Major Research Paper
presented to Ryerson University

In partial fulfillment of the requirements for the degree of

Master of Planning
in
Urban Development

Toronto, Ontario, Canada

Abstract

Bus Rapid Transit (BRT) has emerged in the 21st century as a leading form of building rapid transit in urban environs due to their ability as a rapidly implementable, relatively low-cost, flexible, and high-quality transit mode. While the popularity of the BRT mode continues to grow worldwide, there remains a degree of uncertainty over what designing for success looks like for BRT systems. This paper sought to determine whether there was a "correct" design approach for BRT implementation through literature review and case study. The case study revealed that despite differences in design and implementation, the cases successfully attained their respective planning and performance objectives. The inherent flexibility of the BRT mode allowed for BRT systems to be scaled to a wide array of operating and ridership contexts, as well as allow for incremental enhancements to the system as the passenger demands, available financing, and political will for upgrades arise.

Key Words: bus rapid transit; BRT; BRT Lite; service package; system design.

BRT Omnibus: How Bus Rapid Transit Enhances Mobility
Master of Planning, 2019

Michael Niezgoda
Urban Development, Ryerson University.

Acknowledgements

I would like to thank my family who were always supportive and understanding of the challenges of completing a Masters degree, and especially to my parents, Jacek and Mary, for their unfailing support and continuous encouragement throughout my years of study. I would also like to thank my friends and colleagues who were a constant source of inspiration throughout these two years.

I would like to thank my supervisor, Dr. Matthias Sweet, for his guidance and support throughout this research and writing process. Professor Sweet constantly kept me on the right track with my research, and always pushed me to keep asking the right questions. It was a pleasure to work with you as my supervisor, and your feedback has been crucial in crossing the finish line. I would also like to thank my second reader, Sean Hertel, for agreeing to review my paper, and for providing valuable insights into aligning my research with professional practice.

As a graduating planner, I would be remiss not to save a few words for my hometown, the City of Toronto. I have no doubt that this beautiful city has been influential in my decision to pursue a career in this profession. Throughout the past two years I have grown to understand and appreciate your many intricacies, and imagining how to resolve all of your pesky problems has been a consistent source of motivation for completing this paper. I look forward to tackling all these challenges with my unbelievably driven colleagues.

Dedicated to my abuela, Irma.

Table of Contents

1.0 Introduction

Bus Rapid Transit (BRT) has been widely regarded as "one of the most wide-spread urban public transportation revolutions" of recent decades (Jiang, Zegras, & Mehndiratta, 2012). BRT is a form of delivering rapid transit using rubber-tired vehicles that has received increasing attention from policy-makers and experts as they look towards alternative ways of delivering cost-effective and high-quality service.

Rapid transit is distinguished from other forms of transit by making use of specific infrastructure that is separated from general traffic (Deng & Nelson, 2011). Rapid transit modes are usually thought of as being rail-based systems, however, rubber-tired systems that replicate the qualities of rapid transit are increasingly prevalent. In theory, these enhanced bus services, provide greater service frequency and reliability, faster operating speeds, and increased convenience and accessibility, when compared to conventional bus services.

The emergent popularity of BRT systems is said to be due to the ability of these bus schemes to deliver a rapidly implementable, relatively low-cost, flexible, and high-quality service solution to developing cities' transportation needs (Wright & Hook, 2007). Many of these BRT schemes have been implemented in Latin America, Southeast Asia, China, and increasingly in Africa and India (Deng & Nelson, 2011). As of January 2019, there were 170 cities in 42 countries with BRT systems or corridors, serving over 33 million passengers every day (Centre of Excellence for BRT, 2019), with many extensions and new systems also under development.

While the implementation of bus rapid transit systems worldwide continues to grow, there remains a degree of uncertainty over what designing for success looks like for BRT. For instance, it is difficult to compare a BRT system with several state-of-the-art operational and performance characteristics against a BRT system with modest but desirable service enhancements (Hensher, Li, & Mulley, 2014). Consequently, two distinct views of BRT have emerged: (a) BRT as a new form of high-speed, rail-like, rubber-tired, rapid transit; and (b) BRT as a cost-effective way to upgrade both the quality and image of conventional bus service (Hess, Taylor, & Yoh, 2005). Some authors have distinguished the two views into the terms “high-end BRT” or simply “BRT” and “low-end BRT” or “BRT Lite”, reflecting the range of quality of service offered between the two views (Cervero, 2013).

The focus of this paper is to provide a comprehensive review of which core design components are considered essential for BRT implementation, to explore the implications of different policy objectives on BRT design, and whether there is a "correct" design approach for implementing BRT systems.

This paper will begin with an overview (Section 2.0) of what has been written about BRT systems, drawn from both academic and institutional sources. This will include a scan of how BRT is defined in the literature, which key design components comprise BRT systems, and what benefits are ascribed to BRT systems. The third section will explore the debates within the literature and their implications for BRT implementation (Section 3.0), as well as assemble different BRT service packages based on recommendations from the literature. The fourth section will describe the methodology (Section 4.0) that will be used to answer the questions that had arisen from the literature review. The fifth section will include a case study of BRT implementation (Section 5.0) in three localities of interest for this paper, with a focus on the implementation objectives and results of each project, followed by a brief discussion. The sixth section will summarize what has been looked at in the preceding sections (Section 6.0) and concludes with what insights can be offered to transit planners designing BRT systems.

2.0 BRT Literature Review

BRT began as an evolution of bus priority measures that has been implemented by public agencies to simulate the infrastructural and operational qualities of a rapid transit system while retaining the distributional flexibility of a bus system.

The first recorded BRT scheme is usually considered to be the 1937 Chicago Plan, where two engineers looked towards retrofitting an existing elevated structure for the use of express bus service (Harrington & De Leuw, 1937). However, it was not until 1972 when Jaime Lerner (then Mayor of Curitiba) with his team of architects and civil engineers conceived of building a system of dedicated bus lanes throughout the city of Curitiba, Brazil, consolidated into the Integrated Transit Network (RIT) in 1982 (Hidalgo & Muñoz, 2014). The term 'Bus Rapid Transit' to refer to such schemes originates in a 1966 study for the American Automobiles Association by Wilbur Smith and Associates (Levinson, et al., 2003a).

Following a few pioneering implementations in the later part of the 20th century, BRT has emerged as a leading mode of urban mass transit in the 21st century (Deng & Nelson, 2011). This has been largely attributed to the ability of BRT systems to implement mass transportation capacity quickly at a low to moderate cost (Nikitas & Karlsson, 2015). In the last twenty years, new world class BRT systems in Latin America and Asia have emerged, which have demonstrated that BRT can provide both the speed and capacity that is comparable to metro systems (Weinstock, Hook, Replogle, & Cruz, 2011).

In this section, a literature review was conducted in order to ascertain the definition of "bus rapid transit" and how it differentiates from conventional bus service (Section 3.1). This will follow with a detailed overview of the seven design components that comprise of BRT systems (Section 3.2) and how they may be implemented. Finally, a brief overview of the benefits of the implementing BRT systems is provided (Section 3.3) for the purpose of establishing an increasing number of cities are looking towards BRT as a rapid transit alternative to rail-based systems.

2.1 BRT Definitions

Although there are many systems described as 'BRT' currently implemented or underway across the globe, many questions regarding this transit mode, including *'what exactly is BRT'*, remain unresolved (Jarzab, Lightbody, & Maeda, 2002). Traditionally, distinctions between transit modes have been defined based on technological characteristics (Vuchic, 1981). Technology-derived modal distinctions have become less precise and increasingly complex due to technological advances. In the case of bus-based transit, technology has transformed simple bus priority measures into high performance BRT systems (Hidalgo & Muñoz, 2014).

Consequently, BRT does not have a single meaning and image (Hidalgo & Gutiérrez, 2013). A broad spectrum of applications, from modest, low-technology service improvements operating under mixed traffic, to new capital-intensive services operating in exclusive rights-of-way, are considered BRT (Hess, Taylor, & Yoh, 2005). This has ultimately led to BRT systems operating under a wide variation of capital and operating costs, ridership, service levels, performance, among other considerations (Polzin & Baltes, 2002).

The question of how BRT is defined is not a trivial matter. The cost of planning, constructing, and operating BRT depends greatly on the complexity of new service features (Hess, Taylor, & Yoh, 2005). Additionally, the availability of funding for transit projects may be different for BRT projects versus conventional bus services, resulting in the definition of BRT influencing the number and nature of the projects eligible for funding (Polzin & Baltes, 2002).

How different and distinct from conventional bus service does a BRT need to be in order to receive the designation of "Bus Rapid Transit" has also been a questioned raised by many within the literature (Polzin & Baltes, 2002). Meanwhile, the existence of a separate BRT mode has been challenged (Vuchic, 1981), with the suggestion that BRT systems actually refer to the next generation of bus services, indicating that transit agencies will eventually adopt BRT technology on all bus services as they modernize their bus systems (Hess, Taylor, & Yoh, 2005).

As will be explored throughout the literature review, BRT does constitute a mode of transit distinct from the conventional bus. The distinguishing factor between conventional bus services and BRT routes are the presence of some degree of separation from mixed traffic conditions on major parts of the service route.

In this section, the definitions of BRT in the literature are looked at closer, with the intention of answering some of the above questions, including, which service design elements are considered integral to BRT. In the table below, a collection of definitions of bus rapid transit has been collected from a review of the literature. This is followed with a discussion on what trends and debates emerge from the literature.

Table 1. Definitions of Bus Rapid Transit

BRT Definitions	**Source**
BRT is “a flexible mode that integrates capital and operational improvements to create a faster, higher-quality mode of travel than conventional bus service. BRT projects should include, at minimum, exclusive rights-of-way on at least a major part of the corridor.”	(Carey, 2002)
BRT is “a flexible, rubber-tired rapid-transit mode that combines stations, vehicles, services, running ways, and Intelligent Transportation System (ITS) elements into an integrated system with a strong identity … that collectively improves the speed, reliability, and identity of bus transit.”	(Levinson, et al., 2003a)

BRT is "an integrated, well-defined system using buses to provide faster operating speeds, greater service reliability, and increased convenience over conventional bus service. The goal is to … achieve similar ridership and economic development responses competitive with those of urban rail systems."	(Barker, Brosch, & Polzin, 2004)
BRT are "[employing] various facilities, services, amenities, and technologies to make buses faster, more reliable, more convenient, and safer."	(Hess, Taylor, & Yoh, 2005)
BRT is "a rubber-tyred rapid transit service that combines stations, vehicles, running ways, a flexible operating plan, and technology, into a high quality, customer focused service that is frequent, fast, reliable, comfortable, and cost efficient."	(CUTA, 2007)
BRT is "an integrated system of services, facilities, and amenities that is designed to improve speed, reliability, and identity. It calls for packaging various components in a coherent and supportive manner that reflects specific needs, resources, and opportunities.	(Danaher, Levinson, & Zimmerman, 2007)
BRT is "a high-quality bus based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service. BRT essentially emulates the performance and amenity characteristics of modern rail-based transit system but at a fraction of the cost."	(Wright & Hook, 2007)
BRT is "a system operating on its own right-of-way either as a full BRT with high quality interchanges, integrated smart card fare payments, and efficient throughput of passengers alighting and boarding at bus stations; or as a system with some amount of dedicated rights-of-way (light BRT) and lesser integration of service and fares."	(Hensher & Golob, 2008)
BRT are "schemes that apply rail-like infrastructure and operations to bus systems in expectation 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."	(Currie & Delbosc, 2011)
BRT is "characterized by modern vehicles, dedicated busway and application of intelligent transportation systems (ITS) technologies, [and] is increasingly considered a cost-effective approach of providing a high-quality transport service."	(Deng & Nelson, 2011)

BRT is "essentially, [aiming] to emulate more upfront- capital-intensive rail-based systems on key performance characteristics – including reliability, comfort, and speed – by utilizing measures like segregated and dedicated rights of way, pay-before-boarding at dedicated stations/stops, advanced traffic control and management measures for bus priority, and enhanced system marketing and branding."	(Jiang, Zegras, & Mehndiratta, 2012)
BRT is "a 'mass transit' system has typically been characterised by high running speeds, passenger capacity, frequency and operating on an exclusive right-of-way (ROW)".	(Hensher, Li, & Mulley, 2014)
BRT is "a homogenous system of facilities, services, and amenities that has the potential to become an alternate far more competitive to car-oriented mobility than conventional buses, to the degree that it could redefine the very identity of a city."	(Nikitas & Karlsson, 2015)
BRT is "designed using delicate transportation design strategies which will improve time, safety and cost-effectiveness to the public by accomplishing the goals of a BRT system, including, increased speeds to lower travel times, increased ridership, increased quality, and minimized effects to businesses and environments."	(Racehorse, Parker, Sussman, Jian, & Zhang, 2015)
BRT is "[comprising of] high capacity buses that are prioritised on purpose-designed roads, with stations at widely spaced stopping distances and distinct branding, which in effect mimic the operation of light rail transit (LRT) systems"	(Tanko & Burke, 2015)

In the above table, a wide range of definitions for BRT are considered. The lack of a sweeping standard definition within the literature is indicative of the lack of "single meaning and identity" for BRT as referenced by Hidalgo and Gutiérrez (2013). Even so, the presence of a distinct BRT mode is not in doubt within the literature, belying the notion that BRT are merely a technological evolution to the conventional bus that might one day achieve widespread adoption on all bus routes and systems (Hess, Taylor, & Yoh, 2005).

There is general agreement in the literature over some core aspects of BRT. All definitions naturally consider BRT as a rubber-tired, bus-based transit system that typically operate in urban environs. The other qualities and characteristics of BRT that achieve broad consensus within the literature can generally be summarized by the Canadian Urban Transit Association's (CUTA) definition where they describe BRT as "a rubber-tyred rapid transit service that combines stations, vehicles, running ways, a flexible operating plan, and technology into a high quality, customer focused service that is frequent, fast, reliable, comfortable and cost efficient" (CUTA, 2007). The CUTA definition encompasses both the design components of BRT, as well as the performance objectives of BRT, that are referenced to varying degrees by all other definitions provided in Table 1.

While some have argued that BRT is an attempt to inject new energy into traditional bus services (Polzin & Baltes, 2002), it is viewed as a distinct mode based on all literature reviewed. The question of how BRT relates to and differentiate from conventional buses remains. Several of the definitions make allusions to conventional bus routes in their definition of BRT. For instance, Deng and Nelson (2011) described BRT as sharing the "operational flexibility and lower cost of a conventional bus service".

The two modes are contrasted by some in the literature when they describe BRT as "a flexible mode that integrates capital and operational improvements to create a faster, higher-quality mode of travel than conventional bus service" (Carey, 2002), or as providing "faster operating speeds, greater service reliability, and increased convenience over conventional bus service" (Barker, Brosch, & Polzin, 2004).

These descriptions are alluding to the "one-size-fits-all" conventional bus service that has been traditionally adopted by many transit agencies (Jarzab, Lightbody, & Maeda, 2002). In many transit systems, bus operations have been relegated as the "mundane workhorse of the transit industry" with the average conventional bus service typically operating at half the speed of general traffic (Jarzab, Lightbody, & Maeda, 2002). In contrast, BRT is designed to operate much faster and more reliably than conventional bus transit systems. BRT is described as "an alternative far more competitive to car-oriented mobility than conventional buses" to the extent that it could "redefine the very identity of a city" (Nikitas & Karlsson, 2015).

There has been an attempt by many transit agencies to improve the service provided by their conventional bus system. Improvements such as "express" or "limited-stop" services have been implemented in some fashion by many transit agencies. An express bus offers a faster bus service than a regular bus via a faster schedule, fewer stops, and usually taking a quicker or more direct route (Deng & Nelson, 2011). Conventional bus services on any given route may be designed as an express or limited-stop route with frequent and all-day service. However, these services still retain a bus service operating within a mixed traffic environment and subject to the standard cycling of traffic signals (Jarzab, Lightbody, & Maeda, 2002).

BRT can be regarded as a significant improvement in terms of capacity and speed above and beyond the express bus (Deng & Nelson, 2011). The existence of some degree of separation from mixed traffic conditions in BRT systems result in reduced journey times and improved service reliability compared to conventional bus services (Currie & Delbosc, 2011). When BRT is implemented to replace an existing bus route, most BRT systems outperformed the original route in regards to passenger demand, user satisfaction, travel time, and reliability (Nikitas & Karlsson, 2015).

Consequently, it becomes evident that the distinguishing factor between conventional bus and BRT modes is not service design, but in attaining some degree of separation from mixed traffic conditions. This is corroborated in the literature with the majority of BRT definitions explicitly stating the necessity of a dedicated running way, and virtually all definitions describing some degree of bus priority measures as contributing to the definition of BRT. This distinction from conventional buses also provides a commentary on the greater performance objective of BRT systems as directly challenging the traditional position of buses on the roadway modal hierarchy.

BRT systems represent a move toward reorganizing limited and precious road space in favour of bus services, often with the provision of dedicated infrastructure (Nikitas & Karlsson, 2015). BRT constitute a higher order of transit when compared to conventional bus systems (Cain, Flynn, McCourt, & Reyes, 2009). To this end, BRT could shift the perception of buses within a transit system and change the balance of the entire mobility network in a city (Polzin & Baltes, 2002).

2.2 BRT Components

BRT systems are among the most flexible transit modes. Examples of BRT systems have emerged worldwide in recent decades representing a great variety of design components and features. The wide range of BRT design components internationally utilized provides for an opportunity to investigate the mode in terms of their application of infrastructure and technology (Jarzab, Lightbody, & Maeda, 2002).

Seven design components of BRT have been identified from the list of definitions provided in Table 1 in the preceding section. These seven components were also variously considered by Nikitas and Karlsson (2015) and Deng and Nelson (2011) in their reviews of the literature. They are as follows:

a) Running Ways;
b) Stations and/or stops;
c) Vehicles;
d) Service design and operations;
e) Fare collection;
f) Branding; and
g) Intelligent transportation systems (ITS)

In this section, these seven design components will be looked at in further detail.

Running Ways

The running way forms a key element of BRT systems. BRT vehicles are able to operate under various traffic environments, but preserving limited or exclusive use for BRT vehicles on a running way dictates the performance of the overall BRT system (Jarzab, Lightbody, & Maeda, 2002). The purpose of a running way is to provide BRT with an operational environment where vehicles are free from delays caused by other traffic and to provide transit riders with a faster, more reliable service (Levinson, et al., 2003b). The overall performance of a BRT system, especially in terms of speed, reliability, and image, depends greatly on the quality of the busway (Deng & Nelson, 2011). The degree of separation from mixed traffic conditions was also found to be the critical differentiating factor between BRT and conventional bus systems in the preceding section.

Running way types vary in degree of separation, busway alignment, and treatment of intersections (Wright & Hook, 2007). Running ways for BRT operations can be found in many places, including on abandoned rail lines, within a highway median, or on city streets (Jarzab, Lightbody, & Maeda, 2002). Running way configurations can range from exclusive transit-ways, to dedicated busways on freeways or arterial streets, to shoulder bus lanes on city streets, and sometimes, as queue bypass lanes in mixed traffic conditions (Levinson, et al., 2003a).

The type of running way determines the capital cost and performance of the overall system (Cain, Flynn, McCourt, & Reyes, 2009). The construction of the busway will typically represent around half of the total infrastructure costs, thus savings through efficient design can be significant for transit providers (Wright & Hook, 2007). How to implement dedicated rights-of-way for BRT thus becomes a critical issue for implementation (Levinson, et al., 2003b). Options that provide for a high degree of right-of-way segregation cost more compared to alternatives with less intensive physical infrastructure demands (Danaher, Levinson, & Zimmerman, 2007).

Beyond cost, exclusive transit-ways can sometimes be difficult to find or build, and are sometimes not an available option near major transit corridors. Therefore, on-street BRT operations in median busways, bus lanes, or even mixed traffic often are made necessary (Danaher, Levinson, & Zimmerman, 2007). The choice of running way type for any given corridor will depend greatly on market demand and route specific opportunities and constraints (Danaher, Levinson, & Zimmerman, 2007).

Exclusive busways are corridors that are generally not used by other traffic, and are located either in the median or boulevard of an existing road, or in a separate corridor (CUTA, 2007). Many cities have been creative in finding space to locate exclusive busways for their BRT systems. These sometimes include BRT operating along railroad alignments, on arterial medians on freeways, and even on bridges, tunnels, and elevated structures (Deng & Nelson, 2011). Median busways that are located in the centre median of city streets and major arterials are the next degree of separation. Locating the bus lane in the centre median allows for the reduction of the number of conflicts caused by shoulder lane alignments (Cain, Flynn, McCourt, & Reyes, 2009).

The most basic form of separation from traffic is a shoulder bus lane. These can be provided at minimal cost by simply dedicated an existing lane for traffic or parking for use as a bus lane (Cain, Flynn, McCourt, & Reyes, 2009). For both shoulder bus lane and median busway configurations, intersection design and treatment becomes critical for maintaining BRT priority on arterial streets with mixed auto and BRT traffic conditions. There are several ways to reduce bus delays at intersections, including, forbidding turns across the bus lane, queue jumping, and far-side bus stops in order to expedite vehicle flows and reduce travel times (Carey, 2002). Traffic-signal priority measures, when activated by an approaching BRT vehicle, is useful on lower-frequency corridors (ITDP, 2016).

Some BRT systems have also introduced manual guidance systems to increase speed in narrow corridors and improve safety, prevent unauthorized vehicle use, and to improve boarding and alighting by reducing the horizontal gap at stations (Hidalgo & Muñoz, 2014).

Stations

Stations are one of the essential components of a BRT system, as they provide the key link between passengers and the BRT system. BRT stations are particularly important since they accommodate fare payment before boarding the bus, allowing for faster, multi-door boarding and alighting, reducing dwell time at stops (Cervero, 2013). The stations can range from simple stops with well-lit shelters to complex facilities with extensive amenities and features, akin to those found at urban rail stations (Danaher, Levinson, & Zimmerman, 2007). Simple BRT stops can be distinguished from conventional bus service by using unique station design elements, such as real-time vehicle arrival information, more effective and weather-protected passenger shelter designs, along with branding (Jarzab, Lightbody, & Maeda, 2002).

According to Danaher, Levinzon, & Zimmerman (2007), BRT stations provide three major benefits. First, they can reduce travel times by expediting passenger boarding and alighting and by being widely spaced. Second, they can attract riders by providing a range of services for boarding and alighting patrons, and by being pedestrian-friendly and safe. Third, they can serve adjacent developments and encourage additional development activity in the surrounding area.

A wide range of station types exist for BRT stations, reflecting the flexibility of the mode. Features of the running way such as degree of separation (at-grade, elevated, or tunnelled) and the busway alignment (shoulder lane, median arterial, or mixed-traffic operation) greatly influence the design and cost of stations (Danaher, Levinson, & Zimmerman, 2007). Station stop spacing for BRT systems is also wider compared to conventional bus systems, more akin to the stop spacing found in urban rail, in order to allow high operating speeds (Cervero, 2013).

BRT stations can also incorporate a number of design features to help enable passenger comfort and convenience, improve BRT performance, and bolster the reputation and permanence of BRT systems. BRT stations should be designed as permanent, weather-protected facilities that are convenient, comfortable, safe, well-lit, and fully accessible (CUTA, 2007). The station structure should serve the purpose of providing safety to passengers as well as shelter from the elements (Racehorse, 2015). They should also be well-connected to nearby destinations and street network through stairs, escalators, and pedestrian bridges as necessary (Danaher, Levinson, & Zimmerman, 2007). The inclusion of passing lanes at BRT stations can allow BRT vehicles to overtake one-another as the enter or leave a station, avoiding possible delay (Danaher, Levinson, & Zimmerman, 2007). Designing the passenger boarding area at the same height as vehicles to enable level boarding (and eliminate the need for passengers to climb steps to board or alight vehicles) helps to reduce overall dwell time at stations and increase accessibility for all passengers (Carey, 2002) (Cervero, 2013).

There are a number of station amenities that can also be included at BRT stations depending on their size and scale, such as various passenger amenities (benches, shelters, restrooms, and drinking fountains) and auxiliary features (temperature control, telephones, passenger information systems, and security provisions) (Danaher, Levinson, & Zimmerman, 2007).

Vehicles

As BRT is a rapid transit system based on the usage of rubber-tired vehicles, the vehicle serves as an essential component to the BRT system and vehicle rolling stock must be carefully selected and considered. Vehicles have a strong impact on every aspect of the BRT system performance, from ridership attraction, revenue speed and reliability, environmental friendliness, to operating costs (Levinson, et al., 2003b). It is also the BRT component most widely observed by both users and potential customers. According to Levinson (Levinson, et al., 2003b), bus noise, air emissions, cleanliness and the state of repair, and general aesthetics all affect public perception of the quality of the entire BRT system. Vehicles should have strong passenger appeal and should be environmentally friendly, easy to access, and comfortable (Danaher, Levinson, & Zimmerman, 2007).

BRT vehicles range from conventional buses to distinctive, dedicated BRT vehicles (Levinson, et al., 2003a). A distinctive, dedicated vehicle is one that is specifically designed to meet the functional requirements of the BRT system (Carey, 2002). Vehicles should be designed to provide sufficient capacity for the anticipated ridership levels of the BRT system, as well as considering the comfort of the passengers onboard. Four important characteristics have been identified as important considerations when selecting the BRT vehicle rolling stock. These are are propulsion systems, vehicle size, passenger circulation, and vehicle amenities (Diaz & Hinebaugh, 2004).

Propulsion systems impact the revenue service times (acceleration and maximum speeds), fuel consumption, emissions, and operating and maintenance costs of BRT vehicles (Danaher, Levinson, & Zimmerman, 2007). They also affect the noise and smoothness of operation and service reliability (Diaz & Hinebaugh, 2004). Diesel buses currently dominate most bus operations, however, other propulsion technologies are also available and becoming increasingly popular, such as natural gas and diesel-electric hybrids (Danaher, Levinson, & Zimmerman, 2007). BRT vehicles using clean fuels or alternative power create lower emissions for a better environment for the surrounding urban environment (Racehorse, Parker, Sussman, Jian, & Zhang, 2015).

The second consideration is vehicle size, which is a function of the vehicle dimensions, floor height, and body type of the vehicle. The physical size of the BRT vehicle is important for determining aisle width, seating arrangement, and the number of doors on the vehicle, all of which influence the passenger capacity of the vehicle, and ultimately, of the entire BRT system (Danaher, Levinson, & Zimmerman, 2007). BRT vehicles can be of higher capacity compared to conventional bus vehicles, as the standard 10.7m bus can carry approximately 50-60 people, whereas an articulated 18.3m bus can carry over 120 persons (Racehorse, Parker, Sussman, Jian, & Zhang, 2015). Increasingly, the articulated bus is becoming the standard for BRT systems (Wright & Hook, 2007). There are trade-offs with larger vehicles however, as noted by Wright and Hook (2007), larger vehicles on lower-demand corridors tend to also mean lower frequency, and the heavier weight of the vehicles reduces fuel efficiency.

The third consideration for BRT vehicles is passenger circulation, both within the vehicle and while boarding and alighting the vehicle. Vehicles should be easy to board and alight, as any delay derived from passenger circulation will impact dwell times at stations, revenue service travel time, and overall passenger comfort (Jarzab, Lightbody, & Maeda, 2002). Wide aisles and sufficient passenger circulation space on buses can lower dwell times and allow for a better distribution of passengers within the bus. A sufficient number of door channels should be provided, especially if fares are collected off-vehicle. One door or narrow doorways become bottlenecks that delay buses and add substantial dwell time at stations (ITDP, 2016). Low floor heights of 15 inches or less above the pavement are desirable unless technologies and station designs permit reliable level boarding (Danaher, Levinson, & Zimmerman, 2007). Transit vehicles in the United States have traditionally been high-floor vehicles with steps. With the introduction of the American with Disabilities Act (ADA), low-floor vehicles have increasingly become the norm (Diaz & Hinebaugh, 2004). The low-floor height in addition to improving accessibility to vehicles, also significantly reduces dwell time at stations by allowing for fast and convenient boarding and alighting (Jarzab, Lightbody, & Maeda, 2002).

The fourth consideration are the number of amenities that can be provided on BRT vehicles for the purpose of improving the general comfort of passengers and the public perceptions of the BRT system. Vehicles may have interior air conditioning, noise control, bright lighting, panoramic windows, security provisions, as well as on-board information systems (Danaher, Levinson, & Zimmerman, 2007) (Racehorse, Parker, Sussman, Jian, & Zhang, 2015). On-board information systems include information on next stops, transfers, vehicle schedule, delays, and other types of announcements, that can be provided both audibly and with electronic displays (Hidalgo & Muñoz, 2014).

Service Design & Operations

The physical features and infrastructure of a BRT system are complemented by their system service plan. BRT services need to be frequent, direct, easy-to-understand, comfortable, reliable, operationally efficient, and most of all, rapid (Diaz & Hinebaugh, 2004). The underlying goals of a service plan is to provide for a rapid and reliable service, and to meet passenger demand on a given corridor (Danaher, Levinson, & Zimmerman, 2007). The service plan should be designed for the specific needs of each BRT environment (Levinson, et al., 2003b). BRT service plans relate to a number of characteristics, including route length, route structure, service span and frequency, station spacing, and the type of service provided (Diaz & Hinebaugh, 2004) (Danaher, Levinson, & Zimmerman, 2007).

The route length affects what locations a passenger can directly reach without having to transfer services. Longer routes can minimize the need for transfers, but require greater capital and labour resources. Shorter routes may require passengers to transfer, but can provide higher travel time reliability (Diaz & Hinebaugh, 2004). BRT service does not need to operate on dedicated facilities for their entire length. The flexibility of the BRT system and facilities allows for BRT services to branch away from the dedicated running way and into mixed traffic conditions to provide local service towards the outer ends of a route (Danaher, Levinson, & Zimmerman, 2007).

The flexibility of the BRT system and facilities allows for significant flexibility in designing the route structure in order to accommodate different vehicles serving different routes. This flexibility allows BRT operators to provide a service plan that is responsive to passenger demand, including, "one-seat rides" to local destinations through the aforementioned use of route branching (Jarzab, Lightbody, & Maeda, 2002). This also provides opportunities for interoperability with conventional bus routes and services. For instance, BRT may allow conventional bus services to access certain key sections of its infrastructure, improving the service level provided on those routes (Deng & Nelson, 2011). The trade-off when considering complex route structures however, is that they become more difficult to understand and navigate for passengers (Diaz & Hinebaugh, 2004).

Service span represents the period of time that a service is available for use. Generally speaking, BRT routes operate all day, from about 5:00am to 11:00pm (Racehorse, Parker, Sussman, Jian, & Zhang, 2015). Where BRT service are complemented by local conventional bus service, a shorter peak-to-peak period 12-hour span may be appropriate (Danaher, Levinson, & Zimmerman, 2007). Service frequency directly determines how long passengers must wait for a vehicle to arrive. Service frequency on BRT corridors is important for maintaining system image as a rapid transit system and for encouraging ridership. Quantitative modeling designed by Lan, Xuewu, & Tao (2015) found that service frequency was the largest indicator of increased ridership under various different configurations of BRT systems, underlying its importance. Service frequencies for existing BRT systems vary depending on the context, ridership demands, and type of service provided (Levinson, et al., 2003b). The basic BRT service should operate at five to ten minute intervals, or less, during peak hours, and a maximum of eight to twelve minutes at midday, and twelve to fifteen minutes at all other times (Danaher, Levinson, & Zimmerman, 2007).

BRT stations are typically spaced farther apart than stops for conventional bus systems providing local service. The longer stretch between stations allows vehicles to sustain higher operational speeds between stations, whereas fewer stops reduces the delay imposed by acceleration and deceleration, as well as dwell time at stations. These factors lead to overall higher revenue operation speeds and reduces the total travel time for passengers (Diaz & Hinebaugh, 2004).

BRT facilities can support several types of services at the same time, including all-stop services, peak or counter-peak direction express services, or limited stop services (CUTA, 2007). An express service offers a faster service via a faster schedule and fewer stops (Hidalgo & Muñoz, 2014). The integration of local and express services can reduce long-distance travel times (Levinson, et al., 2003b). When BRT operates on its own exclusive running way, the service pattern that works best features an all-stop service, complemented by some express services during peak periods (Levinson, et al., 2003b).

Fare Collection

Fare collection has been identified as an important component to the operating plan of BRT systems in the literature. The basic objective of planning for fare collection is to maximize passenger convenience and minimize dwell times at stops (Levinson, et al., 2003b). Fare collection can happen off-board or onboard the vehicles (Diaz & Hinebaugh, 2004). Multi-door boarding of buses, to maximize passenger throughput, can be achieved by off-board or on-board multi-door payment.

With conventional bus services, the driver is typically responsible for the collection of fares as well as driving the vehicle, and passengers are only allowed to enter through the front door (Wright & Hook, 2007). In contrast to conventional bus systems, BRT systems aim to provide for fast and efficient fare collection systems that speed boarding and increases convenience to passengers (Jarzab, Lightbody, & Maeda, 2002).

According to Wright and Hook (2007), with on-board fare collection, passengers take from two to four seconds just to pay the driver. This delay is made longer if the driver must verify the fare, provide a transfer, or if a passenger enters the vehicle and stops to search through their belongings for the fare. Once passenger flows reach a certain point, the delays and time loss associated with on-board fare collection become a significant overall system liability (Wright &

Hook, 2007). Thus, the speed and reliability of BRT systems can be hampered by conventional on-board fare collection (CUTA, 2007).

Off-board fare collection is one the most important factors in reducing travel time and improving the overall passenger experience (ITDP, 2016). Elimination of onboard fare collection can significantly reduce dwell times at stations (Carey, 2002). Fare collection can be taken prior to entering the station, much like at an urban rail station (Racehorse, Parker, Sussman, Jian, & Zhang, 2015). When fares are collected off the vehicle, there is no delay associated with fare collection process when boarding and alighting vehicles. Off-board collection also allows for the free use of multi-door boarding, further reducing dwell times and overall operating costs (Levinson, et al., 2003b).

Off-board fare collection can be achieved a number of ways. According to ITDP, the two most effective approaches are "barrier-controls", where passengers pass through a gate, turnstile, or checkpoint upon entering the station where their fare is paid, and a "proof-of-payment" system, where passengers may be required to show their validated ticket or passes on vehicles when requested to do so (ITDP, 2016). Barrier-controlled systems are slightly preferable because they help to minimize fare evasion and enable the transit agency to collect data to better assist future service planning (ITDP, 2016).

However, there are three significant downsides to designing off-board fare collection systems as identified by Levinson et al (2003b). The first is that fare gates, barrier-controls, or paid zones occupy a significant amount of space, which may not be available at curbside or arterial median boarding locations. The second downside are that installation costs are substantially higher, requiring dedicated infrastructure, and increasing the overall capital cost of a BRT system. The third downside is that heavy passenger demand is needed to support staffed stations, thus resulting in an impractically to provide off-board fare collection systems at many BRT stations with lower passenger boarding.

Fare collection systems involve selling, recharging and validating of fare payment (Hidalgo & Muñoz, 2014). Helpful strategies include smart cards, prepaid passes and tickets, fare-free zones, or "proof of payment" policies in vehicles and platform areas (CUTA, 2007). The introduction of contactless smart cards and other modern payment systems can reduce on-board payment to below 2 seconds per passenger (Wright & Hook, 2007). While this provides time savings for passengers, it is not as efficient as off-board systems (ITDP, 2016). An off-board fare collection system reduces boarding times to 0.3 seconds per passenger, effectively matching the speed of alighting passengers (Wright & Hook, 2007).

Branding

While not an operational feature of a BRT system, many in the literature have identified the image and "branding" of the BRT system as an important component of the mode. This importance is potentially fueled with the desire for transit agencies to portray BRT services as distinct to the rest of the conventional bus routes operating in the system (Cervero, 2013). System branding and identity can also convey important customer information such as routing and stations served (Levinson, et al., 2003b). It may also influence the willingness of customers to try a BRT system, particularly those who may opt to use a private automobile instead (Levinson, et al., 2003b).

BRT system branding may be provided in the form of a distinctive system name and logo that can be applied to vehicles, stations, and various amenities (Danaher, Levinson, & Zimmerman, 2007). Banding can be provided at stations (through the use of passenger information displays, fare collection equipment, and media), on vehicles, on running ways (using special paving materials, colours, and markings), and on marketing materials (such as route maps and schedules, web sites, and media information) (Danaher, Levinson, & Zimmerman, 2007).

According to Carey (2002), the BRT system should endeavor to develop a unique identity where the look of its vehicles supports the overall image of the operation. A unique vehicle identity for BRT systems would not only advertise the system, but also help inform the large number of infrequent customers where and how they can board BRT service (Levinson, et al., 2003b). Unique identities for BRT vehicles may be achieved through the use of livery (paint schemes and colours), and graphical design elements (Jarzab, Lightbody, & Maeda, 2002). BRT vehicles also have the option of providing advertisement as an added revenue source for the maintenance to the BRT system (Racehorse, Parker, Sussman, Jian, & Zhang, 2015).

Intelligent Transportation Systems (ITS)

BRT systems strive to incorporate the use of information and communication technologies in order to improve the quality of the services provided in terms of customer convenience, speed, reliability, integration, and safety (Nikitas & Karlsson, 2015). Intelligent transportation systems (ITS) has been referenced as an important component of BRT systems within the BRT literature.

ITS is defined as "advanced technologies of electronics, communications, computer, control and sensing, and detection in all kinds of transportation systems in order to improve safety, efficiency and service, and traffic situation through transmitting real-time information" (Racehorse, Parker, Sussman, Jian, & Zhang, 2015). The application of ITS technologies in BRT systems typically include advanced vehicle location (AVL), passenger information systems, and traffic signal preference at intersections (Levinson, et al., 2003b).

Advanced vehicle location (AVL) technologies have also been regarded as "part and parcel" of high-end BRT systems (Cervero, 2013). AVL technologies allow for real-time management and dispatching, preferential signal treatment of BRT vehicles at signalized intersections, and real-time dynamic passenger information systems at stations.

Aside from passenger convenience, the performance goals of utilizing ITS on BRT systems are considered to be improved traffic safety, reduced traffic congestion, increased transportation efficiency, and lowered emissions (Racehorse, Parker, Sussman, Jian, & Zhang, 2015).

2.3 BRT Benefits

A growing body of academic literature surrounding BRT projects has emerged in the preceding two decades as global interest and the number of cities adopting BRT systems grows. Institutional and government-sponsored publications have also been published supporting bus rapid transit (BRT) adoption under particular circumstances. The advantages of bus rapid transit schemes have become increasingly well known and recognized in the literature. The purported advantages of BRT systems broadly fall under four categories: (1) cost effectiveness; (2) operational flexibility; (3) increased service capacity and ridership; and (4) expeditious implementation. These will be briefly discussed below.

A review of case studies suggest that bus rapid transit could be the most cost-effective way of providing a high-performance public transit (Levinson, et al., 2003a) (Wright & Hook, 2007). Bus rapid transit has emerged as a popular economic alternative to rail-based transit systems. When compared to BRT systems, light rail has been found to be costly both in terms of capital costs and in financial performance. BRT infrastructure and facilities cost less to build than light rail because they do not require specialized electrical, track, vehicle maintenance or storage infrastructure (CUTA, 2007). A BRT system typically costs four to twenty times less than an LRT system depending on the degree of separation and other design elements provided, while providing comparable and at times, improved, capacity and operating speeds (Wright & Hook, 2007) (Deng & Nelson, 2011). In addition, light rail often requires significant funding from both the local government and the central government to become a reality (Hodgson, Potter, Warren, & Gillingwater, 2013). Nikitas & Karlsson (2015) however, caution that while BRT may be cheaper to implement than a rail-based system, this does not mean that BRT is not a capital-intensive system.

Bus rapid transit combines the quality of rapid transit with the operationally flexibility of conventional bus systems (Deng & Nelson, 2011). When compared with other forms of rapid transit, BRT systems are considered more flexible as they can allow for a greater variety of services. A single running way can support express, local, and skip-stop services (CUTA, 2007). For instance, a BRT corridor may allow conventional bus services to access BRT infrastructure, servicing a much wider geographic range when compared to an LRT on a fixed-guideway (Nikitas & Karlsson, 2015). Additionally, BRT services on busways and bus lanes can reach average operating speeds of 45 to 50 km/h with reliable travel times. This is substantially more attractive than conventional bus routes operating at half that speed and with less reliability due to congestion (CUTA, 2007).

According to Currie and Delbosc (2011), compared to conventional bus systems, BRT systems develop increased ridership due to their higher frequency and longer hours of operations, their priority systems which reduce journey times and improve service reliability, and their better-defined networks, branding, and technology information systems which are said to improve the ease of using the system. Hidalgo (2005) states "there is range, between 20,000 and 40,000 passengers/hour per direction, in which Metros and HBRT are able to provide similar capacity" referring here to high-level BRT as HBRT. This is exemplified by the TransMilenio in Bogota, Colombia, which can carry more passengers per hour than many rail systems. The main trunk corridor in Bogota can support a maximum ridership of 35,000 passengers per peak hour direction, with three-minute maximum peak headways, average station dwell time of twenty-five seconds, and with articulated buses having a carrying capacity of 160 passengers (Hensher &

Golob, 2008). These high capacity, high-ridership BRT systems demonstrate that the traditional depiction of a natural evolution from a bus in mixed traffic to heavy rail in terms of passenger capacity per hour is no longer valid (Hensher & Golob, 2008).

Finally, the capability of BRT to be implemented rapidly makes these projects attractive to political leaders looking to complete systems in an expeditious manner (Hidalgo & Carrigan, 2010). For instance, the city of Guadalajara, Mexico, completed a high-quality 16-kilometre-long bus corridor for 125,000 daily passengers, in a project that took just two years to go from ideation to implementation (Hidalgo, Voukas, Freiberg, & Alveano, 2010). While the political and planning context may differ drastically among jurisdictions, the flexibility of bus operations allow for BRT projects to be completed in phases as funding is made available (Jarzab, Lightbody, & Maeda, 2002). This incremental implementation approach provides an opportunity to show progress much sooner than with most rail projects. To contrast with BRT, the planning timescales and consultation process for rail-based systems are excessively long (Hodgson, Potter, Warren, & Gillingwater, 2013).

3.0 BRT Design Objectives

In the preceding section, a literature review was conducted in order to establish the definition of BRT, which design components comprised BRT systems, and what were the benefits of implementing BRT systems over alternative transportation modes. Through conducting this literature review, a number of observations arose about BRT systems, including that BRT systems constituted a transportation mode separate from conventional buses, that BRT components differed greatly from system to system, and finally, that the degree of dedicated physical infrastructure significantly impacted how the seven design components of BRT systems were implemented.

The findings of the literature review have naturally raised a number of questions about how BRT systems are designed and implemented, including whether different planning objectives result in different BRT implementation strategies, and whether there was a "correct" design approach for BRT implementation. In this section, some of the contradictions that emerged in the literature over how BRT systems are designed and implemented will be explored and analyzed. Through this analysis, a set of emerging "BRT service packages" will be identified and are summarized in

Table 2. These service packages correspond to the different planning objectives of BRT and impact the delivery of the seven design components that comprise BRT systems.

There are certain areas within the literature where the definitions of BRT begin to differentiate from one another. The first set of differences that emerge are technical, relating to the design components of BRT. The definitions vary in the degree of dedicated physical infrastructure that should be provided for BRT, including facilities such as bus vehicles, bus stops or stations, and importantly, the running ways and physical corridor that the bus vehicles operate in.

Most definitions reviewed have referenced the importance of a protected running ways as a core component of BRT systems. However, the manner and degree to which BRT services are separated from mixed traffic conditions varied widely among the literature. Many of the definitions provided in Table 1 indicate that BRT systems operate mostly or entirely within a segregated or exclusive right-of-way, including Carey (2002), Wright and Hook (2007), Currie and Delbosc (2011), Deng and Nelson (2011), Jiang, Zegras, and Mehndiratta (2012), and Hensher, Li, and Mulley (2014). Some definitions, such as Hensher and Golob (2008), suggested instead that a BRT system with some amount of dedicated right-of-way is sufficient. Other definitions, such as Levinson (2003a), Tanko and Burke (2015), and Racehorse et al. (2015), simply state that BRT represents an evolution of bus priority measures or transportation design strategies, including purpose-designed roads and bus lanes.

The definitions also vary in their acknowledgement of whether the designated area for pick-up or drop-off of passengers on BRT should be a traditional sheltered bus stop, or a more elaborate station structure, akin to train stations on rail-based systems. Many of the definitions exclusively favour a ‘bus station’, whereas Jiang, Zegras, and Mehndiratta (2012) describes BRT as stopping at either dedicated stations or stops. The station stop-spacing was also a consideration in some definitions such as Tanko and Burke (2015), with implications for station scale and design, as well as the total number of stations built.

The second set of differences that emerge in the literature related to the degree of flexibility or rigidity in the definition of BRT. Many have hailed BRT systems as a cheaper alternative to rail-based transit (Hodgson, Potter, Warren, & Gillingwater, 2013). This is reflected in multiple definitions of BRT in the literature drawing a direct comparison to rail-based transit modes or as described by Currie and Delbosc (2011) as emulating “rail-like infrastructure and operations”.

This is in comparison to some of the other definitions, which in lieu of a comparison to rail-based transit modes, instead emphasize BRT as a “homogenous system of facilities, services, and amenities” (Nikitas & Karlsson, 2015) that together, are a “strategy for significantly increasing the level of transit service” (Barker, Brosch, & Polzin, 2004) among other performance goals sought through BRT. The two differing interpretations of BRT have led towards a branching within the literature over the objectives of BRT implementation.

According to some, two distinct views of BRT have emerged: (a) BRT as a new form of high-speed, rail-like, rubber-tired, rapid transit; and (b) BRT as a cost-effective way to upgrade both the quality and image of conventional bus service (Hess, Taylor, & Yoh, 2005). Some authors have distinguished the two views into the terms “high-end BRT” or simply “BRT” and “low-end BRT” or “BRT Lite”, reflecting the range of quality of service offered between the two views (Cervero, 2013).

The first interpretation creates a greater opportunity to deliver a unique, positive image for BRT (Polzin & Baltes, 2002) and to further differentiate these systems from the negative perceptions of conventional bus services (Jarzab, Lightbody, & Maeda, 2002). This has been the view that has been accepted, or at least, suggested by many as a definition of 'good' or 'successful' implementation of BRT (Hensher, Li, & Mulley, 2014). This includes outspoken advocates for BRTs, such as the New York-based Institute for Transportation & Development Policy (ITDP), who first published their *BRT Standard* in 2012, in an effort to settle the debate and create consensus on the “BRT Brand”. The *BRT Standard* favours a BRT service package that imitates the high-performance of BRT systems such as the Bogota TransMilenio, which has received the “Gold” appellation within their ranking system (ITDP, 2016).

A higher standard of definition of BRT, as per the first view, describes the objective of BRT as mimicking the high-capacity and high-quality characteristics of urban rail systems (Cervero, 2013). Some authors have described BRT as "in many respects … a rubber-tired light-rail transit (LRT), but with greater operating flexibility and potentially lower capital and operating costs" (Levinson, et al., 2003a). This comparison with urban rail has the consequence of dictating how BRT should look and function, with the end-goal of matching service quality (and therefore service features) of BRT systems with that of urban rail. This interpretation of BRT as a service mirroring urban rail systems has resulted in the creation of a "High-End BRT" service package composing of high-quality design and service features (Cervero, 2013).

The second view is an attempt to deliver on many of the performance enhancing aspects of BRT in a more cost-effective manner, and to a greater number of routes and service contexts. This view references the position of BRT as situated along a wide continuum between improved conventional bus services on one end, and rail-like rapid transit on the other (Hess, Taylor, & Yoh, 2005). The existence of a continuum among BRT systems can be observed through the myriad of ways that BRT systems across the world have combined various design elements into service packages (Hensher, Li, & Mulley, 2014). The TCRP-funded *Bus Rapid Transit Practitioner's Guide* has commented on the need for BRT to be designed to the specifications of individual routes and favours a contextual approach to designing service packages (Danaher, Levinson, & Zimmerman, 2007).

These views from the literature suggest that rather than a "single-technology" approach, that there is instead a continuum of BRT service packages with a wide range of implementation. At the upper-end of this BRT continuum is the "High-End BRT" service package, while BRT systems with minimally capital-intensive features and modest separation from mixed traffic also exist at the lower end (Cervero, 2013). A lower standard of BRT has led to the formulation of a "Low-End BRT" service package that emphasizes service flexibility and cost-effectiveness, and is sometimes referred to as "BRT Lite" (Cervero, 2013).

Considering that BRT systems represent a range spanning from lower-end to a higher-end implementation, there too exists a middle-ground where a BRT system may not enjoy the high-quality features of high-end BRT systems, but are also too physically intensive to be considered as BRT Lite. These systems generally incorporate the seven design components effectively, which enable a service quality and system capacity surpassing that of BRT Lite. While these systems are simply referred to as BRT in the literature, for the purposes of this paper, the service packages of these hybrid systems will be ascribed the moniker of "Moderate BRT".

Using the knowledge acquired through the literature review on BRT design components, the three BRT service packages have been mapped onto the seven design components in Table 2 below.

Table 2. BRT Service Packages

	BRT-Lite	**Moderate BRT**	**High-End BRT**
Running Ways	Shoulder bus lane, queue jumps at intersections	Median busway, traffic signal prioritization	Exclusive, and often grade-separated running way
Bus Stations	Sheltered stops, multi-door boarding	Dedicated stations, level boarding	Elaborate station design, presence of passing lanes
Vehicles	Conventional vehicle	Dedicated BRT vehicle	Dedicated articulated bus vehicle
Service Design	More traditional service designs	Medium Capacity, moderate to high frequency	High capacity, high frequency, high level of service integration
Fare Collection	More traditional fare collection	Use of smart cards, all-door boarding	Off-board fare collection
Branding	Limited branding	Dedicated branding distinct from other bus services	Strong branding, including dedicated livery
Intelligent Transportation Systems (ITS)	On-board electronic displays	Dynamic information displays at stations	Automated Vehicle Location (AVL), passenger information systems

The "High-End BRT" and "BRT Lite" service packages constitute the upper and lower range of BRT design and service, and were developed as a result of the inherent flexibility of the BRT mode and the ability of jurisdictions to hand-pick the BRT components that appeal to them (Hess, Taylor, & Yoh, 2005). These service packages have consequently arisen from the differing planning objectives that may arise as different jurisdictions consider how they implement their BRT system (Cervero, 2013). The context from which the high-end BRT and BRT Lite service packages were developed, and their appropriateness in design and implementation are considered below.

"High-End BRT" Service Package

The high-end BRT service package places significant emphasis on a performance and design outcome, deviation from which is actively discouraged as lesser quality or stripped-down features are seen as degrading the service level of BRT below that of its urban rail comparative (Racehorse, Parker, Sussman, Jian, & Zhang, 2015). This hard-line approach is on display with some authors suggesting that in order for BRT to represent a mode that is truly time-competitive with urban rail systems and private automobiles, an exclusive, dedicated running way is essential (Cervero, 2013).

The high-end BRT service package will typically include exclusive, dedicated running ways with traffic signal priority, off-board fare collection, all-door boarding, high-level of service frequency, dedicated articulated vehicles, strong branding, and more elaborate stations facilities.

The Institute of Transportation & Development Policy (ITDP) first published their *BRT Standard* in 2012, and has since updated the standard in "BRT Standard, 2016" (ITDP, 2016). This standard was created to develop a common definition of bus rapid transit and to recognize "high-quality" BRT corridors worldwide (ITDP, 2016). The *BRT Standard* is intended to serve as an evaluation tool for BRT corridors based on international best practices. The document was also created as a means of protecting the "BRT brand" and offering recognition to high-quality BRT corridors around the world (ITDP, 2016). According to ITDP, there was no common understanding of what constituted as BRT prior to the release of the *BRT Standard*, which had resulted in a lack of "quality control" where modest bus corridor improvements were branded as BRT (ITDP, 2016).

The *BRT Standard* ranks a BRT corridor based on a criterion and weighting system that assigns points derived from the inclusion of certain corridor design features or service operational standards (ITDP, 2016). Each feature of the *BRT Standard* is given a certain amount of points out of a hundred. The standard has four categories: "Gold" (85-100 points), "Silver" (70-84 points), "Bronze" (55-69 points) and "Basic BRT" (less than 55 points). Bronze, silver and gold rankings all reflect well-designed corridors that have achieved excellence (ITDP, 2016). A ranking of basic BRT signifies that the corridor meets the minimum criteria to qualify as BRT, but has not quite reached the same level of excellence as those that have received bronze, silver, or gold designations (ITDP, 2016). Point deductions also exist to penalize BRT schemes for poor performance in commercial speeds, service capacity, lack of enforcement of running ways, overcrowding, and low service frequencies (ITDP, 2016).

The establishment of the BRT Standard to evaluate BRT systems and monitor their adherence to the design principles of the high-end BRT service package demonstrates that this higher end BRT service is in the process of being institutionalized as the norm for practice. High-end BRT systems are effective for responding to operational contexts where BRT is expected to service high ridership corridors that necessitate higher levels of service. However, the necessity of dedicated, physical infrastructure such as stations and dedicated running ways, increases the costs per kilometre, as well as the difficulty of implementation in corridors with limited roadway space. The high-end BRT service package may provide for greater system capacity than is required on routes which do not anticipate high ridership. The high cost of implementation may discourage some systems from investing in BRT, while others may be forced to lower service frequencies to reduce costs.

"BRT Lite" Service Package

The second interpretation emphasizes the flexibility of BRT in addressing a range of urban transportation problems such as traffic congestion, travel time savings, and enhanced service reliability, comfort and safety (Deng & Nelson, 2011). Given the many applications for BRT, their inherent flexibility, and the ease of incremental implementation, transit agencies may adopt some, most, or all BRT components to match the level of service to travel demand, improve transit service quality, and attract new riders (Hess, Taylor, & Yoh, 2005). BRT can include minimally capital-intensive features (such as low floors, shoulder bus lanes, intersection queue jumps, and on-board electronic displays), moderately capital-intensive features (such as dynamic next-bus information displays at stops, median busways with limited or exclusive running ways, and traffic signal prioritization), as well as high-cost features (such as grade-separated running ways, off-board fare collection, articulated buses, and elaborate stations) (Hess, Taylor, & Yoh, 2005) (Cain, Flynn, McCourt, & Reyes, 2009).

The inherent flexibility of the BRT mode has lead to BRT schemes being described as consisting of a systematic combination of multiple design elements into a service packaging that work together to guarantee the efficiency and effectiveness of BRT systems. (Hidalgo & Muñoz, 2014) (Deng & Nelson, 2011). This suggests that there is no single-approach to designing BRT as might be suggested by the high-end BRT service package, and instead recognizes that BRT systems vary widely worldwide in implementation (Levine, Singer, Merlin, & Grengs, 2018).

This has given rise to the labelling of a BRT spectrum from “BRT Lite” at the lower end to the aforementioned “High-End BRT” at the upper end (Hensher, Li, & Mulley, 2014).

The BRT Lite service package is defined as including “basic BRT elements such as new station design, off-board fare collection, realtime information, and often new branding, but which does not provide dedicated ROW along the entire length of the route and signal priority that would allow faster, more reliable service” (Levine, Singer, Merlin, & Grengs, 2018).

While the BRT Lite service package describes a BRT design that is comprised of the minimal design elements and service features necessary for a system to be considered as a BRT system, this is not a necessarily unfavorable proposition. Even a modest degree of separation from mixed traffic conditions can greatly enhance service quality, capacity and general service operations when compared to conventional bus services (Nikitas & Karlsson, 2015). This systematic approach has helped to improve the user experience, capacity, productivity and the environmental performance of bus systems of many cities (Hidalgo & Muñoz, 2014).

Detaching BRT from the capitally-intensive infrastructure and physically separated running ways also result in substantial cost savings for cities that are constrained by budgets or external funding sources (Danaher, Levinson, & Zimmerman, 2007). BRT Lite systems provides flexibility to cities that are unwilling or unable to expropriate the necessary running ways to construct higher-end systems, but are able to appropriate an existing traffic lane for a dedicated bus lane. BRT Lite systems also do not necessarily require a dedicated running way throughout the entirety of the corridor, which provides additional service planning flexibility (Levine, Singer, Merlin, & Grengs, 2018).

BRT applications are designed to be appropriate to the market and the physical environment they serve (Levinson, et al., 2003a). Many examples of BRT implementation worldwide demonstrate systems having been designed as a response to accommodate specific local conditions and the needs of an urban area (Polzin & Baltes, 2002) (Hensher, Li, & Mulley, 2014). The BRT Lite service package provides an alternative for planners to improve service quality on corridors that may not have the ridership demand to justify investment in higher-end BRT services.

4.0 Research Design

Bus rapid transit systems operate under a broad spectrum of service and operational conditions. This paper first sought out to determine the definition of bus rapid transit systems, how they differentiated from conventional bus systems, and what were the design components that comprised BRT systems. Through the literature review, it was determined that BRT constituted a transportation mode separate from conventional buses, and that the defining characteristic of BRT systems was a separation from mixed-traffic conditions through the use of a dedicated running way.

Beyond the simple distinction of a separated running-way however, BRT as defined by the literature and as implemented worldwide, differentiated greatly from system-to-system in terms of performance and design. This necessitated further review of what design components comprised of BRT systems and how they were implemented. Seven design components were identified from the literature and were looked into further detail.

The varying degrees to how each of the seven design components may be implemented, as well as the wide range of combinations therein, raised the question of whether there was a "correct" design approach for BRT implementation. An analysis of how different planning objectives led to differing BRT implementation strategies resulted in the formalization of three BRT service packages, as follows: (1) high-end BRT; (2) moderate BRT; and (3) BRT Lite. These three service packages and their constituent design components were summarized in Table 2.

The methodology used in this paper is a combination of an inductive analytical approach and case study. An inductive approach was used in the preceding sections to analyze the findings of the literature review and to formalize the three BRT service packages. This is followed below with a case study approach (Section 5.0) to interpret the above findings with professional practice. The case study explored under what conditions or contextual environments could the three BRT service packages be able to achieve 'success' in implementation. Success was defined as whether the BRT system as implemented fulfilled the policy objectives of the project, and were reviewed for their appropriateness in design given the transportation and planning contexts of each city.

The purpose of the case study is to explore whether there was a "correct" design approach for implementing BRT systems. Three case studies of jurisdictions that had recently implemented BRT were chosen based on how closely their respective systems matched with each of the three identified BRT service packages. The following three cities were chosen for the case study: (1) Brisbane, Australia; (2) Rio de Janeiro, Brazil; and (3) Cleveland, United States.

5.0 BRT Implementation – An Overview of Practice

In the previous section, three BRT services packages were identified and summarized in Table 2. The BRT service packages were as follows: (1) High-End BRT; (2) Moderate BRT; and (3) BRT Lite. The three BRT service packages were identified as corresponding with different BRT planning objectives that resulted in different BRT design outcomes, and aligned with differing degrees of capital intensiveness. What remains uncertain is whether there is a “correct” design approach for BRT implementation that professionals engaged with the planning of BRT systems may follow.

In this section, three case studies were chosen to explore under what conditions or contextual environments could the three identified BRT service packages achieve ‘success’ in implementation. Success is defined as whether the BRT system as implemented fulfilled the planning objectives of the agency or government leading the project, and is being used as a means for evaluating the appropriateness of the BRT service package design for implementation.

The three cases were chosen for how closely their respective BRT systems matched with each of the identified BRT service packages. The city identified for the high-end, moderate, and BRT lite service packages were, in their respective order, Brisbane in Queensland, Australia, Rio de Janeiro in Rio de Janeiro, Brazil, and Cleveland in Ohio, USA.

5.1 “True BRT” - Designing for Excellence in Brisbane, Australia

Australia is noted as an early adopter of the BRT mode, with the first BRT route opening in 1982 in Adelaide. The Australian city that has attracted international recognition for one of the most successful BRT deployments in a developed economy however, is Brisbane, Australia. The Brisbane Busway is the largest BRT system in Oceania, with three BRT corridors running on 28-kilometres of mostly grade-separated right-of-way, and serving 356,800 passenger trips per day

(Centre of Excellence for BRT, 2019). The Brisbane Busway is also considered as one of the most successful mass transit systems on the continent (Nikitas & Karlsson, 2015).

The City of Brisbane is the capital of the state of Queensland, and is the third largest city in Australia with a population of 1.2 million inhabitants. The large and navigable Brisbane River meanders through the city presenting a barrier to mobility, even so, Brisbane is well-served by public transport, including trains, conventional buses, and river ferries. However, car-ownership remains high with more than 80% of households in Brisbane owning a vehicle, and remains the preferred mode of transportation (Mallqui & Pojani, 2017).

Brisbane's busway network was conceived in the mid-1990s as a scheme for improving travel times and lessening the congestion impacts of the Brisbane Transport bus fleet (Tanko & Burke, 2015). The municipal and state government at the time sought to build a public transport system that would complement Brisbane's existing heavy rail network and could be delivered as a cost-effective and rapid transit system (Brisbane City Council, 2017). The move to adopting BRT as the solution for Brisbane was partially inspired by a visit by municipal officials to the city of Ottawa in Canada to observe their BRT (Tanko & Burke, 2015). One reason why BRT was chosen over rail-based modes was due to an unwillingness of the independent Queensland Rail to share their rail corridor, and the associated high costs, forced transfer, and disruption to traffic a standalone LRT option would create (Tanko & Burke, 2015).

Once committed to, the project moved quickly through consultation, design, and construction stages. The first section completed was the Southeast Busway, which was proposed along what was a state government road within the South East Freeway's reserved land (Tanko & Burke, 2015). The South East busway was completed in 2001 with the aims of removing bus services from the adjacent South East Freeway, in reducing congestion for private vehicles, and with the intention of consolidating bus services in a corridor free from congestion (Clifton & Mulley, 2016). The South East busway introduced a fast, frequency, high capacity transit service adjacent to a freeway corridor, and improved bus services that travelled along the corridor, before they dispersed into the surrounding suburbs.

The Brisbane Busway network would continue to grow over the next ten years to consist of the Southeast Busway, the Northern Busway, and the Eastern Busway, spanning a total of 28-kilometres and comprising of 25 stations (Mallqui & Pojani, 2017). The busways include significant grade separation both above the surface street network, particularly along the Southeast Busway, as well as large underground sections in the central business district (CBD) and inner city (Mulley, Ma, Clifton, Yen, & Burke, 2016). The system reverts to bus-lanes and interfaces with mixed traffic through three intersections for around 400 metres total (Mulley, Ma, Clifton, Yen, & Burke, 2016). The busways are designed as two-lane rights-of-way that can support 80km/h travel throughout most of the network (Mulley, Ma, Clifton, Yen, & Burke, 2016).

The station stop-spacing on the Brisbane Busway averages to a stop every 1.1 kilometres, with passing lanes present at most stations (Mallqui & Pojani, 2017). The fares are based on distance, are paid on vehicles by smartcard, and are integrated with the rest of public transit system in Southeast Queensland (Mallqui & Pojani, 2017). The BRT buses are the same design as conventional buses, with a capacity of just 60 passengers per bus, though there are a handful of articulated buses with an 85 persons capacity (Mulley, Ma, Clifton, Yen, & Burke, 2016). The average bus commercial speed is 25km/h at peak periods. The quality of the vehicles are high and include air condition and priority seating (Mallqui & Pojani, 2017). The fast-moving vehicles on busways running on clean fuels has led to Brisbane to receive praise as one of the world's eco-friendliest BRT systems (Cervero, 2013).

The Brisbane Busways are serviced with multiple routes, including a mixture of all-stop and limited stop services, alongside a number of non-stop express services operating at peak hour (Clifton & Mulley, 2016). This operational flexibility is in large part due to the presence of passing lanes at most stations. The Brisbane Busway contains many routes that branch off the busway corridor to service the surrounding suburban areas, offering what is effectively a single-seat journey to many passengers (Mulley, Ma, Clifton, Yen, & Burke, 2016). This service design allows for a dense network of routes that service a wide area of the city that then coalesce into a single trunk corridor, reducing travel times and offering high-volume operations (Tanko & Burke, 2015).

The Brisbane Busways have significantly reduced travel times for passengers and is considered as competitive service (Currie, 2006). A study on Brisbane's Southeast Busway suggested ridership had increased by 40% in the first six months of operations (Deng & Nelson, 2011) and in carrying over 30 million trips per annum within two years of opening (Clifton & Mulley, 2016). The Brisbane Busways have been considered a patronage success as passenger levels across the system has grown to serve 105 million trips per annum (Currie & Delbosc, 2011).

The Brisbane Busway network has delivered fast, comfortable, and cost-effective urban mobility through the use of the "high-end BRT" service package, which includes a grade-separated running ways, rapid and frequent operations, and excellence in customer service (Nikitas & Karlsson, 2015).

A 2015 study found that the Southeast Busway was ranked eight in the world in terms of bus vehicle frequency, and the highest frequency segregated busway in the world (Brisbane City Council, 2017). The Southeast Busway carries 12,000 passengers per hour into the CBD during morning peak periods, which compares to around 6,500 passengers on rail lines approaching from the south, showing how the Brisbane Busways have in some respects, supplemented the role of rail within the Brisbane public transit network (Brisbane City Council, 2017). The appeal of the Brisbane Busways is also demonstrated by travel demand forecasting, which has projected the demand for bus travel in the Brisbane region to double between 2016 and 2041, growing to more than 730,000 bus passengers per day (Brisbane City Council, 2017).

In many respects however, the Brisbane Busway has become a victim of its own success. Critical parts of Brisbane's busway infrastructure have reached capacity and cannot accommodate significant growth. There are critical bottlenecks that significantly limit the effectiveness of BRT operations, including the short but vital connection on the Victoria Bridge that links the Southeast Busway and the Brisbane CBD. Even with dedicated bus lanes linking the busways, buses sit in queues and compete with other traffic at intersections (Brisbane City Council, 2017).

This congestion has impacted travel times and service reliability through this stretch. There are also a few network and operational inefficiencies embedded in the Brisbane Busway system. Low-frequency and low-patronage bus routes share the constrained inner parts of the busway network in peak periods, adding to congestion, while the current boarding and ticketing practices on busway stations, including single-door boarding and on-board fare collection, impacts dwell times and reduces network capacity (Brisbane City Council, 2017).

In order to address these pressing concerns, Brisbane's Lord Mayor announced the Brisbane Metro concept in 2016, which envisioned repurposing existing busway infrastructure to improve the public transport network in the inner-city and to accommodate significant additional growth (Brisbane City Council, 2017). The goals of the Brisbane Metro were to increase the capacity of the busway network, reduce bus congestion on the busway, improve travel times and reliability, deliver first-in first-out operations at stations, reduce the number of buses in the inner-city, and to expand services in the suburbs (Brisbane City Council, 2017). The Brisbane Metro is slated to commence construction in 2019 and is projected to be completed in 2022.

The Brisbane Metro plan seeks to retrofit the existing busway infrastructure to create two new high capacity lines, named "Metro 1" and "Metro 2", servicing the 18 existing busway stations. The plan would see the purchase of a new, dedicated bus fleet of 60 vehicles, each with the capacity of carry up to 150 passengers, alongside off-board fare collection, all-door and level-boarding, new and upgraded infrastructure, and improved service and operational changes (Brisbane City Council, 2017). In addition, a new state-of-the-art underground metro station would be built at the Cultural Centre, and the problematic Victoria Bridge would be converted to a 'green bridge' dedicated to metro and bus services, pedestrians, and cyclists (Brisbane City Council, 2017).

While the Brisbane Busway already operated towards the level of high-end BRT, the use of conventional buses, on-board fare collection, as well as the operational bottlenecks existing at critical junctures served as limitations to the system. The proposed Brisbane Metro remedies the limitations of the busway by taking advantage of a reliable and frequent trunk service to reduce vehicle congestion and dwell times at stations, improve busway capacity and travel time reliability, and to expand service throughout the system. Upon project completion, the Brisbane Metro will deliver a system that characterizes the very definition of the high-end BRT model.

Figure 1 –Operational context of Brisbane South East Busway corridor

Source: Cyron Ray Macey, (CC BY 2.0); https://commons.wikimedia.org/wiki/File:South-East_Busway,_Brisbane.jpg

Figure 2 – Brisbane Metro, Artistic impression of a metro vehicle

Source: Brisbane Metro Business Case Key Findings, May 2017 (Brisbane City Council, 2017).

5.2 “Moderate BRT” – The Middle-of-the-Road in Rio de Janeiro

The birthplace of the modern BRT system is typically considered to be South America, with the Brazilian city of Curitiba hailed as the "cradle of the BRT concept" (Hidalgo & Muñoz, 2014). Curitiba first experimented with BRT in 1963 with the introduction of priority measures, and in 1974 with those priority measures evolving into dedicated busways (Lindau, Hidalgo, & Facchini, 2010). It was not until 1982 however, when the Integrated Transit Network (RIT) scheme brought the addition of pre-board payment, multi-door and level-boarding, and articulated buses, introducing to the world the first modern BRT system (Lindau, Hidalgo, & Facchini, 2010).

In addition to being an early adopter of the BRT mode, the high-capacity and performance of Curitiba’s BRT system has contributed to Curitiba’s global influence as a best-practice city for BRT over the past 40 years (Lindau, Hidalgo, & Facchini, 2010). The success of the Curitiba model has been particularly influential in promoting the use of BRT systems throughout Brazil (Hidalgo & Muñoz, 2014). Following the lead of Curitiba, BRT systems have been introduced in many Brazilian cities, with over 12 cities now operating multiple BRT lines (Centre of Excellence for BRT, 2019).

The most recent wave of investment in mass transit in Brazil came in the wake of the 2014 FIFA World Cup and 2016 Olympic Games (Kassens-Noor, Gaffney, Messina, & Phillips, 2016). A major investment program to fund rail, bus, and cycling corridors and systems across the country was established in 2013, with a preference for schemes that would ensure a timely conclusion for the games (de Aragão, Yamashita, & Orrico Filho, 2016). As such, over 28 BRT projects were commenced across the country in the past decade, including several in the former capital city and host of the 2016 Olympic Games, Rio de Janeiro (de Aragão, Yamashita, & Orrico Filho, 2016).

The city of Rio de Janeiro has approximately 6 million inhabitants, and like many other cities in the Global South, is the result of decades of population growth and fragmented urban development (UN-HABITAT, 2010). Between the years 2012 and 2017, the city would launch the construction of a subway extension, a light rail system in the city centre, and four new BRT corridors (Pereira, 2019). These investments were motivated with a desire to provide shorter travel times, improve transit and employment access to low-income neighbourhoods, and to improve air quality (ITDP, 2013). In addition, there was a major desire to reduce the number of bus vehicles and routes in operation (de Aragão, Yamashita, & Orrico Filho, 2016).

The transportation context that the city of Rio de Janeiro was presented with in the first decade of the 21st century has been one of alarming increases in traffic congestion. From 2001 to 2011, Rio de Janeiro's automobile fleet grew by over 1 million, representing a 61 percent increase in total motorization (ITDP, 2013). The consequence on the streets of Rio de Janeiro was a significant increase in traffic congestion, with the average speed on the major transportation corridors declining from 27 km/h to 20 km/h between 2003 and 2012, with a further decline to 16 km/h projected by 2032 (ITDP, 2013).

The centre of Rio de Janeiro (the Centro, Copacabana, and Ipanema districts) benefits from access to the three subway lines of the MetrôRio system, but were in need of a more efficient surface public transit network to feed into and compliment the underground service (de Aragão, Yamashita, & Orrico Filho, 2016). There was also a desire to expand transit access and reduce commute times for lower-income neighbourhoods, in a bid to aid the city in overcoming its socially fragmented urban development patterns (Pereira, 2019).

The existing bus network in the city was largely operated by private bus companies who competed for service, resulting in an oversupply of both vehicles and service lines. The excess congestion and noise and air pollution produced from the oversupply of vehicles resulted in the degradation of vibrant street commerce areas (de Aragão, Yamashita, & Orrico Filho, 2016). In the face of growing congestion, pollution, and cost of motorized mobility, the city of Rio de Janeiro looked towards these sporting mega-events as an opportunity to invest in the city's transportation system.

BRTs emerged as the dominant urban mass transit solution for Rio de Janeiro in order to meet the transportation demands of the Olympic Games and due to their relatively low cost, speed of implementation, Brazilian best-practice knowledge, ease of land acquisition, and planning flexibility (Kassens-Noor, Gaffney, Messina, & Phillips, 2016). The preference for BRT investment in Rio de Janeiro also involved political considerations, including heavy lobbying from the bus industry and political expediency to deliver transit in-time for the Olympic Games (de Aragão, Yamashita, & Orrico Filho, 2016). The four BRT corridors were planned as physically separated bus lanes, platform-level boarding, off-board fare collection at all stations, by-pass lanes at stations, and wheelchair accessibility (ITDP, 2017). The TransOeste BRT opened in 2012, followed by the TransCarioca in 2014, and the TransOlímpica in 2016, while the TransBrasil remains an uncompleted project.

The TransOeste began revenue service in 2012 and was the first of Rio de Janeiro's four BRT corridors to open to the public. The TransOeste corridor spans 58-kilometres from the Santa Cruz neighbourhood in the northwest of the municipality, to the Jardim Oceânico Station at the far east of the Barra da Tijuca neighbourhood, providing an interchange with the expanded subway system (ITDP, 2013). The busway corridor largely operates within the road median of Avenida das Américas, the main thoroughfare of Rio’s southern coast (ITDP, 2013). The TransOeste, opened in stages, consists of 68 stations, and serves 240,000 passengers per day (Centre of Excellence for BRT, 2019). In their 2013 report, ITDP found that the TransOeste BRT had significantly improved mobility, emissions and passenger comfort within first 9 months of service (ITDP, 2013).

The TransCarioca was the second of the four planned BRT corridors enter revenue service when it opened in 2014 on the eve of the World Cup. The corridor spans 39-kilometres and connects the Alvorada terminal, at Barra da Tijuca where many of the Olympic Games venues were located, with Rio de Janeiro’s Tom Jobin International Airport. The corridor serves 216,000 daily passengers on 45 stations that connect 27 neighbourhoods of the North and West zones of the city (Centre of Excellence for BRT, 2019). ITDP Brazil found that TransCarioca was delivering significant benefits to its riders, including improved perceived quality of service, reduced travel times, emissions and costs (ITDP, 2015). A survey of passengers conducted by ITDP Brazil saw that the majority of trips (68%) were reported as journeys to or from work, highlighting the importance of the system for accessing employment opportunities for lower-income neighbourhoods (ITDP, 2015). The reduction of bus vehicles post-intervention also led to a reduction of carbon and particulate matter emissions, improving air quality along the corridor (ITDP, 2015).

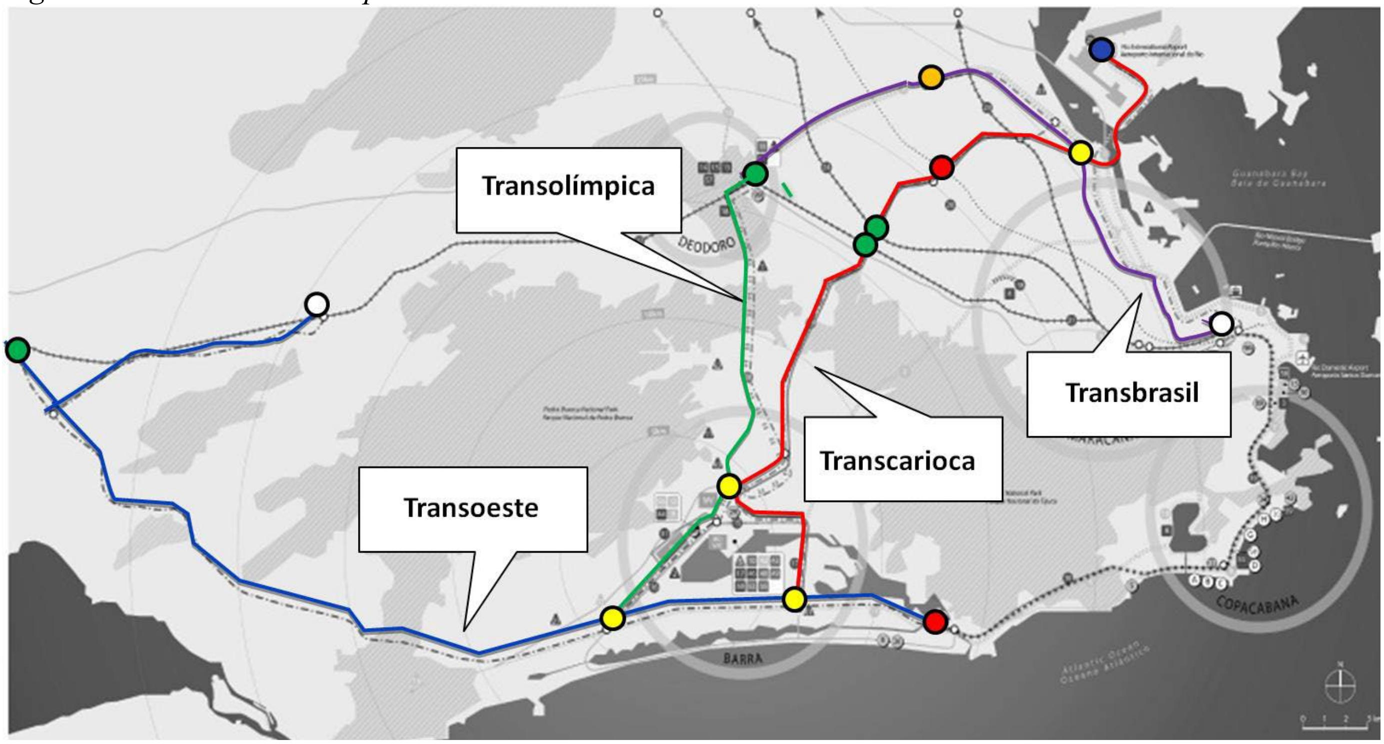
The third BRT corridor to open was the TransOlímpica BRT, which launched in August 2016 with 18 stations and 3 terminals (at Recreio, Centro Olímpico and Sulacap). The 26-kilometre-long system passes through 11 neighbourhoods, is projected to carry 70,000 daily passengers, and is purported to reduce travel times by up to 60% (ITDP, 2017). The TransOlímpica was an integral infrastructure piece in the bid for the 2016 Olympic Games, as it would provide a direct connection between Deodoro Olympic Complex and Barra da Tijuca Olympic Park. The corridor also connects with the two existing BRT lines, allowing flexibility for service route design that incorporates corridors from multiple BRT lines (ITDP, 2017). According to ITDP Brazil, the infrastructure of the line is of high quality, allowing high operating speeds (42km/h on average), dedicated passing lanes at stations, and express service operations (ITDP, 2017). Passengers can travel from one end of the corridor to another in approximately 30 minutes, and the buses run at a maximum of 12-minutes during off-peak hours (ITDP, 2017).

While the three other BRT corridors were fully or partially operational prior to the 2016 Olympic Games, the fourth BRT corridor remains uncompleted. The 26-station and 32-km long TransBrasil BRT project is considered as one of the most important pieces of promised transport infrastructure as it would have connected some of the most densely populated neighbourhoods with employment opportunities in the city centre (Pereira, 2019). However, complications arose when legal disputes with construction companies resulted in the suspension of work for over nine months in 2016. The municipality was subsequently hit with a severe economic crisis, which resulted in budget cuts and the continued delay of the project (Pereira, 2019). Despite the uncertain future of the project, the TransBrasil BRT project was expected to be the BRT corridor with the highest passenger demand, and would have brought benefits to up to 58% of the city population (Pereira, 2019).

The objectives of Rio de Janeiro's recent transit investments were to improve transit service and reduce commute times, to expand rapid transit service into low-income neighbourhoods, and to reduce the number of bus vehicles and routes in operations. The challenge that planners in Rio were faced with was a limited budget, and a constrained timetable to complete these BRT corridors in time for the sporting mega-events. The planners were cognizant that neither a rail-based or Curitiba inspired high-end BRT systems were feasible options due to the expensive and lengthy expropriation that would be necessary to build the corridor. The mayor of Rio de Janeiro revealingly stated in an interview in 2012 that "if we were planning only metros, we would still be planning because there is no money" (Kassens-Noor, Gaffney, Messina, & Phillips, 2016).

Given these constraints, the solution was to proceed with a middle-of-the-road approach, in a bid to shorten the construction time and costs. This included the appropriation of the right-of-way of existing arterial streets to build busway medians, instead of the separated busways as used in the BRT model of Curitiba (de Aragão, Yamashita, & Orrico Filho, 2016). While the fourth BRT corridor is still undelivered, the three completed busways have proven to be a cost-effective and successful approach in accomplishing the objectives of Rio's transit investments.

Figure 3 – BRT corridor map in Rio de Janeiro



Source: Secretary of Transportation, Rio de Janeiro, January 2013, via (ITDP, 2013).

Figure 4 – Operational context of BRT TransOlímpica corridor

Source: BRT TransOlimpica: Olympic Project Just Misses Gold BRT Standard Rating (ITDP, 2017).

5.3 "BRT Lite" – Simple but Effective Approach in Cleveland, Ohio

While there have been some early adopters of the BRT mode in North America (notably the cities Pittsburgh, Pennsylvania in the United States and Ottawa, Ontario in Canada), these schemes failed to catch the adoration of the public and municipal planners for a number of speculated reasons. Support for rapid transit expansion in the United States has in the latter part of the 20th century been focused towards rail-based systems, including subway expansions and investments in LRT technology (Weinstock, Hook, Replogle, & Cruz, 2011). For many decades, this was reinforced by the availability of federal funding for rail-based transit, which were not made available for bus-based rapid transit schemes until a change in policy in the late 1990s (Barker, Brosch, & Polzin, 2004).

It has also been suggested that there is public unwillingness to expropriate road space away from general traffic. According to Blumgart (2017), the notion of giving up a lane for cars, or a sizeable number of parking spaces, is a trade-off that few American cities are willing to make. There are also negative perceptions associated with conventional bus travel in North America due to the traditional "one-size-fits-all" conventional bus service that can be found throughout the United States (Jarzab, Lightbody, & Maeda, 2002). Advocates for BRT services in the United States must overcome the negative image of bus-based mobility if they are to attain the support of the public.

Nevertheless, with the worldwide spread and acceptance of BRT systems as a viable alternative for mass mobility, cities in the United States have begun investing in BRT as a cost-effective option with increasing frequency (Nikitas & Karlsson, 2015). As of 2018, there are over 20 cities which claim to have at least one BRT corridor, however, only eight cities have built lines that score high enough by ITDP to qualify as a BRT system (ITDP, 2016). Among them include the systems of Eugene, Oregon and Hartford, Massachusetts, which demonstrates that BRT is not restricted to just large population centres but can also be implemented in low-density suburban communities so long as project objectives for BRT are clearly defined (Racehorse, Parker, Sussman, Jian, & Zhang, 2015).

One of the most successful examples of BRT implementation in the United States is the HealthLine in Cleveland, Ohio. The HealthLine spans for 11.4-kilometres along the Euclid Corridor from the Cleveland Public Square in downtown Cleveland to Louis Stokes Station in

East Cleveland (GCRTA, 2019). However, the HealthLine is only segregated from mixed traffic for a distance of 7.2-kilometres between Cleveland Public Square and East 105th Street (Centre of Excellence for BRT, 2019). Consequently, the HealthLine can only be considered as a BRT for 7.2-kilometres of its service span. The naming rights to the BRT corridor were sold by the municipality to Cleveland Clinic and University Hospital for $6.75 million in funding that was then dedicated towards a 25-year maintenance plan, thus resulting in the HealthLine name (Nikitas & Karlsson, 2015).

The Euclid Avenue Corridor is one of the oldest areas of Cleveland. Prior to the Euclid Corridor Transportation Project, the most recent redevelopment occurred in the 1960s as large areas of the corridor were cleared as part of urban renewal programs to revitalize Downtown Cleveland and to encourage development of University Circle (GCRTA, 2019). The Greater Cleveland Regional Transit Authority (GCRTA) and the City of Cleveland in the following four decades studied various transit options on the corridor, as technical analysis and community discussion indicated the need for improved mobility on Euclid Avenue (GCRTA, 2019). This culminated in a 1995 decision that the most cost-effective solution for providing high-capacity transit service on the corridor was a BRT scheme, which would become the Cleveland HealthLine (Weinstock, Hook, Replogle, & Cruz, 2011).

The objectives of the HealthLine according to the GCRTA were three-fold (GCRTA, 2019). First, it was to improve public transit service for users by increasing the efficiency of the system. There was a specific desire to reduce congestion and travel time for transit users along Euclid Avenue, where the busiest bus routes in Cleveland were located (Nikitas & Karlsson, 2015). The second objective was to promote long-term economic and community development and growth adjacent to the Euclid Avenue corridor, with a focus on targeting private economic development (GCRTA, 2019). The third objective was to improve the quality of life for those visiting, working, or living in the Euclid Avenue corridor. This would include improvements to the pedestrian environment, increasing regional access to employment, education, and healthcare, and improving the regional air quality along the Euclid Avenue corridor (GCRTA, 2019).

The project details for the Euclid corridor were finalized in 1999 following public consultation. The total budget for the project was approximately $200 million, though this included substantial corridor improvements such as roadways, utilities, new sidewalks, and street furniture (GCRTA, 2019). Of the $200 million, only $50 million was allocated for buses and stations, meaning that the HealthLine was built at a cost of about $7 million per mile, including rolling stock (Weinstock, Hook, Replogle, & Cruz, 2011). The HealthLine BRT began operation on October 24th, 2008.

The operational plan for the HealthLine involved converting the existing bus line on Euclid Avenue into an upgraded service with new articulated BRT buses operating mostly within a newly constructed segregated running way for 7.2-kilometres of the corridor using both median and shoulder alignments (Nikitas & Karlsson, 2015). Other bus routes which previously operated on the corridor would continue to do so as the original low-floor vehicles were compatible with the station stops of the HealthLine (Nikitas & Karlsson, 2015). The system interfaces with mixed-traffic conditions at intersections. There were originally signal priority measures at intersections to ensure green-light traffic cycles for the HealthLine, but this was removed weeks following opening due to complaints from drivers about long red-light cycles (Schmitt, 2014).

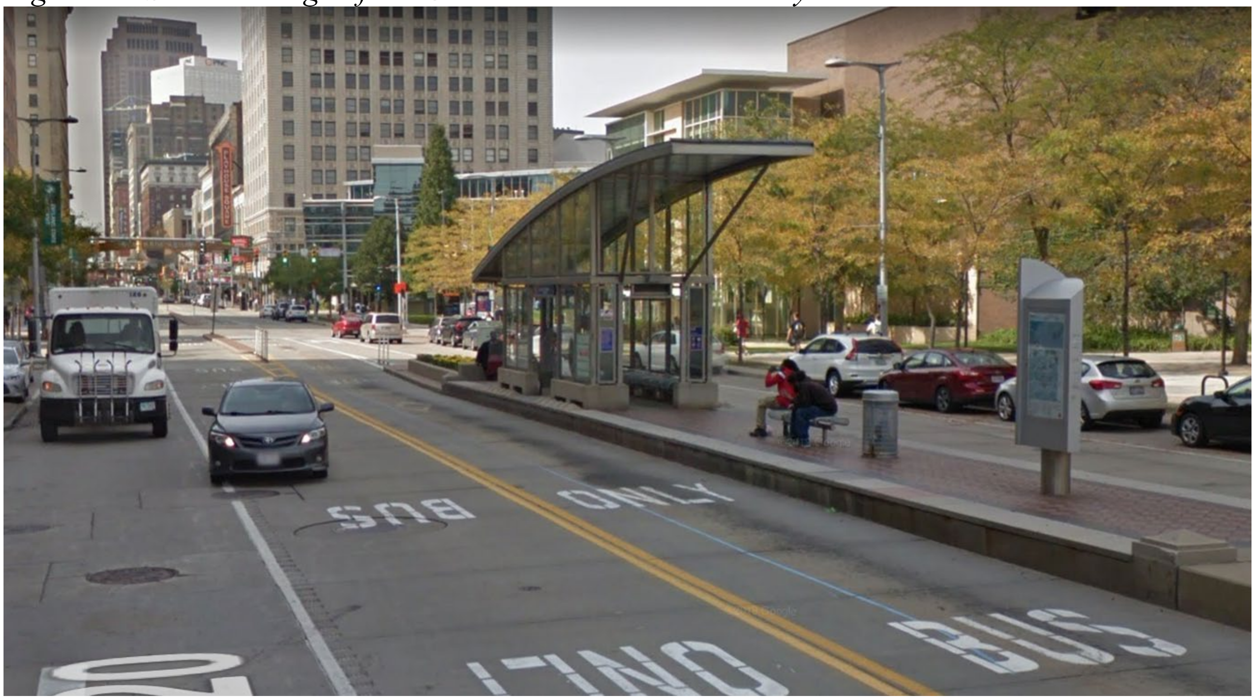
The stations for the HealthLine are a sheltered-stop design, but allows for level-boarding with the vehicle and off-board fare collection, and include a host of amenities such as seating and vending machines (Weinstock, Hook, Replogle, & Cruz, 2011) (GCRTA, 2019). The specialty-designed HealthLine bus vehicles allow for multi-door boarding, include digital displays, have a capacity of approximately 50 passengers, and make use of green hydro-electric technology to reduce carbon emissions (GCRTA, 2019). The HealthLine has also received praise from accessibility advocates for equipping the buses with sensors enabling them to pull into the station platform to ease boarding, especially for disabled passengers (Schmitz, 2013).

The HealthLine BRT is generally considered to be a major success for BRT implementation in the United States (Schmitz, 2013). Prior to the system opening, the average bus speed on the corridor was only 15 km/h and it would a 46-minute trip to traverse the corridor (Weinstock, Hook, Replogle, & Cruz, 2011). Following the intervention, the bus speed increased by 34%, averaging 20 km/h on the corridor, and traversing the corridor now takes 34 minutes, with the grade-separated section taking just 20 minutes (Schmitz, 2013). The HealthLine operates 24 hours a day, with bus frequencies of seven to ten throughout much of the day (Schmitz, 2013). Ridership on the Euclid Corridor increased by 60 percent after two years of operation (Nikitas & Karlsson, 2015) and the Cleveland Healthline now serves 15,000 passenger trips per day (Centre of Excellence for BRT, 2019). Additionally, the investment into the HealthLine has spurred nearly $4.3 billion in real estate investment and economic development along the Euclid Avenue corridor, according to a 2013 report (Nikitas & Karlsson, 2015).

The Cleveland HealthLine BRT is an example of how the BRT Lite service package can be effectively deployed. While the HealthLine does have some higher-end BRT design elements, such as off-board fare collection and level-boarding, the use of shoulder bus lanes, lack of physical separation from mixed-traffic, the modest service frequencies, and the absence of signal prioritization measures at intersections prevent the HealthLine from achieving the service levels featured by other international BRT systems. Further, the decision to eliminate signal priority measures at intersections is a significant black mark on the system.

However, the Cleveland HealthLine was never designed to be comparable in productivity, efficiency, or scale of the BRT schemes of cities like Curitiba or Bogotá (Nikitas & Karlsson, 2015). The objectives of the project as stated by the GCRTA were more modest in character, and were delivered by the BRT Lite service package offered by the HealthLine corridor design (GCRTA, 2019). Despite the relatively simple design, the Cleveland HealthLine has been considered by the ITDP as the most successful example of BRT implementation in the United States (Nikitas & Karlsson, 2015) and considered by some as "the best bus rapid transit project in the country" (Schmitt, 2014), further demonstrating the potential for the BRT Lite service package in the American context.

Figure 5 – Station Design of the Cleveland HealthLine busway



Source: Google Maps, via https://goo.gl/maps/uhHZfDnQ6PA2.

Figure 5 – Operational context on the Cleveland HealthLine corridor

Source: NACTO Urban Street Design Guidelines, Euclid Avenue BRT, Cleveland, OH.

5.4 Discussion

The above three case studies were an opportunity to review whether there was a “correct” design approach for implementing BRT systems. The three case studies of Brisbane, Rio de Janeiro, and Cleveland were selected for how closely their respective BRT systems matched with each of the three identified BRT service packages. Each of the three cases established how the three BRT service packages can be effectively implemented under the appropriate transportation and planning contexts. Some insights about BRT implementation are discussed below.

The first system that was reviewed was the Brisbane Busway in Brisbane, Australia. The Brisbane Busways are notable for being internationally recognized as one of the most successful BRT deployments in a developed economy, as well as the largest BRT system in Oceania. It was found that the Brisbane Busway closely resembled the high-end BRT service package in many respects, including notably, an expensive grade-separated right-of-way for the majority of its route that included above, below, and at-grade sections. However, the Brisbane Busways have become a victim of its own success. The high ridership levels and service frequencies highlighted the limitations of the system, including the use conventional buses, on-board fare collection, and operational bottlenecks at critical junctures of the system including the vital crossing at the Victoria Bridge.

These conditions resulted in a 2016 decision by Brisbane City Council to approve a major capital-investment in the system to remedy these limitations in the form of the proposed Brisbane Metro. The decision to invest in the Brisbane Metro system demonstrated that within the Brisbane context, the high level of patronage and service demanded by the system necessitated a BRT design with the high capacity and performance of the high-end BRT service package.

The second system that was reviewed were the BRT corridors of Rio de Janeiro, the former capital city of Brazil. The three complete (and fourth to-be-delivered) BRT corridors were proposed and constructed to meet the transportation demands imposed by the 2014 World Cup and 2016 Olympic Games. The planners were challenged to deliver a mass transit system that would meet the needs of the city while delivering the project on a limited budget and constrained timeline. Under these circumstances, neither a rail-based or high-end BRT system as popularized in other Brazilian cities were feasible options due to the expensive and lengthy expropriation that would be necessary. The solution sought were four BRT corridors that would be constructed through the appropriation of right-of-way on existing arterial streets in order to build busway medians rather than grade-separated busways. The three constructed BRT corridors, the TransOeste (2012), TransCarioca (2014), and TransOlímpica (2016) were designed with a moderate BRT service package that included a physically separated busway median, platform-level boarding, and off-board fare collection.

Alongside their timely completion prior to the games, the BRT corridors also delivered on the objectives of the project, which included a reduction of the bus vehicle fleet, improved transit service, significant reductions in commute time, and the expansion of rapid transit service to low-income neighbourhoods. The design of the moderate BRT service package allowed the cost-effective implementation of a BRT system in Rio de Janeiro to achieve many of the planning objectives of the city, while not compromising the performance goals sought by higher-end BRT systems.

The third case study that was reviewed was a North American example of BRT implementation found in the city of Cleveland, Ohio. The Cleveland HealthLine spans for 11.4-kilometres along the Euclid corridor, and has been hailed as one of the most successful examples of BRT implementation in the United States. The objectives of the Euclid Avenue Transportation Project were to improve transit service, reduce congestion and travel time, and promote long-term economic development along the corridor. The Cleveland HealthLine scheme involved converting the existing bus line on Euclid Avenue into a segregated running way using median and shoulder alignments for 7.2-kilometres of the corridor, as well as other performance measures such as level-boarding, off-board fare collection and increased service frequency. These measures resulted in the substantial reduction of commuter times, improvement to service quality, and increase in ridership when compared to the previous route.

The Cleveland HealthLine is an example of how the BRT Lite service package can be an effective intervention for cities to consider in order to improve the quality of service of existing conventional bus routes while meeting various planning objectives. The service package of the Healthline is unable to attain the service levels and performance of other international examples of BRT systems which feature qualities of the high-end BRT service package. However, the HealthLine system was never designed to be comparable in productivity, efficiency, or scale of those other BRT schemes. The objectives of the project design were more modest in character, and were supported by the ridership levels anticipated in Cleveland (Weinstock, Hook, Replogle, & Cruz, 2011).

6.0 Conclusion

Bus rapid transit systems operate under a broad spectrum of service and operational conditions. This paper used a combination of an inductive analytical approach and case study to determine whether there was a "correct" design approach for BRT implementation. There are three important lessons arising from this analysis, which can be learned from the range of BRT implementations employed worldwide and the three case studies reviewed in the preceding section.

The first lesson gleaned from this analysis is that regardless of the BRT service package employed, BRT systems are designed to operate much faster, more reliably, and with greater capacity than conventional bus systems (Jarzab, Lightbody, & Maeda, 2002). This is largely attributed to the benefits gained from separating BRT vehicles from operating in mixed traffic conditions, which was determined through the literature review to be the defining distinction between conventional bus service and BRT systems.

Indeed, the three case studies demonstrated how each of the three BRT service packages can be implemented effectively to improve transit performance and service quality. The example of the Cleveland Healthline in particular, demonstrates how a system employing the BRT Lite service package, which is situated at the lower-end of the BRT spectrum and lacking many qualities found in high-end BRT systems, has greatly outperformed the pre-existing conventional bus route in terms of speed, reliability, capacity, and comfort, resulting in a significant increase in service ridership and system prestige.

The effectiveness of BRT systems compared to conventional bus services, regardless of the service package employed, is an important consideration for planning practitioners to recognize. The establishment in recent years of various BRT design guidelines and standards for the purposes of evaluating BRT systems based on their adherence to the design principles of the high-end BRT service package, has demonstrated that high-end BRT systems are in the process of being institutionalized as the norm for practice. The institutionalization of high-end BRT undercuts the potential that BRT systems situated at the lower end of the spectrum can present to municipalities looking to improve the performance and service quality of their transit systems. Moreover, the higher cost of implementing the high-end BRT service package may discourage some municipalities from investing in BRT.

The second important lesson for planning practitioners is that the inherent flexibility of BRT system design allows for incremental enhancements to the system, with operational and corridor improvements made possible as the passenger demands, finances, and political will for upgrade arise. This is in contrast to rail-based modes, where the specialized tracks, vehicles, electrical infrastructure and storage facilities necessitate a large up-front capital investment that is then difficult or costly to move or alter.

This allows for scenarios such as in the Brisbane case study, where policy-makers moved ahead with the decision to invest in a system at the very high-end of the BRT spectrum once demand grew to justify the investment. The Brisbane Busways were introduced in 2001 and the Brisbane Metro is projected to open in 2022, spanning a 21-year period where planners and policy-makers were able to study how travel behavior and demand responded to the intervention of the busways, and to identify critical nodes that required specialized interventions. This informed the next phase of investments as shown by the planned conversion of the Victoria Bridge into a transit mall or 'green bridge', in order to provide transit priority and eliminate congestion on this vital connection.

The third lesson for planning practitioners is that BRT design is scalable to a wide array of operating and ridership contexts. The flexibility of BRT design allows for jurisdictions to align the seven design components of BRT to meet the operational and planning context of the corridor. High-end BRT service packages for instance, are effective for responding to operating contexts where BRT is expected to service high-ridership corridors that necessitate higher levels of service. Meanwhile, a BRT using the BRT Lite service package is scalable to corridors where the high-end BRT would have provided greater system capacity than is required.

This scalability allows BRT to be designed to the operating and ridership contexts of smaller municipalities and lower demand corridors (such as suburban arterial roads), which are not often the target of rapid transit investment. The BRT Lite service package is able to deliver on many of the performance objectives sought by rapid transit while keeping the costs per kilometre relatively low for municipalities. There can even be great advantages for municipalities investing in BRT Lite, as in the case of the Cleveland HealthLine where nearly $4.3 billion in private investment and economic development has been spurred by the investment in BRT (Schmitz, 2013).

This paper sought out to determine whether there was a “correct” design approach for BRT implementation. Three service packages spanning the spectrum of BRT design and implementation were identified and studied through case studies. Despite their differences in design, all three service packages were examples of successful BRT systems given their respective operating and planning contexts. It is essential therefore, for transportation planners and public officials engaged with the design and delivery of BRT systems to be primarily concerned with determining the needs and desired outcomes of the project, as opposed to which “technology package” to deliver.

7.0 References

Barker, W. G., Brosch, G., & Polzin, S. E. (2004). Issues Related to Federal Funding of Bus Rapid Transit. *Transportation Research Record: Journal of the Transportation Research Board, 1884*(1), 10-17. doi:10.3141/1884-02

Blumgart, J. (2017, July). Nothing lite about it. *Journal of the American Planning Association, 83*(7), pp. 36-40. Retrieved from http://ezproxy.lib.ryerson.ca/login?url=https://search.proquest.com/docview/1923949159?accountid=13631

Brisbane City Council. (2017). *Brisbane Metro Business Case (May 2017).* Brisbane: City of Brisbane. Retrieved from https://www.brisbane.qld.gov.au/traffic-transport/public-transport/brisbane-metro

Cain, A., Flynn, J., McCourt, M., & Reyes, T. (2009). *Quantifying the Importance of Image and Perception to Bus Rapid Transit.* National BRT Institute, U.S. Department of Transportation. Washington, D.C.: Federal Transit Administration. doi:FL-26-7109-03

Carey, G. N. (2002). Applicability of Bus Rapid Transit to Corridors with Intermediate Levels of Transit Demand. *Journal of Public Transportation, 5*(2), 97-113. doi:10.5038/2375-0901.5.2.5

Centre of Excellence for BRT. (2019, January 18). *Global BRTData*, 3.43. Retrieved February 1, 2019, from BRTData: https://brtdata.org

Cervero, R. (2013). *Bus Rapid Transit (BRT) - An Efficient and Competitive Mode of Public Transport.* Berkeley, California: ACEA. Retrieved from https://www.acea.be/uploads/publications/20th_SAG_HR.pdf

Clifton, G. T., & Mulley, C. (2016). A historical overview of enhanced bus services in Australian cities: What has been tried, what has worked? *Research in Transportation Economics, 59*, 11-25. doi:10.1016/j.retrec.2016.07.009

Currie, G. (2006). Bus Rapid Transit in Australasia: Performance, Lessons Learned and Futures. *Journal of Public Transportation, 9*(3), 1-22. doi:10.5038/2375-0901.9.3.1

Currie, G., & Delbosc, A. (2011). Understanding bus rapid transit route ridership drivers: An empirical study of Australian BRT systems. *Transport Policy, 18*(5), 755-764. doi:10.1016/j.tranpol.2011.03.003

CUTA. (2007). *Bus Rapid Transit: A Canadian Perspective.* Toronto: Canadian Urban Transit Association.

Danaher, A., Levinson, H. S., & Zimmerman, S. L. (2007). *Report 118: Bus Rapid Transit Practitioner's Guide.* Transit Cooperative Research Program (TCRP). Washington D.C.: Transportation Research Board. Retrieved from https://nacto.org/docs/usdg/tcrp118brt_practitioners_kittleson.pdf

de Aragão, J., Yamashita, Y., & Orrico Filho, R. (2016). BRT in Brazil: Designing services in function of given infrastructure projects or designing infrastructure in function of established service quality patterns? *Research in Transportation Economics, 59*, 304-312. doi:10.1016/j.retrec.2016.07.008

Deng, T., & Nelson, J. D. (2011). Recent Developments in Bus Rapid Transit: A Review of the Literature. *Transport Reviews, 31*(1), 69-96. doi:10.1080/01441647.2010.492455

Diaz, R. B., & Hinebaugh, D. (2004). *Characteristics of Bus Rapid Transit for Decision-Making.* United States Department of Transportation. Washington D.C.: Federal Transit Administration. doi:FTA-VA-26-7222-2004.1

GCRTA. (2019). *RTA Healthline - Euclid Corridor Transportation Project*. Retrieved from Rtahealthline.com: http://www.rtahealthline.com/project-overview.asp

Harrington, K., & De Leuw. (1937). *Chicago "L".org: Transit Plans - 1937 Plan*. Retrieved February 01, 2019, from Chicago-l.org: http://www.chicago-l.org/plans/1937plan.html

Hensher, D. A., & Golob, T. F. (2008). Bus rapid transit systems: a comparative assessment. *Transportation, 35*(4), 501-518. doi:10.1007/s11116-008-9163-y

Hensher, D. A., Li, Z., & Mulley, C. (2014). Drivers of bus rapid transit systems – Influences on patronage and service frequency. *Research in Transportation Economics, 48*, 159-165. doi:http://dx.doi.org/10.1016/j.retrec.2014.09.038

Hess, D. B., Taylor, B. D., & Yoh, A. C. (2005). Light Rail Lite or Cost-Effective Improvements to Bus Service? *Transportation Research Record: Journal of the Transportation Research Board, 1927*(1), 22-30. doi:10.1177/0361198105192700103

Hidalgo, D. (2005). Comparing transit alternatives after recent developments in BRT in Latin America. *Transportation Research Board Annual Meeting.* Washington DC.

Hidalgo, D., & Carrigan, A. (2010). *Modernizing Public Transportation - Lessons Learned from major bus improvements in Latin America and Asia.* EMBARQ. World Resource Institute.

Hidalgo, D., & Gutiérrez, L. (2013). BRT and BHLS around the world: Explosive growth, large positive impacts and many issues outstanding. *Research in Transportation Economics, 39*(1), 8-13. doi:10.1016/j.retrec.2012.05.018

Hidalgo, D., & Muñoz, J. (2014). A review of technological improvements in bus rapid transit (BRT) and buses with high level of service (BHLS). *Public Transport, 6*(3), 185-213. doi:10.1007/s12469-014-0089-9

Hidalgo, D., Voukas, Y., Freiberg, G., & Alveano, S. (2010). The macrobus system of Guadalajara: An evolved concept in BRT planning and implementation for medium capacity corridors. *First NACTO BRT Workshop.* New York City. Retrieved from https://wagner.nyu.edu/files/rudincenter/Hidalgo.pdf

Hodgson, P., Potter, S., Warren, J., & Gillingwater, D. (2013). Can bus really be the new tram? *Research in Transportation Economics, 39*(1), 158-166. doi:10.1016/j.retrec.2012.06.009

ITDP. (2013). *Impact Analysis of Transoeste Bus Rapid Transit System in Rio de Janeiro.* New York: Institute for Transportation and Development Policy.

ITDP. (2015, May 11). *ITDP Brazil Survey Finds TransCarioca BRT Reduces Travel Times, Cuts Costs -*. Retrieved from Institute for Transportation and Development Policy: https://www.itdp.org/2015/05/11/itdp-brazil-survey-finds-transcarioca-brt-reduces-travel-times-cuts-costs/

ITDP. (2016). *The BRT Standard, 2016.* New York: Institute for Transportation and Development Policy. Retrieved from https://www.itdp.org/2016/06/21/the-brt-standard/

ITDP. (2017, September 27). *BRT TransOlimpica: Olympic Project Just Misses Gold BRT Standard Rating*. Retrieved from Institute for Transportation and Development Policy: https://www.itdp.org/2017/09/27/transolimpica-misses-gold-brt-rating/

Jarzab, J., Lightbody, J., & Maeda, E. (2002). Characteristics of Bus Rapid Transit Projects: An Overview. *Journal of Public Transportation, 5*(2), 31-46. doi:10.5038/2375-0901.5.2.2

Jiang, Y., Zegras, C., & Mehndiratta, S. (2012). Walk the line: station context, corridor type and bus rapid transit walk access in Jinan, China. *Journal of Transport Geography, 20*(1), 1-14. doi:10.1016/j.jtrangeo.2011.09.007

Kassens-Noor, E., Gaffney, C., Messina, J., & Phillips, E. (2016). Olympic Transport Legacies: Rio de Janeiro's Bus Rapid Transit System. *Journal of Planning Education and Research, 38*(1), 13-24. doi:10.1177/0739456x16683228

Lan, W., Xuewu, C., & Tao, L. (2015). Additional Riderships Estimation under Different Configurations of Bus Rapid Transit System. *Mathematical Problems in Engineering*, 1-7. doi:http://dx.doi.org/10.1155/2015/406545

Levine, J., Singer, M., Merlin, L., & Grengs, J. (2018). Apples to apples: Comparing BRT and light rail while avoiding the "BRT-Lite" trap. *Transport Policy, 69*, 20-34. doi:10.1016/j.tranpol.2018.05.015

Levinson, H., Zimmerman, S., Clinger, J., Gast, J., Rutherford, S., & Bruhn, E. (2003b). *Volume 2: Implementation Guidelines for Bus Rapid Transit.* Transit Cooperative Research Program (TCRP) Report 90. Washington D.C.: Transportation Research Board. Retrieved from https://nbrti.org/wp-content/uploads/2017/05/tcrp_rpt_90v2.pdf

Levinson, H., Zimmerman, S., Clinger, J., Rutherford, S., Cracknell, J., & Soverman, R. (2003a). *Volume 1: Case Studies in Bus Rapid Transit.* Transit Cooperative Reseach Program (TCRP) Report 90. Washington D.C.: Transportation Research Board. Retrieved from https://nbrti.org/wp-content/uploads/2017/05/tcrp_rpt_90v1.pdf

Lindau, L., Hidalgo, D., & Facchini, D. (2010). Bus Rapid Transit in Curitiba, Brazil. *Transportation Research Record: Journal of the Transportation Research Board, 2193*(1), 17-27. doi:10.3141/2193-03

Mallqui, Y., & Pojani, D. (2017). Barriers to successful Bus Rapid Transit expansion: Developed cities versus developing megacities. *Case Studies on Transport Policy, 5*(2), 254-266. doi:10.1016/j.cstp.2017.01.004

Mulley, C., Ma, L., Clifton, G., Yen, B., & Burke, M. (2016). Residential property value impacts of proximity to transport infrastructure: An investigation of bus rapid transit and heavy rail networks in Brisbane, Australia. *Journal of Transport Geography, 54*(1), 41-52. doi:10.1016/j.jtrangeo.2016.05.010

Nikitas, A., & Karlsson, M. (2015). A Worldwide State-of-the-Art Analysis for Bus Rapid Transit: Looking for the Success Formula. *Journal of Public Transportation, 18*(1), 1-33. doi:10.5038/2375-0901.18.1.3

Pereira, R. (2019). Future accessibility impacts of transport policy scenarios: Equity and sensitivity to travel time thresholds for Bus Rapid Transit expansion in Rio de Janeiro. *Journal of Transport Geography, 74*, 321-332. doi:10.1016/j.jtrangeo.2018.12.005

Polzin, S., & Baltes, M. (2002). Bus Rapid Transit: A Viable Alternative? *Journal of Public Transportation, 5*(2), 47-69. doi:10.5038/2375-0901.5.2.3

Racehorse, V., Parker, T., Sussman, A., Jian, A., & Zhang, G. (2015). Bus rapid transit system deployment for high quality and cost-effective transit service: a comprehensive review and comparative analysis. *IET Intelligent Transport Systems, 9*(2), 175-183. doi:10.1049/iet-its.2013.0176

Schmitt, A. (2014, June 12). *The Ridiculous Politics That Slow Down America's Best BRT Route*. Retrieved from Streetsblog USA: https://usa.streetsblog.org/2014/06/12/the-ridiculous-politics-that-slow-down-americas-best-brt-route/

Schmitz, J. (2013, June 20). *Cleveland's HealthLine has boosted transit ridership and development*. Retrieved from McClatchy - Tribune Business News: http://ezproxy.lib.ryerson.ca/login?url=https://search-proquest-com.ezproxy.lib.ryerson.ca/docview/1369743331?accountid=13631

Tanko, M., & Burke, M. (2015). Why busways? Styles of planning and mode-choice decision-making in Brisbane's transport networks. *Australian Planner, 52*(3), 229-240. doi:10.1080/07293682.2015.1047873

UN-HABITAT. (2010). *State of the World's Cities 2010/2011- Cities for All: Bridging the Urban Divide.* UN-HABITAT. Retrieved from http://unhabitat.org/books/ state-of-the-worlds-cities-20102011-cities-for-all-bridging-the-urban-divide/

Vuchic, V. (1981). Urban public transportation. In V. Vuchic, *Systems and Technology* (p. 560). Englewood Cliffs, NJ: Prentice-Hall.

Weinstock, A., Hook, W., Replogle, M., & Cruz, R. (2011). *Recapturing Global Leadership in Bus Rapid Transit: A survey of select U.S. Cities.* New York: ITDP. Retrieved from https://www.itdp.org/2011/05/26/recapturing-global-leadership-in-bus-rapid-transit-a-survey-of-select-u-s-cities/

Wright, L., & Hook, W. (2007). *Bus Rapid Transit - Planning Guide.* New York: Institute for Transportation & Development Policy (ITDP). Retrieved from https://www.itdp.org/wp-content/uploads/2014/07/Bus-Rapid-Transit-Guide-Complete-Guide.pdf