BUS RAPID TRANSIT: THEORY AND PRACTICE IN THE UNITED STATES AND ABROAD

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Carlos Campo

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BUS RAPID TRANSIT: THEORY AND PRACTICE IN THE UNITED STATES AND ABROAD

Approved by:

Dr. Michael D. Meyer, Advisor
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Laurie A. Garrow,
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Jiawen Yang,
School of City and Regional Planning
Georgia Institute of Technology

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LIST OF ABBREVIATIONS

AVL	Automatic Vehicle Location
BRTCLASS	Bus Rapid Transit Classification Score
BRTECSS	Bus Rapid Transit Element Classification Score Share
BRT	Bus Rapid Transit
CII	Coverage Intensity Index
CBRT	Characteristics of Bus Rapid Transit
CDM	Clean Development Mechanisms
CV	Coefficient of Variation
FTA	Federal Transit Administration
HDI	Human Development Index
ITDP	Institute for Transport and Development Policy
ITS	Intelligent Transportation Systems
IVTT	In-Vehicle Travel Time
HRT	Heavy Rail Transit
KPI	Key Performance Indicators
LRT	Light Rail Transit
LRL	Light Rail Lite
NGO	Non-governmental organization
O&M	Operations and Maintenance
PM	Particulate Matter
PPP	Public-Private Partnerships
PV	Present Value
RBS	Regular Bus Transit
THEMP	Theoretical Market Penetration
TCRP	Transit Cooperative Research Program
TOD	Transit Oriented Development
TCQSM	Transit Capacity and Quality of Service Manual
TDM	Transportation Demand Management
TRB	Transportation Research Board
TSP	Traffic Signal Priority

SUMMARY

BRT Bus Rapid Transit (BRT) is a relatively new mode with a wide range of applications that are still not well understood. Its explosive growth in developing and developed countries has increased its exposure but has led to mostly experimental implementation with mixed results. Therefore, better understanding about the reasons behind BRT implementation success and shortcomings is needed. The objective of this thesis is to evaluate the state of BRT planning under different contexts by assessing how background theory and practical implementation of BRT systems compare. The main analysis methods are comprised of a critical literature review and a case study approach.

The thesis begins with a literature review of the characteristics of BRT systems and how these relate to performance in terms of operations, cost, and sustainability, as well as some findings about its implementation. Chapter 3 then reviews the major planning guidelines for the US and for developing countries, compares them to find common ground, and contrasts their scope and methods. These guidelines were found to be a major step forward in planning but still suffer from regional bias and the lack of a sounder theoretical framework.

Before initiating the case studies, an overview of the state of the mode worldwide as compared to rail transit was performed in order to put things into perspective. This overview looked at the number of systems in the world, as well as their extent and ridership. BRT was found to be a rapidly growing mode, especially in Latin America and Asia, but the levels of ridership were much lower for developed countries, as expected. From all these systems, a pool of 20 that represent the most well known, established and arguably successful systems was chosen. This included systems in Western Europe, East Asia, Australia, and the Americas in developed and developed countries alike. Finally, the list was narrowed down 13 case studies

using a BRT scoring framework and selection criteria developed by the author that is based on the review of Chapter 2. This list represents systems in United States, Canada, Australia, Mexico, Brazil, Colombia, and Ecuador, and was chosen for an in-depth analysis and evaluation.

This evaluation was first performed through a qualitative perspective. This approach classifies BRT systems by characteristics and assesses the relationship between their implementation and performance using the criteria defined in the literature. This analysis found profound differences in the conception, application, and performance of BRT, which are related to historic, economic, and institutional reasons. However, the common denominator was strong ridership with respect to previous modes and competitive costs (except Boston), on the "positive" side, and rushed, incomplete implementation on the "negative". Aside from system elements, which have a large effect on performance, the most significant aspects affecting performance were the service pattern and integration strategies. This analysis did not find particularly difference in benefits between the different fare and subsidy structures used, although it is well known that all systems have a superior scheme to that of unregulated transport, and that over-subsidization leads to increasing inefficiencies.

Quantitative methods build upon the previous analysis to more precisely assess their performance from both the users' and the transit providers' perspectives through application of traditional and novel key performance indicators (KPI). This method allowed comparing systems more directly and finding enormous differences in operational and cost performance. However, some of these differences do not appear to arise from a particular context, but rather from a different application of BRT components.

CHAPTER 1. INTRODUCTION.

Developing sustainable transportation strategies has become a major focus of many cities around the world. Such strategies can range from improved pedestrian and bicycle infrastructure to investing in metropolitan rail systems. In major cities, where longer distance, high capacity services are necessary, city officials often debate the merits and costs of rail systems versus bus services. Each has its own advantages given specific context, with rail systems usually providing higher capacity, higher speed service, but often at much higher costs. Over the past two decades, bus rapid transit (BRT) has emerged as a major alternative to a rail versus bus debate. Although BRT systems are found in cities throughout the world, their greatest success has occurred in developing countries, where people demand a high quality transit system without having to pay the high price of heavy rail, a lifelong dream for many developing countries unable to afford large scale infrastructure development. For these urban centers, BRT has become, in roughly 10 years, the alternative choice for mass, yet affordable and quick-to-implement, transit. It portrays a different picture of the role that buses can play in public transportation, an echelon above what regular bus service offers, entering a realm traditionally reserved for rail-based transit.

The purpose of this thesis is to examine the success and failure of BRT systems around the world, to identify what is necessary to make BRT systems an important component of an urban area's multimodal transportation system.

1.1. Context

Bus Rapid Transit is a relatively new concept that still suffers from ambiguous definitions. Before the turn of the century, only isolated cases such as Curitiba (Brazil), Ottawa (Canada) and later Adelaide (Australia), among a few others, presented early forms of a distinctive, bus based-system that exhibited a higher degree of reliability and versatility than that of express buses in urban corridors. However, it was in the late 1990’s, that a new wave of systems in Quito (Ecuador) and Bogotá (Colombia), which based their design on Curitiba’s system, came to form what is known as the Latin American BRT model, having a set of common technical, financial and institutional characteristics. This model has been emulated recently in developing countries like China and India, and also in the United States. Given the different cultural, economic, and political contexts of these countries, new experience has been gained on the potential and flexibility of BRT, and also on its shortcomings. Despite its taxonomical ambiguity, BRT is now recognized worldwide as a separate mode of transportation with unique characteristics.

BRT has often been misunderstood because it has been misapplied. Even if only elements of a fully featured BRT have been implemented, its ‘upscale’ name is almost always used not only due to taxonomical confusion, but for its higher marketability compared its “inferior cousins” (“busways” or “bus improvements”). Such misunderstandings trouble academics and practitioners alike, and can give the wrong impression to the general public. Most people do not know the characteristics of BRT and generally underestimate the system’s ability to transport high passenger demand with a reliable and comfortable service. A first step in this study is to provide an adequate definition for Bus Rapid Transit, and to relate existing systems to this definition.

The relatively recent development of BRT systems that most of the academic literature and planning guidance has been written during the last decade. Most studies have investigated the characteristics of BRT and how it compares with other modes in terms of cost and implementation. Examples include documents from the Federal Transit Administration (Levinson et al, 2003), the Transportation Research Board (Levinson et al., 2007) and the Institute for Transportation and Development Policy (Wright and Hook, 2007) that have examined costs, transit oriented development (TOD) impacts, service characteristics, planning, and implementation. Agencies in the US have seen increased incentives to develop BRT lines via the FTA New Starts and Small Starts funding programs, but the overall future for BRT systems is still unclear. Close monitoring of continuing experience with BRT is crucial to understand the boundaries and applicability of BRT systems. Research needs to move on beyond the early case studies and focus on the maturing of older systems in Australia, the United States and Latin America, the early experience of newer systems in China, India, and Africa. Special emphasis needs to be put on how BRT affects its users and the broader community it serves.

BRT is still a relatively new mode, giving rise to many policy questions. Most importantly, will BRT grow to become a more important mode in underdeveloped and developed countries alike, or, will it primarily be limited to a niche market? In many ways, it may be too early to answer this question, as few BRT systems have come of age, when true lifecycle costs can be determined. Nonetheless, there is preliminary performance and financial data that show the current state of the mode and at provide some insight into its future.

If BRTs evolve to emulate rail transit in performance and appearance, and provide an advantage in costs, public perception could become very favorable. Such parameters could affect ridership and system design. Having this in mind, this thesis will examine the full spectrum of BRT services using the state of the art in research and performance (international case studies), in order to determine the reasons behind BRT success and failure This goal translates into the following tasks, no particular order:

1. Describe the characteristics of BRT systems, evaluate different definitions of BRT and determine the characteristics that make up these definitions. This is based on both a literature review of reports such as Characteristics of Bus Rapid Transit for Decision Making (CBRT: Díaz et al., 2009), and the TCRP Report on Bus Rapid Transit, vols. 1 and 2, (TCRP report 100: Levinson et al., 2003) as well as other research that focused on the same objective. Characteristics are also observed through a case study approach, since they are also important to describe findings not previously observed in the literature.

2. Assess the relative importance of these characteristics and determine their interactions and implications. While basic characteristics can be easily determined and do not change rapidly, the role that each one plays independently and the positive and negative synergies are still not completely understood. A rating system that helps categorize different BRT systems should be developed. Important progress has been made in the literature in this aspect since 2004, but is has not been sufficient. To achieve this goal, a study of recent systems is undertaken, as many are still teaching us different ways of designing and implementing BRT systems; some performing as expected, some even more successful, and others underperforming. Performance will be assessed using both the transit agency and user perspectives.

3. Develop recommendations for planning, design and implementation, focusing on the key elements to stress under specific situations. This will be done not merely from an

engineering perspective, but taking into account the financial and social environment in which the BRT service will operate. The TCRP Bus Rapid Transit Practitioner' Guide (TCRP 118: Levinson et al., 2007), the CBRT (Díaz et al., 2009) and the BRT Planning Guide (Wright and Hook, 2007) offer many recommendations, but a synthesis combined with innovative analyses, could prove highly useful. One main outcome expected from this step is to come up with a way to evaluate a current system and suggest improvements that do not rely only on expertise. In a similar fashion, using the same principles to suggest the best design alternatives based on context would maximize BRTs' potential and drastically reduce inappropriate applications.

As part of this research, some specific questions are addressed in qualitative and quantitative ways:

- How can success be measured? Performance measures, such as capacity, coverage, productivity, dwell times, headways? Cost/benefit? What about service quality, ridership, equity, popularity, image? What is the time span for its measurement and assessment?

- Why are BRTs more successful in some places than others?

- For this level of success, how much can be attributed to design? To implementation? Political, community and governmental structure involvement? Ownership structure? Wealth and socio-economic structure (e.g. value of time)? Culture? How do these vary across the world? Along these lines, which reasons for success or failure can be described as systemic or circumstantial?

- What is the relationship between cost and success? Is there a variable relationship? Is it possible to estimate marginal benefit with respect to investment (e.g. adding a new feature)?

- BRT is touted as the best transit solution for developing countries. What about developed countries? Aside from operating cost differentials, institutional aspects are important factors. For example, how effective has the federal initiative to promote and support BRTs in the US been? How do these vary in other countries as well?

- Will BRT be able to gain widespread recognition and status as a serious alternative/complement to both heavy rail transit (HRT) and light rail transit (LRT) services? What lessons do cities like Curitiba and Bogotá have in this regard?

- With respect to the recent proliferation of BRTs all over the world, how of this phenomenon can be attributed to 'success' (cost and performance), its promoters (consultants, academia, INGOs), governmental economic support, or just being 'new'? Is there any evidence of massive 'copy/paste' designs and inappropriate implementation in developing countries? What irreparable damage could that cause to the future inclusion of BRTs in other developing and developed countries when this initial success and marketing wave is over?

- For cities planned mostly for cars, such as Miami, Houston and Atlanta, how can BRTs work more effectively? How much investment would have to be made to make the current infrastructure more accessible to transit and BRT-friendly?

Feeder services are crucial for high speed BRTs. How would the feeder system work in such cities?

- What about the cultural aspects of buses as an everyday transit option? Are they seen as being much inferior to rail by prospective users? Would a large publicity campaign be needed to change people's minds with regard to this, or should performance speak for itself?

- Does BRT, compared to other systems, have advantages, not just in performance vs. cost of investment, but with ownership structure compared to other systems, e.g., being more conductive to public/private financing? What added complexities would there be in cities with previous HRT systems (Sao Paulo, Mexico, Boston) compared to cities with no previous rapid mass transit (Bogotá, Curitiba)?

Not all of these questions will be completely answered nor will all answers be considered satisfactory. But the goal of this study is to gain a much better understanding of BRT applications worldwide. The challenge really should not be about modes, as they tend to converge with advances in technology. It is about finding flexible ways to implement sustainable transportation that makes sense for particular urban contexts.

1.2. Thesis Organization

The next Chapter describes the characteristics of BRT as examined in the current literature, while Chapter 3 explores current best practices for BRT planning. Chapter 4 analyses the state of the practice in BRT implementation through various lenses, relates it to best practices, and concludes about the current state of the system.

CHAPTER 2. CHARACTERISTICS OF BUS RAPID TRANSIT

2.1. Definition

TCRP Report 118: Bus Rapid Transit Practitioner's Guide (Levinson et al., 2007) defines BRT as "…an integrated system of features, services, and amenities that improves the speed, reliability, and identity of bus transit". Along the same lines, Levinson et al. (2003) define it as "A flexible, high performance rapid transit mode that combines a variety of physical, operating and system elements into a permanently integrated system with a quality image and unique identity". The Bus Rapid Transit Planning Guide (Wright and Hook, 2007) defines BRT as 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 operation, and excellence in marketing and customer service". Of these definitions, the most satisfactory (and most recent in print) is the one provided by the TCRP Report 118, since it specifies BRT as being bus-based and relates service characteristics to performance. The other definitions either do not mention buses or are too subjective. While the mentioning of buses as part of the BRT definition might seem nitpicky, it is still needed to specify the type of vehicle used and the operating characteristics that directly relate to its attractiveness as a transportation mode. And while cost-effectiveness is one of the main advantages of most BRT systems, especially in the developing world, it is not a defining characteristic per se; similarly, excellence in marketing and customer service should apply to any transit mode, not just to BRT.

The literature has also offered various characteristics of the BRT system (Wright, 2004), especially after the Transmilenio system in Bogotá broke some paradigms and set new trends. The main elements that make up a BRT system are: running ways, stations, vehicles, fare collection, ITS, service and operations plan, and branding elements (FTA, 2009). The degree of advancement in each element and the way they are integrated determine the bus transit performance levels achieved. In Bogotá, for example, busways were implemented prior to the Transmilenio system and the results were better operations in a mixed traffic environment, but did not come close to Transmilenio's numbers and quality. A novel to approach to system characterization was offered by Hoffman and Cain (2008), who, instead of trying to define BRT as a single mode meeting some specific characteristics, subdivided the system into "Quickways" (e.g. in Bogotá, Ottawa, and Brisbane), and "Light Rail Lite" (Los Angeles, Miami). Defining these major 'submodes' of BRT was important because it helped understand the prevailing differences in philosophy and application of these systems between the United States and the rest of the world, and the impacts the different systems might have in future application and ridership. In practice, however, it may become increasingly difficult to characterize a new BRT system of being of one or another type. In light of this, the ITDP Planning Guide (2007) clearly distinguishes between BRT (e.g. Metrobús)[1] and fully featured BRT (e.g. Transmilenio), and puts both in a bus transit continuum. Providing a set of characteristics with different levels of BRT implies a qualitative continuum helpful to the practitioner.

The literature also lacks a systematic definition of BRT that includes a quantitative component. While there will always be a 'gray area' when defining a mode, it is important for decision-

[1] This document was printed when Metrobús had recently opened, had only one line (Insurgentes), and lacked many features (Hidalgo, 2008). Now, only an echelon behind Transmilenio in terms of throughput (no overtaking lanes at stations), in could be included among the exclusive group of fully featured BRTs.

making purposes to establish quantifiable measures that relate system characteristics to performance, even if the latter is context dependent. A classification method for BRT in Chapter 4 will attempt to bridge that gap.

2.2. Performance

2.2.1. Cost

The major advantage BRT systems have over other transit alternatives designed to serve the same market is its higher cost-effectiveness. Despite the arguments made by advocacy groups such as lighrailnow.org, which claim the cost advantages are not real even in the short term, the literature generally agrees that there is a big difference in capital cost with respect to light rail transit (LRT) and an order of magnitude cost savings with respect to heavy rail transit (HRT), which also has higher operations and maintenance (O&M) costs on average (Zhang, 2009). GAO (2001) found capital cost advantages compared to rail, but mixed results when comparing operational costs. This study only considered US systems (many of which could not be considered ‘true’ BRT by a strict definition) and predated newer, more BRT-like projects. However, there is no new evidence that suggests a different trend, despite outliers such as the Boston Silver Line-Waterfront (this one in terms of capital cost), a case study in this thesis. Bruun (2005), using parametric cost functions, and Hess et al. (2005), segmenting BRT by 3 types, both suggest slightly higher operating costs for BRT when compared to rail service as capacity increases past a threshold[2], but operating costs are consistently lower than regular bus service, due to greater efficiency in service.

It is important to point out that these and other similar studies are based on US-specific values coming from the national transit database (NTD), which still does not consider BRT as a distinct mode. Consequently, the costs tend to reflect what is considered "Bus Improvements"[3], while basing higher-end options on hypothetical values. These are the same values used by consultants and transit agencies nationwide, so a practitioner should be cautious when using reference values even in a pre-feasibility planning phase. It would be more appropriate to use component values such as those suggested by Wright and Hook (2007) and adjust them based on local market conditions.

However, most recently, researchers have been creating more sophisticated spatial models that remove modal bias and take into account a more comprehensive economic framework, while using unbiased parameter estimates. Daganzo (2009) modelled a typical city's network and treated public transport a logistics problem. He found that high quality BRT was more competitive than the car unless density and demand were too low, and always more competitive than other modes as long as there is enough road space to fit it. The results are being applied to Barcelona. Hensher (2010) applied data from Australian systems[4] to a user and agency cost theoretical model and showed that BRT outperform all rail modes unless speed differentials were significant. To showcase cost advantages beyond jurisdiction-specific boundaries, Hidalgo (2005), using an adjusted international average, showed a present value cost favoring BRT

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[2] This study uses a robust methodology but bases LRT's benefits on variable size trains to accommodate higher capacities with lower labor costs. However, this scenario does not consider user costs or network characteristics present in real life transportation systems.

[3] This submodal denomination applies to traditional bus service with marginal improved operations, such as TSP or GPS tracking.

[4] This data includes higher crew cost per vehicle for LRT.

investments for high capacities. This study was significant because it attempted to normalize performance across modes and performed a lifecycle cost comparison. However, since the origin of these costs is not reported, it is difficult to determine if any system, especially in the developed world, would be represented by this average value. In the most comprehensive study of BRT characteristics relating to performance to date, Hensher and Golob (2008) took 44 systems (creating dummies for ultra-expensive systems like Boston's) and developed a statistical analysis, identifying key variables related to infrastructure cost performance. Infrastructure costs were found to be most dependent on traffic signal priority (TSP) improvements and number of terminals, with no significant influence on location or level of economic development. In this case, then Light Rail Lite type systems could be costlier than "Quickways" like Transmileno, or at least much less cost-effective than those in Brisbane. It is important to note that recently planned systems in the US are higher investment levels than previous ones on average and that the FTA is supporting this trend (Cain et al, 2006).

However, operational costs were not part of the study. Because the difference between operational costs in developed versus developing countries could help explain the varying success across the globe, there is a need to perform a comparative study of all types of costs for all regions. The major hurdle in developing this type of research is the availability and reliability of data, especially in developing countries. Also, the lag between data collection by the agency and publication of results during a fast paced implementation may render results obsolete especially since much innovation is going on technically and financially. A universal, 'real-time' database would not erase these shortcomings, especially in the short term, but would be a step forward in transit research.

Another topic mentioned in the literature cost effectiveness of both network expansion and technical improvements. TCRP Report 118 (Levinson et al., 2007) showed a positive linear relationship between investment and performance, and provided for cost effectiveness of different elements. This study is the only one of its kind and helps practitioners follow a procedure for determining what they should include in their design. However, its results are based on regression using average values so it does not take into account the order of implementation or other structural characteristics affecting component performance.

2.2.2. Service

Transmilenio (Bogotá) has shown that BRT can even surpass LRT systems in capacity, and rival most HRTs around the world as well[5]. The main reason behind this unforeseen performance (for a pre-BRT reference, read Vuchic (1992)) was the introduction of passing lanes in the vicinity of all stations, allowing for different types of routes that optimize passenger throughput. This configuration exponentially increases capacity and is much easier to implement than its rail counterpart. If combined with higher capacity buses and optimized station design, the theoretical limit for BRT capacity could extend beyond 50.000 pax/hr/dir without compromising reliability (SDG, 2007), a value usually achievable only by high investment moving block HRT systems. With this type of design, BRT can also achieve high commercial speeds with greater station density and shorter headways. Even if typical speeds have been found to be in a range lower than LRT and HRT, the difference is less due to technical inferiority (especially when compared to LRT), than the tradeoff between speed and accessibility (Hook and Wright, 2007). For example,

[5]Hook and Wright, 2007.ITDP Planning Guide Appendix. Volume = 45.000 pax/dir-hr

the O-Bahn in Adelaide has speeds that rival most rail systems but also higher average station spacing than any other BRT in the world.

A third performance characteristic commonly mentioned in the literature is route flexibility and network connectivity. Hensher (2007), mentions network size and service coverage as the main reason for the mode's potential. This is why, even with high station density, travel time remains competitive with faster systems, as transfers are reduced (FTA, 2009). In terms of comfort, no definitive study has been made that quantifies this characteristic for high-speed BRT systems for a similar level of throughput.

2.2.3. Sustainability

BRT is widely considered to have considerably faster implementation times (Levinson, 2003; Ardila, 2004), and this reduces investment risk, a main component in economic sustainability. Hensher (2007) finds BRT aligned with sustainability and value of money principles after reviewing successful cases in the Americas and Australia. If relative high performance comes at a fraction of the cost of comparable rail systems and with a possibility of no direct operational subsidy, then the system has the potential of being more economically sustainable than otherwise. This is an argument that the World Bank and NGOs like EMBARQ and ITDP use to justify the implementation of BRT systems, especially in developing countries[6]. Major efforts are focused on innovative finance using PPPs in order to push BRT projects closer towards financial feasibility. While the upfront costs have been studied exhaustively, the only complete economic

[6] A noteworthy case in the US was EMBARQ's response to the governor of Maryland's modal decision on the Purple Line based on the alternatives analysis submitted to the FTA.

evaluation of these systems that has been published (albeit not in an international peer reviewed journal) is a study by Echeverry et al. (2004) which analyses Transmilenio in terms of its overall impact in the city of Bogotá. While Peñalosa (2005) and Ardila (2007) found inconsistencies in this evaluation, it serves as an example of the type of evaluation should be attempted for many systems in a mature stage of operations. The most important contribution of this study was to look at the effects on Transmilenio on the city as a whole and not just the corridor it ran on. Since it displaced old routes to other corridors, and the old buses were not retired, the overall congestion and pollution benefits obtained were much lower than expected. The high infrastructure costs of subsequent phases must also reduce the B/C ratio significantly.

The environmental aspect is seen as a weaker point of BRT systems since the average American system sees higher emissions than similarly aged and performing LRT (Puchalsky, 2006). The main reason behind this result is that most systems still use high sulfur diesel, which usually, emits more than electricity in SO2 and $PM_{2.5.}$ Since these are mobile, urban emissions, not only could they affect a greater part of the population more directly, but are perceived as worst even when their levels are lower than those in electricity generation plants. Despite the industry having shown major improvements in efficiency and cleaner fuels in the last decade, only until recently have the larger systems in developing countries experimented with hybrid-electric buses and low-sulfur diesel. This step is significant since research done by (Vincent and Walsh, 2003; Vincent and Callahan, 2007) determines the potential of BRT to be effectively cleaner than rail technologies once cleaner fuels and hybrid technologies are generally adopted. When part of this debate, researchers must remember that BRT does not have a set fuel type behind it; the obvious technologies it could use in the future, such as hydrogen, have already been tested. Perhaps, even fully electrical vehicles could be used when the technology permits and the electricity generation becomes cleaner. This could virtually erase the gap in vehicle emissions it has with LRT, its main ‘rival’.

Systems in developing countries vary greatly in terms of fuel quality and emissions but are generally dirtier per mile travelled than in developed countries. Sepulveda (2007) explores this when noting that an expanded Transmilenio (TM) bus fleet with the current diesel quality would increase pollution significantly. However, since throughput is much higher, the impact per capita is not as high as in most American systems. Also, due to the positive impacts of systems like Transmilenio and Metrobús (which uses LS Diesel), they have received millions of dollars for carbon reduction through Clean Development Mechanism (CDM) programs, which are available for developing countries. These findings show that the evaluation of transit systems still lacks comprehensiveness. No article in print has done a comparison in terms of sustainability[7], either within or across modes, so many questions are left unanswered. Would investing in potentially high cost cleaner technologies limit some of its cost advantages? This is difficult to determine with certainty, as it is difficult to estimate the costs of the new technology when first being implemented. Also, in countries with private service provision, how the implementation of newer technologies would come into play with private operators would work is something to wait and see. Nonetheless, it is probable that these buses will quickly equate in price and reliability to petroleum based buses. Overall, while bus systems with current mainstream technology can have a disadvantage with respect to rail depending on the where electricity is produced, there is no big enough advantage that warrants a modal supremacy in this area.

[7] For a first step in an evaluation in terms of sustainability for bus systems under similar contexts, refer to Campo (available Jan 2011).

2.2.4. Implementation

Implementation greatly differs between the United States, Latin America, and Asia. The most successful BRT implementation model so far has been the Latin American model (Hidalgo, 2008) due to the strategies taken to overcome the prevailing bus system and the relative ease with which a strong government can act (Ardila, 2004). ‘Regulated competition for the market’, a concept that describes a PPP with a few bus owning and operating companies, a public agency overseeing operations and setting the rules, and independent fare collection and revenue distribution, has been replicated in many countries in Latin America and has been relatively successful at least in the short term (Ardila, 2007). This organizational structure worked in Bogotá and other cities mostly because it was designed to legally displace the old bus and inefficient service from the BRT corridors (Hidalgo and Sandoval, 2003) through restricted negotiation, as the bigger unregulated bus companies were invited to join the bid process. This selective contracting approach proved to be a smart move to get the Transmilenio going quickly, but it also could be a reason why scrapping old buses has not been that successful (Ardila, 2007). Mexico City with its newer system, Metrobús, has a just slightly different structure in that the public agency also operates buses, but has been much more successful in removing the displaced buses from the city streets (CTS, 2009). No thorough analysis has been made on the topic.

Due to similar prevailing service provisions, in Southeast Asia and India similar strategies have been tried but they have not been as successful because the political and cultural climate there is different (Hidalgo, 2008). Implementation in those countries, especially in India, has been rushed and many systems could not be considered BRT during their first years of operations. The tendency, however, is that through increased international cooperation and feedback from past failures, newer systems will correct some of the implementation mistakes (Hidalgo, 2008b). The results are yet to be seen and it would take a couple of years for new findings to be published.

In the United States, the situation is different in that much transit is publicly owned and operated. Here, the FTA (with its motto ‘Think Rail, Do Bus’) has been investigating and supporting different BRT experiments in the country, funding new projects under the New Starts and Small Starts programs. The efforts have produced systems as different as the Boston Silver Line and the LA Orange Line. Private organizations such as the National Bus Rapid Transit Institute (NBRTI) and GoBRT, affiliated with research universities, have collaborated in understanding and advocating for quick implementation.

Results from this collaboration has produced studies like that of Cain et al. (2008), which looked at the possibilities of implementing a Transmilenio-style system in the United States. This research acknowledges the prevalence of the LRL concept in the United States and identifies the barriers and opportunities of implementing a true BRT system instead of just a simple route along a line. In this study, it was found that while bus transit in the US suffers from lack of non-captive ridership, unattractiveness to private investors, and little understanding among decision makers when compared to Latin America, it could also benefit from growing support for more cost-effective options and more rigorous technical studies.

As suggested by these articles, the institutional framework is the main barrier to replicate a successful model from overseas, but it does not prevent high quality and successful systems to be implemented. The second aspect to be studied regarding implementation success is the relationship of BRT network and land use. A handful of studies, of which Rodriguez and Mojica (2009) is the most recent, look at BRT impacts on land values. They suggest significant property appreciation benefitting from increased connectivity due to system expansion. However, the relationship between these benefits and equitable service quality has yet to be established.

2.3. Concluding remarks

Previous research about characteristics of BRT systems and their relationship to performance has shown that BRT is indeed a distinct mode with unique component characteristics and service that can make it valuable and successful in many countries. The literature reviewed describes the service, environmental, and implementation characteristics of BRT system that make it unique and appealing. However, research specifically lacks a better understanding of how implementation plays a role in the relationship between characteristics and performance. This thesis will build upon this relatively unexplored relationship regarding BRT systems planning. Chapter 3 completes this literature review by taking a look at the existing BRT planning guidance.

CHAPTER 3. PLANNING BUS RAPID TRANSIT – STATE OF THE ART

3.1. Overview

As discussed in the previous chapter, the characteristics of Bus Rapid Transit have been widely studied. Yet it has been only recently that policy-oriented research was done and planning guidelines were developed for this mode. These documents are a first attempt to link the observed aspects of BRT to best practices in system development. Application of their recommendations is supposed to improve the way BRT systems are planned and implemented. Decision-making based on guidelines is important since so many systems around the world are currently in planning and phased implementation. The more that BRT systems learn from previous experience, the better their use of scarce resources and the credibility of the mode.

This chapter looks in depth at the most important research on BRT planning, and makes the case for a synthesis of information that can be used by newer systems, incorporating state-of-the-practice analysis approaches. For congruency with a major theme of this thesis, I stress the importance of considering context within planning and implementation.

3. 2. Practice Guidelines

3.2.1 Planning

The literature (Wright and Hook, 2007; Levinson et. al, 2007) makes it clear that practitioners must first understand the constituent parts of BRT systems and keep them in mind throughout the project. Although not openly stating it, experts agree that the more BRT differentiates itself from regular bus service (RBS), the higher the chances of implementation success. This “growing apart” from standard incremental bus service improvements in planning is considered one of the main characteristics that differentiate highly successful projects (e.g., RIT (Curitiba, Brazil), Transmilenio (Bogotá, Colombia) from less successful ones (e.g.TransJakarta (Jakarta, Indonesia). However, knowing the basic BRT distinctive elements and their relationship to performance is not enough to plan appropriately. For transit planners to achieve this level of success without making the mistake of replicating systems seen elsewhere, planning should generally follow a systematic approach. The ITDP Guide summarizes the following planning steps, which will be used in this thesis, complemented with other sources.

First, ***project preparation*** would include:

- *Initiation:* Look for local political leadership.
- *Modal technology:* Pick a desired technology based on cost-effectiveness, ease of implementation, and overall impacts.
- *Project setup:*
    - Select an interdisciplinary project team based on expert consultants and local government officials.
    - Select the funding sources and design financing mechanisms.
    - Set the scope of the project large enough to start with financially sustainable ridership but not too large as to compromise effective implementation.
- *Demand Analysis:* Depending on the data availability and the budget, use either a quick assessment method or a full transportation network model.
- *Corridor selection:*

    - Chose an alignment based on demand, physical limitations, network advantages, costs, implementation, politics, and social equity.
    - Do not be limited by spatial constraints. One of the main strengths of BRT is that it can adapt to a variety of conditions.
- *Communications:*
    - Perform an inclusive stakeholder analysis.
    - Initiate a public participation process.

This first step is standard for any type of transit planning. The authors include the modal technology sections possibly to avoid portraying a modal bias, yet a BRT guide must assume that the bus alternative has been chosen over its rail counterpart. This discussion then helps to approach the cost and capacity advantages of BRT over other modes. The comparison is valuable, but since it only provides ranges for average costs and capacity, readers could be mislead into overestimating BRT's relative benefits. A capacity-over-capital cost ratio should be provided so that practitioners can understand what level of investment is required to achieve a certain level of capacity and speed. The TCRP Report 118: BRT Practitioners' Guide (Levinson et al., 2007) does not do exactly this, but it includes a relationship between performance (ridership and travel time savings) and cost (component and total). It also mentions that despite BRT in the US usually costing less than comparable LRT investments, it should be studied for funding in the same way as rail alternatives (pg.2.3). Funding programs in the US range from "Bus Corridor Improvements" to "New Starts", although a true BRT system usually needs more than the $25 million dollar limit for the former. In the rest of the world, financing varies significantly (usually is a mix of international development bank loans, and a combination of national and local capital),so capital funding details are not discussed here.

Regarding a demand analysis, Wright and Hook (2007) give examples of the four levels of modeling used, but Levinson et al. (2007) do a much better job at explaining a quick assessment method by using ridership elasticities.

The next major step is ***operational design***. Its main components are:

- *Network and service design:*
    - Choose either a closed (restricted to a set of operators under equal rules with centralized supervision) or open (much more relaxed entry barriers in using infrastructure) system.
    - Choose between a *trunk-feeder* or a *direct services* system, based on accessibility needs, overall travel times, and costs.
    - Take advantage of the high route permutation capacity of BRT systems.
- *System capacity and speed:*
    - Capacity has to be enough to cope with peak demand and speed has to be competitive with alternative modes.
    - Both depend on a range of factors but are greatly determined by busway design (one or more lanes, intersection design), vehicle design (size, multiple doorways, boarding level), and station design (off-board fare collection, spacing, stopping bays).
- *Intersections and signal control:*
    - Focus on turning restrictions, especially in developing countries.
    - Chose an appropriate location for a BRT station (in the middle of a road segment or at an intersection; on the curbside or on the median), based on passenger accessibility, available space, and interaction with cross traffic.

- *Customer service:*
    - Design the system based on customers' needs and wants.
    - Do not neglect signage and other forms of customer information.
    - Be aware of aesthetics.
    - Make security and cleanliness a priority.

This chapter in the Guide is very detailed in the way it explains how operational decision-making affects not only costs and revealed system performance, but also accessibility in its broadest social context. This is an important observation since the social implications of corridor selection is an important topic explored in this thesis.

One element of this chapter in the Guide that could be better developed is its treatment of transit signal priority (TSP). While Wright and Hook(2007, pp. 313-314) talk about cases in which TSP is desired and give a few application examples, the Practicioner's Guide (Levinson et al. 2007, pp. 4.26-32) includes case study and model results, plus a decision-making framework for its implementation. In general, TSP should be implemented where it achieves considerable time benefits (such as on congested routes and when stations are located on the far-side or mid-block part of a road segment), but it is most widely used in developed countries since technology is more available and cheaper, intersections tend to be closer together, reducing signal phases is less common, and bottlenecks are observed mostly at stations (Lleras, 2007). Recent traffic simulation software is expected to become a fundamental tool in operational design.

The next step is to make this operational design closer to reality by turning to **physical design.** The key decisions to be made in this regard are:

- *Infrastructure:*

- Chose the right busway building materials. This may seem trivial, and greatly depends on market pressures, but it directly affects lifecycle costs and station design.
- Since most BRT systems have surface stations, architectural design must focus on temperature and weather issues, and pedestrian-traffic interaction.
- Most BRT systems require transfer terminals, control centers, large depot areas.
- Capital costs must be maintained within reasonable ranges for BRT, but never compromise the basic elements that make it a distinct mode with respect to RBS. The main reason for escalating costs is property acquisition, sometimes a result of pressures to maintain auto capacity. Since BRT investments are usually expended simultaneously with other investments not directly related to the project, direct BRT costs must be separated from complementary works.

- *Technology:*
  - Bus technology decisions are made in terms of size and propulsion system. While size is standard, propulsion technologies are continuously evolving: clean diesel, CNG, hybrid-electric, among others, are the most common.
  - Fare collection range from smart cards to coin-operated machines. This technology does not affect system performance as much as other design aspects (even though it may compromise versatility). Therefore, it should be chosen mostly for budget limits and ease-of-use.
  - Intelligent transportation systems (ITS), including vehicle control and passenger information systems, should be examined carefully.

One of the most important topics from the above list is the high variation in capital costs due to property acquisition (e.g., Bogotá's Transmilenio 3rd phase costing approximately US$20 million/mile, a high price for a developing country). BRT advocates argue that funding is unfairly compromised when these numbers escalate due to the inclusion of external improvements into the BRT budget. Nevertheless, it will continue to be an issue, since surface systems cannot be expected to achieve high capacities and continue to interact with other modes without incurring such costs. This topic is discussed in the next planning step.

Both major guides mention the advantages and disadvantages of technology in terms of costs and user benefits, but none explicitly mention how technology choices can be analyzed in terms of lifecycle costs and scalability.

The next major step for BRT planning is **integration.** Its main components are:

- *Modal integration:*
    - Pedestrian access is the most important modal integration aspect and should take into account connectivity, accessibility, safety, and security.
    - Integration with other modes, motorized and non-motorized, can greatly increase BRT system performance and help reduce direct costs, since these modes can act as feeders into the system.
- *Transportation demand management (TDM) and land use:*
    - These measures, meant to discourage use of the automobile, should encourage increased use of public transit.
    - Land use policies should go hand in hand with BRT development, which has shown to be conducive to TOD.

Much of this final step of the planning process is often rushed and overlooked, yet it is a fundamental aspect of successful transit planning and even more applicable to BRT, given its typical integrated/segregated infrastructure. Aside from this guide, which is comprehensive in its treatment of accessibility, a good set of guidelines were developed by the World Bank (Rickert, 2007; Rickert, 2010) that focus on designing adequate accessibility to BRT systems and evaluating key issues. These guidelines focus on the developing world, where budget cuts are biased towards pedestrian access infrastructure, where public transportation is largely unregulated, and where there is usually no legislation or adequate enforcement that protects the low income and disadvantaged people. The most important contribution of these guidelines is how the whole user experience, from leaving the house to reaching a destination, is accounted for in the case of a physically disadvantaged person. For example, even the fare collection system should be designed in a way that makes it easy for everybody to use it. Although developing nations are the target of World Bank investment, developed nations such as the US have a lot to learn from these recommendations, given that multimodal integration is a challenge here as well. General accessibility guidelines developed by federal and local governments are useful, but a BRT-specific document would come in handy for American practitioners. This is missing from the Practitioners' Guide[8], surprisingly if you consider its effect on ridership, one of the two main topics of the document.

Integration with modes such as taxis, pedicabs, and bicycles are in the early stages of development. There is arguably no BRT system in the world as of yet that can be considered to have high marks in this regard. Much of thislack of integration has to do with limited resources and cultural disregard for egalitarian safety and comfort, but also because most BRTs are called

[8]Throughout the document, classic BRT feature such as level boarding, amenities and image, land development, and off board fare collection are mentioned, but there is no direct treatment of accessibility.

“systems” while they are still only “lines”. However, since the goal of many cities is to integrate their BRT lines with other modes of transport, and the transportation planning community has shifted its values from mobility to sustainable accessibility, multimodal integration will likely receive further attention in the BRT literature and practice. This topic could be tied to research on BRT and TOD, discussed in the previous chapter.

Regarding land use, while both BRT guides focus on planned TOD policies in the US and abroad, these take many decades to implement on a citywide scale through zoning and market policies. On the other hand, BRT systems could cover most of the city in a faster time, especially in developing countries. Since no other mass transit mode has this fast implementation time, BRT could become the main tool to turn urban regions into *transit adaptive cities* (Cervero, 1999) by a more natural mechanism. Triggered by efficient transportation infrastructure, standard zoning practices supporting TOD and “livable communities” concepts could advance more effectively than otherwise.

Lastly, the literature makes clear that BRT should be planned along with transportation demand management (TDM) strategies, especially in countries that subsidize the internal and external costs of auto transportation. Policy recommendations that look to “level the playing field” between cars and transit are described comprehensively, based on the work of the Victoria Transportation Policy Institute (Littman, 2010). With globally increasing motorization triggering problems with cross street traffic at grade level (even with TSP), BRT could lose its comparative advantages over other modes in cost and integration flexibility. Such a scenario could hinder the successful development of BRT, sustainable transit, and all the positive land use and livability benefits it could provide.

After integrating the technical aspects of the project, the final step of the pre-implementation planning phase is the development of a business plan. This plan, which is concerned mostly with the way expenditures are managed, can make a major difference in the success or failure of the system. Below I summarize the basic principles for best practices of a BRT **business plan** in developing countries, according to Wright and Hook (2007, pgs. 547-686):

- *Business and institutional structure:*
    - Traditionally, neither a single public monopoly nor a "free" competitive market with many providers has proven to be an efficient way to operate with high quality and minimum costs. Competitively-tendered concessions for vehicle ownership and operations with strong public oversight allow for enough competition *for* the market but limited competition *in* the market (Ardila, 2008). Transmilenio is a good example of this.
    - Under this scheme, operators are paid by kilometer and not by passenger picked up, and further awarded or penalized based on performance.
    - In cases when it is helpful to bring change, the creation of a new agency for the BRT system is useful. It is important that this agency operates autonomously over planning, infrastructure, and supervision.
    - Direct involvement by a public official ("political champion") has shown to be a catalyst for rapid and successful implementation of BRT systems and is recommended.
- *Operational costs and fares:*

  - The goal in the developing world is to operate without subsidies. This means that the public sector should not subsidize repayment of capital and operating costs (fixed and variable).
  - If vehicles are included in the concession contract, then they can be considered operational costs; otherwise, they can be bundled with the rest of the capital investment.
  - Fares should be defined technically, based on operational productivity.
  - It is recommended that an independent fare company collect the revenues, thus acting as a "trustee" to distribute revenues based on contractual agreements.
- *Financing:*
  - The relative low-cost characteristic of BRT makes it within reach of most cities wishing to implement it, so even many developing cities do not require large amounts of resources from external sources (e.g. World Bank, IADB).
  - The local match generally comes from vehicle ownership fees, gas taxes, value capture, and parking fees. Infrastructure PPPs are also an option, but they bring an additional complexity and have not been as successful as expected.
- *Marketing:*
  - The negative stigma associated to buses is a challenge but also an opportunity for BRT planners to sell change by using modern branding strategies, which start by attractive names and logos.
  - The media should be used to the planner's advantage to get to the public, highlighting BRT strengths and reminding them of the weaknesses of the old

system that BRT is replacing. Direct community outreach is a complementary mechanism as part of the communication strategy.

The structure of this step, as described above, is the base for the relatively successful (at least in the short term) Latin American post-Transmilenio model. However, in recent years there have been issues regarding the replication of this structure in the developing world, which will be explored later in this thesis. Also, many of the recommendations do not apply that well to the US and much of the developed world, despite the lessons these countries can learn from developing nations.

The generalized ownership structure of public transit provision by single public agencies operating over a jurisdiction is different around the world. These agencies subcontract some services but largely own and operate the fleet, and their main challenge is to overcome inter-jurisdictional barriers when metro areas grow beyond a political entity. This configuration leads to a monopolistic situation, which in theory is justified by economies of scale, but at the same time may lead to high inefficiencies. Operating subsidies are very high due to many structural reasons (not necessarily monopolistic inefficiency) so there is no realistic near term possibility of eliminating them, just reducing them as much as possible.

Based on recent experience, BRT planners in Latin America are now reevaluating the strict rule set by them for not allowing non-infrastructure subsidies. The challenge is to design mechanisms that avoid the negative incentives brought by directly subsidizing operations. An option is to allow subsidies for the high cost of capital that some operators face, or to create externality capture mechanisms that help fund operations while not directly rewarding inefficiencies. The possibilities are many, and there is no clear answer, since the debate is as political as it is academic. While traditionally, American economists favored optimal levels of infrastructure subsidies and accepted operating subsidies on the grounds of social benefits (Karlaftis and McCarthy, 1998), others (Obeng and Sakano, 2008) have found strong inefficiencies in productivity that leave no economic argument for any type of subsidy in the presence of slight diseconomies of scale.

In terms of private involvement in operations, varying levels of successful competition for the market in transit industries around the world make it difficult to obtain a consensus on whether negotiation or competitive tendering is a better way to grant contracts to private operators (Wallis et al., 2010). Adelaide (a case study in this thesis) has enjoyed more success through negotiation than through competitive tendering, while Bogotá DC and México DF have been successful through the latter. In México there have been experiments that include competition in operations from the public agency itself, and negotiation over a single operator for a new line (little barriers of entry were placed for the first phase due to political reasons) as strategies to lower costs.

The independent fare company and trustee handling the revenues was an invention of McKinsey and Company for Transmilenio. It makes sense for the objective of transparency, yet the independence of fare collection from the overseeing agency may become an unnecessary cost, burdening the user where it brings no significant added value. Regarding the fare structure, paying strictly by kilometer has proven to be inefficient despite having the effect of de-incentivizing the “War of the Cent”. This year Curitiba implemented paying operators by passenger as well using an undisclosed formula, so this strict recommendation should be revaluated citing more thorough research and results from experience.

Marketing BRT has always been important to differentiate it from RBS. In recent years, due to the exponential growth of motorcycles in developing countries and stiff competition from cheaper, unregulated RBS in cities where BRT remains a minority (as predicted by Lleras (2003)), marketing needs to become a bigger priority than it is now in BRT planning. In the US, where having a good image applies to all transit and marketing is much more developed, one sees even more attractive names, logos, and buses, some of which look very similar to LRT in an effort to remove the negative bias toward bus transit (TCRP Report 111, 2006). In spite of leading the world in this area, there is very little public education on the characteristics of BRT in the US. Legislators and the affected communities tend to be ignorant of what BRT means and represents(the LRT choice by the governor of Maryland for the Purple Line despite BRT showing better cost efficiency ratings might be an example of this, although political considerations certainly played a role in this decision (EMBARQ, 2009)).

3.2.2. Implementation

Successful implementation requires constant feedback and accountability, which in turn demands a **monitoring and evaluation plan**. Costs and impacts should be centered on the user experience, but since not all performance can be measured from stated feedback, a set of measurable indicators and analysis methodologies needs to be developed before the system is in operation. The impacts to be evaluated are:

- *Traffic*: corridor benefits and tradeoff with other modes.
- *Economic*: cost effectiveness and benefit-cost analysis (production + employment).
- *Environmental*: air pollutants, GHG emissions, waste and noise reduction.

- *Social*: expropriation, worker displacement, poverty alleviation, crime reduction, safety, and intangibles.
- *Urban*: urban form

These impact categories are standard for any transportation project, yet estimating impacts for BRT tends to be trickier than for other modes, especially when BRT is part of city-wide bus route reorganization such as in Santiago (Chile).

Positive impacts need to be assessed with no under/over estimating or double counting. Currently, most project evaluation criteria separate environmental assessment from economic feasibility. Therefore, funding is not as dependent on certain non-economic impacts. Nevertheless, when future projects are analyzed in terms of more comprehensive sustainability criteria that include both economic and environmental factors, BRT planners should be familiar with how they are estimated.

Based on the methodologies developed for project evaluation, a monitoring and evaluation plan based on key performance indicators across all areas should be developed according to the Planning Guide. These can be grouped under:

- *System performance*: mode share, travel time and speed, ridership, among others, fare, comfort, among others.
- *Economic:* employment, time savings, property values, technological production.
- *Environmental:* air pollutants, GHG emissions, and noise levels; illnesses; number of retired buses.
- *Urban:* property developments along corridor, quality of public space surveys.

- *Political:* supporting officials and their reelection success.

While the development of political indicators could be meaningless in practice, some of the indicators mentioned above are very useful, yet rarely calculated, monitored, and reported. In this area, agencies that have heavy rail as a major mode typically do a much better job than BRT agencies. Furthermore, the rail industry has strong benchmarking programs based on key performance indicators (KPIs) such as the COMET system, headquartered at the University College of London (UCL). Given it is a new mode, BRT advocates have just started to catch up and recently launched SIBRT, a benchmarking organization for Latin American BRT agencies headed by NGOs, and VRef, a Volvo initiative comprising several universities in Chile, Australia, and the UK, as well as NGOs. The National Transit Database (NTD) still does not identify BRT as a distinct mode, but that could change soon. Continuous monitoring and benchmarking is important not only to a BRT agency and its users, but for the future of BRT worldwide. Evolution of BRT as a mode goes faster with benchmarking because it provides its practitioners and researchers opportunities to comprehend and innovate. Actually, this thesis makes use of key system performance indicators that are useful to assess the state of the practice of successful BRT systems. If such benchmarking had been in place at the time of this research, analysis could have been much more comprehensive.

After the evaluation framework is in place, the actual **implementation plan** can be executed. This plan is similar to the business plan but covers more ground and is more detailed and practical. Its major elements for developing countries according to the Planning Guide are the following:

- *Choosing and preparing the implementing agency*

    - It is generally recommended for the planning agency (be it new or old) to be the same as the operating agency. If not, whichever agency is in charge of implementation must be prepared for the required activities.
    - Responsibility for implementation is divided between construction and operational aspects. Usually construction is handled by an experienced agency (e.g. public works) while operational aspects are dealt with by the BRT agency, and coordination is performed by somebody with direct access to the Mayor or Governor. The decision should be made based on both technical and political criteria.
    - The organizational structure should have, at a minimum, departments of planning, operations, finance, and administration.
- *Operating contracts*
    - These should be completed well before the launch of the system, giving enough time for operators to buy the vehicles.
    - Fare system contracting should ensure no conflicts between the technology provider and the operator, and if these are the same company (e.g. through a lump sum contract type), then the agency should make sure costs do not escalate.

- *Construction*
    - Includes the four basic construction steps, from detailed design to maintenance.
    - Includes construction of: busways, stations, terminals and depots, control center buildings, pedestrian access infrastructure, parking garages, bike lanes, among others.

- The contracting structure should ensure: minimize government's costs, risk, financing cost, delays and transaction costs, coordination problems, and substandard construction. The number of contracts should not be too many or too few, based on local circumstances.
- It is important to note that the construction of a system not only affects its technical performance but also its image. Therefore, it must be as organized as transparent as possible.
- All stakeholders affected by the construction should be given appropriate participation in the process and mitigation strategies should be in place before construction begins.
- Quality and speed should be higher than for standard road projects.

- *Maintenance*
    - Vehicle maintenance is the responsibility of the operators in most cases, but strict contractual standards and supervision comes from the overseeing agency. The case is similar for ITS equipment.
    - BRT stations, especially their turnstiles, should be functioning at all times, since they are small compared to underground transit stations but carry as many passengers.
    - Infrastructure maintenance depends on whether there was a PPP with contractors and what longer term quality contracts demand from contractors.

The implementation plan for developing nations' BRT planning includes many elements applicable to all sorts of public transportation projects in developed countries as well. However, some aspects are particular for BRT under any development context. An important factor to take into account in BRT implementation is that construction differs from that of rail transit projects (highly specialized, fewer interactions with as many urban streets) but also from road projects (lower precision, usually not though as part of a system).

In the US, notable BRT projects have been implemented under the umbrella of an existing transit agency. They continue to be publicly owned and operated and are integrated with RBS and HRT/LRT, so many of the “agency creation” and “contractual agreements” mentioned here are irrelevant under the current institutional framework.

3.3. BRT planning literature assessment

In this chapter, two major planning guides were summarized and reviewed, along with other relevant literature. One (ITDP Planning Guide 2007) is more general and comprehensive in nature, touching almost every aspect of BRT planning possible, yet most of its content is more applicable to developing countries. A strong point of this guide is the contribution of international consultants who actually participated in the design and implementation of many successful systems, and thus bring unique insights and detailed case studies into the mix. Before this edition, the only existing version was one developed by the Sustainable Urban Transportation Project (SUTP) of the German Cooperation Agency (GTZ), which had some good technical information, but was not nearly as comprehensive and practical as the current guide. A weakness of this guide is that it is not compact enough for a practitioner to easily grasp the many iterative factors that affect BRT planning.

The other (TCRP Report 118 Practitioner’s Guide) serves more as a quick reference guide, and is much more US-based. It misses many topics such as implementation and evaluation guidelines and impacts, but does a much better job at focusing on the characteristics of BRT and their relationship to performance and to decision-making. It sees BRT under a much narrower focus: as a packaging of features that enhance current bus service, decreasing travel time and increasing ridership. Its methodologies are built on case studies from previous TCRP Reports 90, vols. 1: Case studies and 2: Implementation Guidelines (Levinson et al. 2003) and the Characteristics of BRT for Decision Making (2004, FTA), which at the time were good sources of reference but were weak in terms of implementation and decision-making. Thus, aside from papers giving recommendations for successful BRT planning (Levinson: 2003; Darrido, 2003), there were virtually no useful guides before 2007. Therefore, their publication was a major leap forward in BRT planning literature and so far nothing of relevance has been produced after. There has been no published feedback and their recent publication makes it is difficult to assess how useful they could be in practice.

Since many of the case studies are either getting old and becoming less relevant in a modern BRT context, or reaching new stages of maturity, planning guidelines could benefit from newer case studies and a fresher look at their assessment that transcends basic metrics such as simple travel time savings benefits and busway local costs. This analysis approach would help determine clearly when a BRT system is successful, what are its strengths and weaknesses, and how to plan for optimum performance. The rest of this thesis uses a case study approach to get closer to this objective.

CHAPTER 4. IMPLEMENTING BUS RAPID TRANSIT – STATE OF THE PRACTICE

4.1. Introduction

The previous chapter looked at implementation from a planning standpoint, while this chapter focuses on the successes and problems of implementing different forms of BRT in different countries. The conclusions are based on an overall case study evaluation, using qualitative and quantitative comparisons. Issues are identified and related to the recommendations given in Chapter 3.

4.2. State of Development

As mentioned in Chapter 2, BRT gets implemented very quickly relative to other modes. This characteristic explains the rapid expansion of the industry around the world, especially in developing countries. Figure 1 shows a map of the current rapid transit systems (bus and rail-based) operating fully and their magnitude in terms of daily transported passengers. Notice that rail systems (HRT, LRT, monorail) are still a majority in number but that BRT has a strong presence in the Americas, Asia, and Australia. The map also shows the countries within geocultural regions, since their characteristics should influence modal distribution.

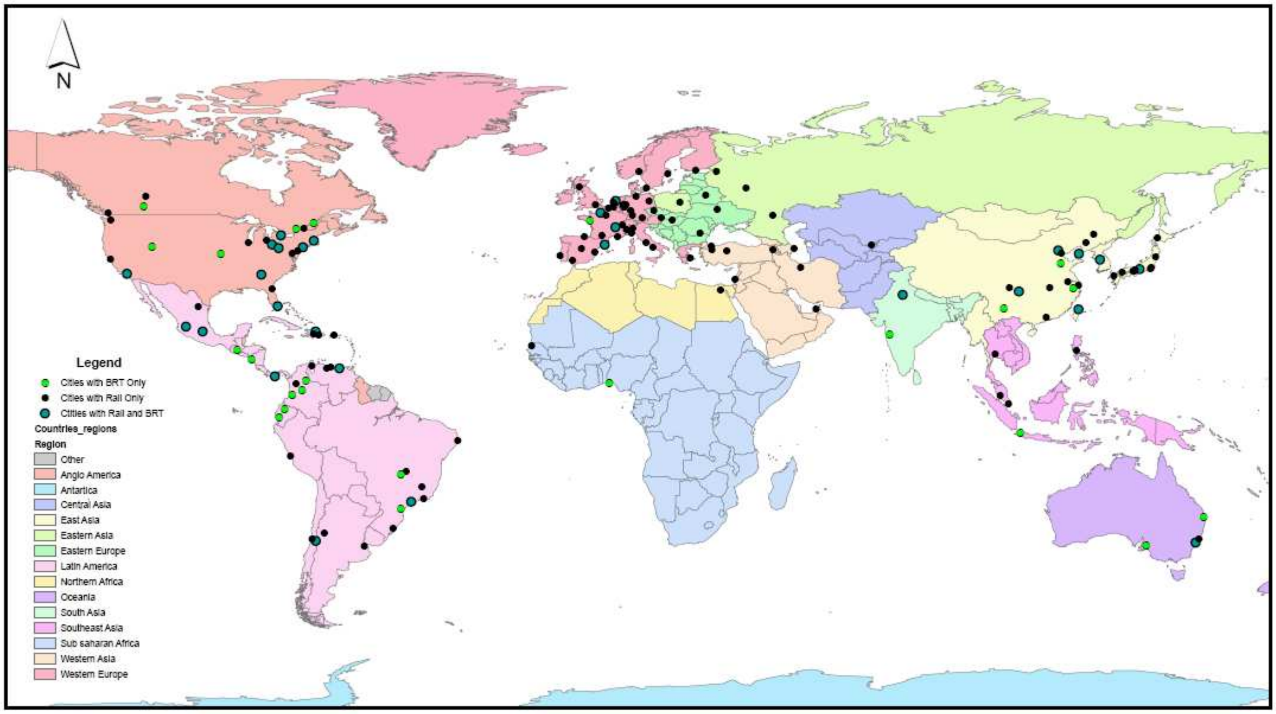

Figure 1. Rapid Transit Systems by Mode

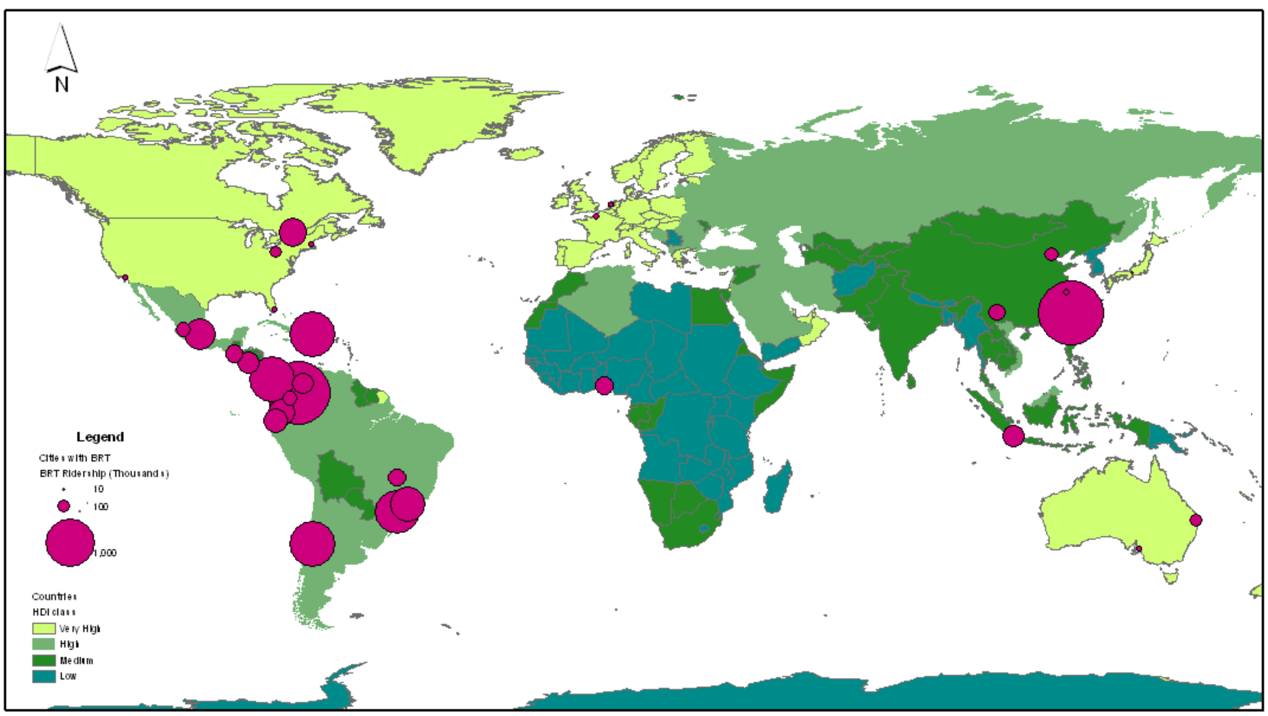

Figure 2. Bus Rapid Transit Systems by Ridership

Figure 2 shows the most relevant BRT systems in the world in terms of ridership and countries by level of human development using United Nations criteria. Even without normalizing for length and population, or modal share, the results clearly show that the utilization level of BRT systems in Latin America is consistently several orders or magnitude above the other regions. The only noticeable systems in terms of ridership in the developed world are in Nagoya (Japan) and Ottawa (Canada). Pittsburgh (USA) and Brisbane (Australia) are still worth mentioning as high ridership systems, but their service quality and capacity would have the potential or much higher patronage. This contrasts with systems like TransJakarta (Indonesia), which is a moderate-low quality BRT system but carries 10 times as many daily passengers as the O-Bahn (Adelaide), which has 5 times as much capacity. This should not come as a surprise, since it is well known that developing countries have a much higher proportion of “captive riders”, but helps but into perspective the different BRT planning principles I have mentioned throughout this thesis.

Despite this contrast, developing countries have been suffering from modal competition within low income travelers in the last 10 years, due to an exponential growth in motorcycle use. While that is not yet a direct problem with having sufficient transit demand, it can affect a systems’ cost effectiveness. In those with no significant subsidies, lower productivity could lead to higher fares, which would create a vicious cycle of increasing motorization. Therefore, the faster systems get implemented without compromising quality, the better chances of continued expansion these could have.

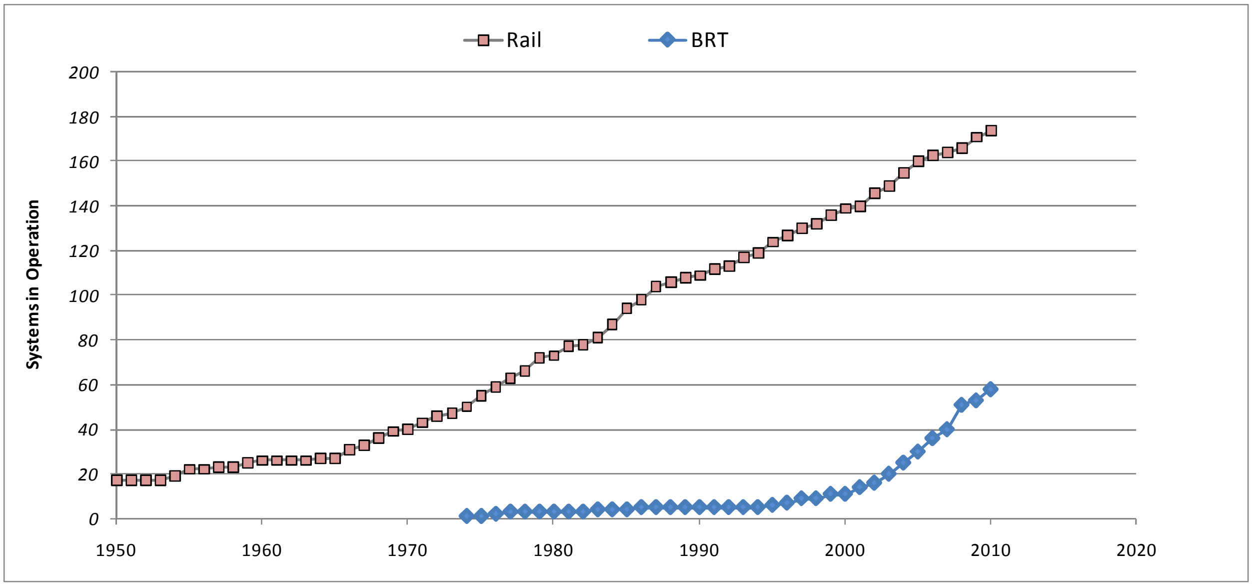

Figure 3. Implementation of Rapid Transit Systems over Time

In this regard, Figure 3 shows that BRT has been really a phenomenon of the last 10-15 years, since the Curitiba model evolved and was replicated. Rail based transit, on the other hand, has kept a linear growth since the late 1960's. What the graph does not show is that within rail as a supra mode, LRT has been gaining more ground over HRT for two main reasons. First, most cities need to fill the gap between their high capacity, low coverage rail systems and their low capacity, high coverage regular bus service, which is most appropriate filled by a BRT-Lite or an LRT (Vuchic, 2007). Second, the prohibitive costs of HRT has led to the popularization of LRRT, which is achieves similar service but at a lower cost. New HRT systems are rare, although they continue to be expanded for demand and political reasons, but a slow pace due to the relative high costs. Figures 4 and 5 better explain the real magnitude of rapid transit systems by showing not only their sheer number but the length of their exclusive right of way (EROW) and their patronage.

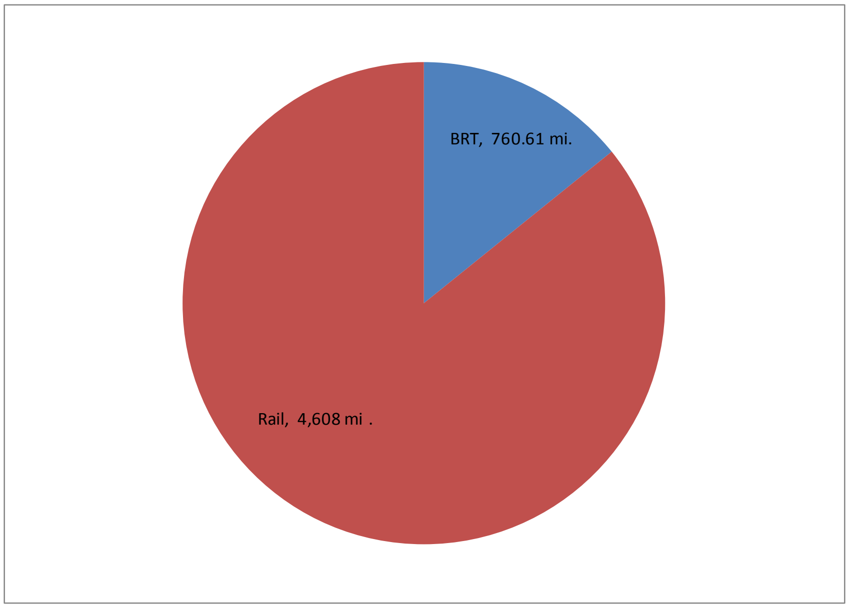

Figure 4. Cumulative Exclusive Right of Way miles for Rapid Transit Systems

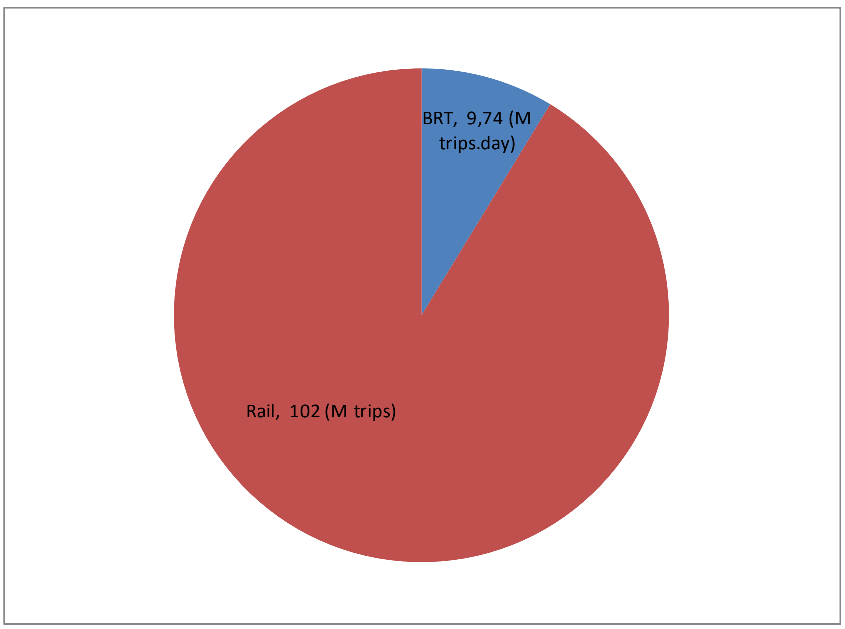

Figure 5. Cumulative Daily Ridership for Rapid Transit Systems[9]

[9] These figures do not take into account all of the systems shown in figure 3, only the ones for which both length and ridership data was found. While data was available for actual length and age of systems, it is not a time series, so real growth cannot be calculated.

Figure 4 shows that BRTs are catching up with rail not only in system quantity but in coverage as well. One out of 10 exclusive right-of-way miles for transit in the world are now used by buses. This was unthinkable 10 years ago. Since most systems until the mid 1990s were based on busways, Figure 4 does not state but suggests that the growth in EROW miles has not been as fast as the growth in systems. This could be confirmed by the many BRT systems that include a significant portion of the trip in mixed lanes. This trend is mostly due to significant improvements in applying signal priority – most often seen in the US - , and phased implementation of BRT elements within an existing corridor, which usually occurs under budget constraints or political pressure. The greater flexibility of BRT with respect to LRT in transitioning from exclusive to mixed right-of-way for many branches becomes a disadvantage when implementers conform to a “bus improvements” concept. Another aspect of this trend is that the exponential growth rate in new systems - which should continue, since more systems are currently planned for the next decade than implemented in the last – is not indicative of their continued expansion. As it is observed later in this chapter, it seems easier to build new systems than to expand them.

Figure 5 shows that BRT’s share of total ridership is similar to its share of total miles of Figure 4. This results supports the argument that (albeit slight differences in IVTT unfavorable to BRT), BRT infrastructure carries just as many passengers as rails on a distance basis. This thesis will not explore the productivity rates for different modes to dispel myths about their capacity, since that has already done before (Mohan, 2008), but it is a finding worth mentioning. As a final observation, a slow system expansion could also be affecting the ridership-to-systems ratio. The next section will explore the practical reasons behind this issue, using case studies.

4.3. Case study selection criteria

What follows from this point on is a deeper look at the characteristics, performance, and implementation issues of related BRT systems. For this purpose, only systems that represent the higher part of a spectrum of BRT systems in terms of system components will be considered. A low threshold is set at the point where systems are not considered according to the definitions of BRT in Chapter 2. This classification will be determined by two metrics defined as the Bus Rapid Transit Classification Score (BRTCLASS) and the Coefficient of Variation of the Bus Rapid Transit Element Classification Score Share (CV – BRTECSS), which are based on the BRT elements framework of the CBRT document (FTA, 2009). Their formulation is shown below:

$$BRTCLASS = \sum_{e=1}^{Nel} BRTECS_e$$

$$CV - BRTECSS = \frac{\sigma(BRTECSS_1 ... BRTECSS_{Nel})}{\mu(BRTECSS_1 ... BRTECSS_{Nel})}$$

Where,

$$BRTECSS_e = \frac{BRTECS_e}{MaxPos..BRTECS_e} = \frac{\sum_{i=1}^{Nsc(e)} Subscore}{\sum MaxPo\text{int}_i}$$

Where,

$$Subscore = \%Met \times MaxPoint_i$$

The "percentage met" means how much of a certain BRT subcomponent the system is accomplishing, with each subcomponent having a maximum score of 100 points (the "maxpoint"). Table 1 shows how both metrics are calculated. Note that for grade separation and TSP the points allocated vary. This variable scoring was included because both components are solutions to a similar problem. Table 2 shows how these translate into a meaningful classification. This is the classification used throughout this paper, since it is simple to define. However, the "Quickway" and "LRL" concepts defined by Cain and Hoffman (2008) are included for comparison purposes.

Table 1. BRT Classification Worksheet

Major elements	Subcomponent	% met		Max Points		Subscore	Max. element score	Element score share
Running Way	% Exclusive		X	17	=		27 to 30	Σ Subscore / Max. Element score
	Grade separation		X	5 to 8	=			
	% Passing @ stations		X	5	=			
Stations	Level Boarding		X	10	=		20	.
	Access & Quality		X	5	=			.
	Off board payment		X	3	=			.
	Auto Payment		X	2	=			
Buses	Capacity Level		X	10	=		15	
	Ease of access		X	5	=			
ITS	AVL w/Control		X	7	=		15 to 18	
	User info system		X	4	=			
	Guidance		X	2	=			
	TSP		X	2 to 5	=			
System	Closed system		X	10	=		20	
	Multiple corridors		X	3	=			
	Multiple routes		X	2	=			
	Modally integrated		X	5	=			
				BRTCLASS	=	Σ		
				CV - BRTECSS	=			σ/μ

Table 2. BRT Interpretation of Classification Metrics

Metric Name	Range of Values	BRT Range	Description
BRTCLASS	0 to 30	RBS	No noticeable improvements
	30 to 60	Pre BRT	Busways or Bus Improvements
	60 to 80	Basic BRT	BRT Lite or BST
	80 to 100	Premium BRT	High Level, true rapid transit
CV - BRTECSS	**Range of Values**	**Element Balance**	**Description**
	0 to 0.2	High	Higher element synergies
	0.2 to 0.4	Medium	Usually one major deficiency
	0.4 to 1	Low	High component disparities

The scoring methodology is not designed to be a performance evaluation metric (i.e. performance based on needs, component synergies, and user experience), but is reliable enough to accurately classify BRT systems. It also serves as an example to show the relationship between characteristics and performance. While the latter sometimes fails to reflect the former, usually an evaluation of characteristics like this method gives a good idea of how the system can perform.

That is why performance is relaxed as a criterion for classification purposes, since assessing it based on actual implementation is precisely what will be done once the systems are chosen. Other practical aspects about choosing a case study are considered, such as data availability and age of system. The summary of the checklist used to choose the BRT system cases is shown in Table 3. All the criteria need to be met to be considered a valid case study prospect.

Table 3. BRT Case Selection Checklist

No.	BRT Case Study Selection Criteria	Met?
1.	BRT Score (BRTCLASS) above 60. BRTCLASS/CV-BRTECSS>100	☐
2.	In operation for one year or more before data acquisition date. (two years if data is gathered from second-hand source).	☐
3.	Reliable and sufficient system data for a high-mid level analysis.	☐
4.	Reliable and sufficient context data for a high-mid level analysis.	☐
5.	Is the case study unique enough in terms of characteristics or known impacts?	☐

Using this methodology, 20 of the most well known "BRT" systems were classified. Out of these, 13 fulfilled the selection criteria (see Table 4). Brisbane Busways, which is arguably a premium BRT system, suffers from the limitations of the method. Otherwise, the scores reflect qualitative descriptions. The systems left out of the case study analyses are all Asian and European systems. The Asian systems were left out because all but Beijing's had a score lower than 60. An exception could have been made for Jakarta, which comes just short of making the list, but is continuously improving and was the first system (the latest is in Lagos, Nigeria) in Asia that tried to make a lighter version of Transmilenio. TransJakarta's implementation issues were studied by Hidalgo (2008) and Wright and Hook (2007) and make a good case study because they show what "not to do" in BRT planning. Classic mistakes in design - small buses with few doors, small stations, and open were made during the first phase. If the scoring method used here had been applied to the system in 2004, it would have scored much lower.

The challenge is that the data needed for the type of analysis performed later in this chapter was not able to be collected - as happened with the two European systems - so no more than a summary of a case study could have been provided. Also, since its problems are clearly identifiable, it is no longer as relevant for people not familiar with BRT planning. More interesting are systems that are arguably successful, but are facing challenges to maintain or improve their success. Finally, to put things into a geographic perspective, Table 5 shows that most established BRT systems fit the "basic" designation, and that all "premium" BRT systems are located in Latin America----not surprising, since this is where the concept was invented. Figure 6 shows this on a map and, not surprisingly as well, shows that "premium" BRT systems correlate well with the high ridership systems observed in Figure 2.

Table 4. BRT Scoring, Classification and Selection

Name	Metro Area	Region	BRT Score	BRT Range	Score variability	Component Balance	Submode	Main Observation
Transmilenio	Bogota	Latin America	90	Premium BRT	0.11	High	"Quickway"	Complete system
Ecovia/Trole/CN	Quito	Latin America	69	Basic BRT	0.40	Medium	Light Rail Lite	Not Integrated
Sistema Integrado	Curitiba	Latin America	84	Premium BRT	0.21	Medium	Hybrid	Integrated, needs upgrade
Interligado	Sao Paulo	Latin America	77	Basic BRT	0.24	Medium	"Quickway"	Low Tech (ITS)
Transantiago	Santiago	Latin America	76	Basic BRT	0.24	Medium	"Quickway"	Infrastructure Deficient
Metrobus	Mexico D.F.	Latin America	88	Premium BRT	0.16	High	"T-Way"	Limiting Infrastructure
TEOR	Rouen	Western Europe	68	Basic BRT	0.34	Medium	Light Rail Lite	Infrastructure Deficient
Zuidtangent	Amsterdam	Western Europe	76	Basic BRT	0.23	Medium	Light Rail Lite	Infrastructure Deficient
Transitway	Ottawa	Anglo America	69	Basic BRT	0.37	Medium	"Quickway"	Low Tech (ITS + Stations)
Silver Line	Boston	Anglo America	70	Basic BRT	0.16	High	Hybrid	Limiting Infrastructure
Busway	Miami	Anglo America	62	Basic BRT	0.37	Medium	"Quickway"	Very Low Tech (ITS + Stations)
South/West/MLK	Pittsburgh	Anglo America	63	Basic BRT	0.57	Low	"Quickway"	Extremely Low Tech (All)
Orange Line	Los Angeles	Anglo America	64	Basic BRT	0.31	Medium	"T-Way" (LRL)	Stations: weakest element
O-bahn	Adelaide	Australia	76	Basic BRT	0.34	Medium	"T-Way"	Stations: weakest element
SE Busway	Brisbane	Australia	75	Basic BRT	0.33	Medium	"Quickway"	Stations: weakest element
Minquan BRT	Taipei	East Asia	49	Pre BRT	0.42	Low	Light Rail Lite	Station-weak, not a system
Median Bus Lanes	Seoul	East Asia	46	Pre BRT	0.40	Low	Light Rail Lite	Highly Infrastructure Deficient
Bus Improvements	Beijing	East Asia	76	Basic BRT	0.24	Medium	Light Rail Lite	User-experience deficiencies
Bus Lanes	Kunming	East Asia	37	Pre BRT	0.55	Low	Light Rail Lite	Just a busway
Transjakarta	Jakarta	Southeast Asia	57	Pre BRT	0.34	Medium	"T-Way"	Low Tech, Mediocre Design

Does not meet Criterion 1
Does not meet Criterion 4

Table 5. Number of BRT systems evaluated

Region	Premium BRT	Basic BRT	Pre BRT	RBS	All types
Latin America	3	3	0	0	6
Western Europe	0	2	0	0	2
Anglo America	0	5	0	0	5
Australia	0	2	0	0	2
East Asia	0	1	3	0	4
Southeast Asia	0	0	1	0	1
All Regions	3	13	4	0	20

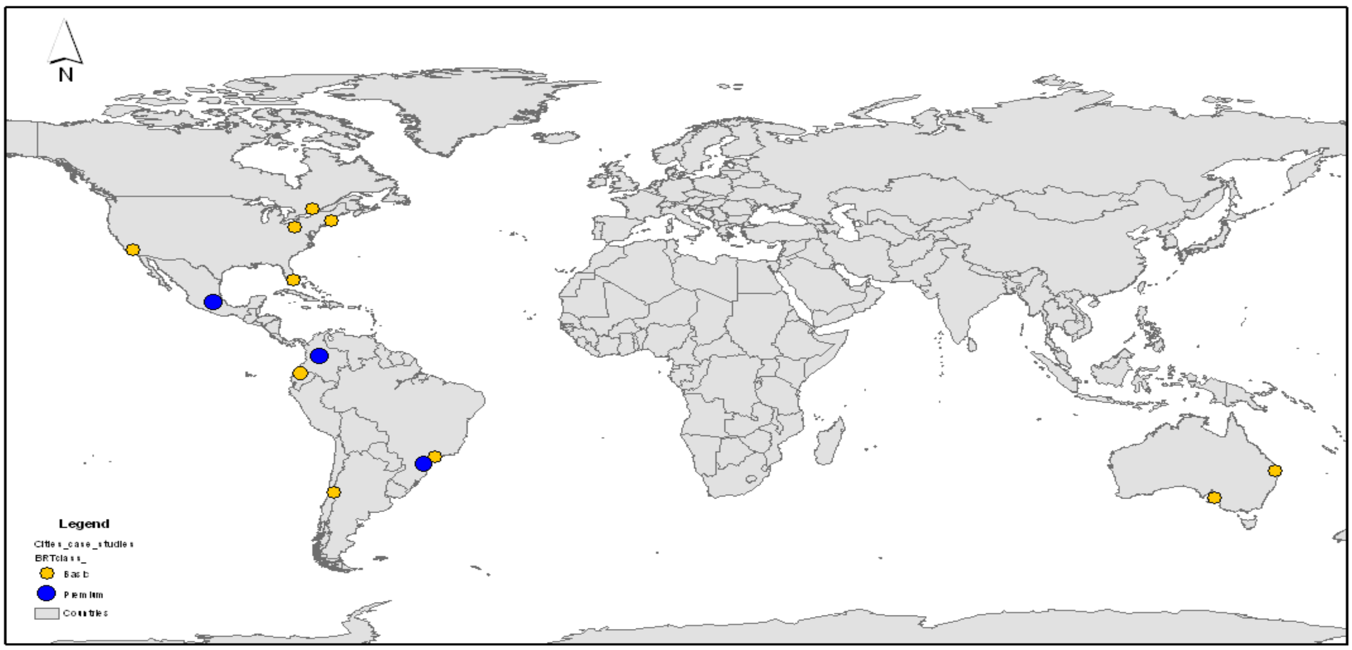

Figure 6. Case studies by BRT Class

4.4. Qualitative Evaluation

This section summarizes the implementation of the 13 systems by comparing key characteristics and identifying current issues. In doing so, the objective is to understand the reasons behind the systems characteristics and performance from a qualitative perspective. By giving a context to the systems, the subsequent quantitative analysis should be easier to interpret.

4.4.1. Context

When a new transit mode emerges, a complex problem arises. Its continued success depends on how it is perceived. Its image greatly depends on the performance of the first few systems that get implemented, and especially, their initial performance. Yet this initial performance suffers more compared to other, more established modes, since there is little experience to draw upon. And if on top of that, the financial constraints and political pressure for rushed implementation that are common in many developing countries are added, chances for success could be very limited. If a major failure occurs, then the industry's modal momentum could be stymied for decades. However, from a more optimistic perspective, these constraints can be used positively to come up with creative, more cost-effective solutions. Given low quality RBS preceding a BRT system and high transit ridership captivity can lead to more satisfied users. All of these conditions presented themselves in South America at a point in time a little more than a decade ago and thus high capacity, fully-featured, premium BRT was born in Bogotá. Before then, notable examples of proto-BRT had been implemented: O-bahn, in Adelaide, Australia; Transitway, in Ottawa, Canada; and RIT, in Curitiba, Brazil. Quito had previously copied some of Curitiba's elements, but the system was quite incomplete at the beginning. So, while these were systems that are now effectively BRT, at the time they did not have all the elements required to fit the modern definition; or if they did, they were not considered a distinctive mode, since they evolved slowly over time, adapting to local conditions. Upon Transmilenio's success in Bogotá, the Federal Transit Administration (FTA) played an important role in promoting this combination of elements as characteristic of a new mode, the first true rapid transit with rubber tires running on concrete. After that, different economic, spatial, institutional, and cultural conditions have made the mode's establishment and maturation perhaps more difficult than expected, despite BRT's popularity. More than difficult, these conditions created an unexpected divergence in scope and quality. In scope, there is the now the well known distinction between "LRL" and "Quickway" and their "siblings". In quality, many systems around the world, especially those in Asia, have copied successful South American BRTs very poorly.

While the case studies are not representative of this wide range of systems since only the highest performing were chosen, their history tells us much about the development of a new mode. Part of their "incremental implementation" and "ease and speed of implementation", which can be huge advantages, are also their Achilles heels, especially when past experience is not applied and quality control is inadequate.

4.4.2. Assessment

Table 6 shows the many factors that affected the implementation of the chosen case studies, how decision-making took place, and how these translated into performance, evaluated from a broad, qualitative perspective. *Function* refers to the place and structure of the system: back--bone, which is basically a trunk-route oriented system that is the major mass transit mode; comprehensive, which means that different levels of BRT cover the whole city; and complementary, when BRT is secondary to another mass transit system.

Table 6. Relationship between urban conditions, implementation, and outcome.

System	Urban Area Characteristics			System Planning and Implementation Approach				Decision-Making		Sustained Outcome		
Name an Location	*Size*	*Density*	*Econ. Dev.*	*Scale*	*Function*	*Integration*	*Expansion strategy*	*Process Direction*	*Main Mode choice reason*	*Expansion speed*	*General Performance*	*Large scale impacts (+ or -)*
Transmilenio, Bogotá	Large	High	Medium	Multiple Corridors*	Backbone	Intramodal	Incremental, Outward	Top-Down	Cost	Slow	Good	Medium
Metrobús-Q, Quito	Medium	High	Medium-Low	Corridor	Backbone	None	Unclear	Top-Down	Cost	Moderate	Fair	Medium
RIT, Curitiba	Medium	High	Medium-High	City-wide	Comprehensive	Intramodal	Incremental, Bidirirectional	Top-Down	Cost	Moderate	Excellent	High
Interligado, Sao Paulo	Very Large	Very High	Medium-High	City-wide	Complementary	Intermodal	Incremental, Bidirirectional	Top-Down	Multimodal integration	Moderate	Fair	High
Transantiago, Santiago	Large	Very High	Medium-High	City-wide	Complementary	Total	Simultaneous	Bottom-Up	Multimodal integration	N/A	Fair	High
Metrobus, Mexico D.F.	Very Large	Very High	Medium	Multiple Corridors	Complementary	Total (P)	Incremental, Outward	Bottom-Up	Cost	Moderate	Very Good	Low
Transitway, Ottawa	Medium	Low	High	Single Corridor	Backbone	Intermodal	Unclear	Bottom-Up	Cost	Slow	Good	Medium
Silver Line , Boston	Large	Medium	High	Multiple Corridors	Complementary	Limited	Incremental, Inward	Bottom-Up	Cost	Slow	Fair	Low
SMD Busway -Mbus, Miami	Large	Medium	High	Single Corridor	Complementary	Intramodal	Unclear	Bottom-Up	Cost	Slow	Fair	Low
Busways, Pittsburgh	Medium	Low	High	Multiple Corridors	Backbone	Total (P)	Incremental, Outward	Bottom-Up	Cost	Slow	Good	Low
Orange Line, Los Angeles	Very Large	Low	High	Single Corridor	Complementary	Intermodal	Incremental, Inward	Bottom-Up	Cost	Slow	Very Good	Low
O-bahn, Adelaide	Medium	Low	High	Single Corridor	Complementary	Intermodal (P)	Incremental	Bottom-Up	Public Choice	Slow	Very Good	Low
Busways, Brisbane	Medium	Low	High	Multiple Corridors	Complementary	Intermodal	Incremental, Bidirirectional	Bottom-Up	Cost	Moderate	Very Good	Medium

Source. Latin American Systems (Hidalgo, 2008). Rest from FTA (2003), and reporting agencies.

Curitiba is unique in this sense given its gradual and successful implementation that benefited from a strong land-use connection. Other cities have integrated the entire public transportation system, including BRT (Santiago and Sao Paulo, which have a "city-wide" *scale*), but the barriers between modes make them only complementary. Their scale of application makes them different types of systems similar to Transmilenio, which in its vision for the future has higher coverage, but in practice only covers a segment of the city through multiple corridors.

A third dimension is called *integration*, which considers how well the system integrates with like modes and other modes. Finally, the expansion strategy tells about the dynamics of the other three variables. First, if the system expands incrementally or results from a simultaneous, "big bang" approach; second, if it displaces other modes and captures the market (outward), or if it is build by segments, complementing other modes (inward). If expansion goes in both directions, which occurs only for well-integrated transportation, then the strategy can be called bi-directional.

This complex implementation approach, which depends on the many characteristics of a city and on the implementers, is carried on through different decision-making processes, mainly top-down or bottom-up. The first generally describes a process led by a strong major or other political figure that expedites the implementation process by having a large degree of control and little public involvement. The second describes a process that can also start at a government level, but is a more rational, pluralistic decision making process, or starts from the community and builds a consensus over time. A top-down approach is more common and effective in developing countries, especially in the short term, while a bottom-up approach may slow things down at the beginning, but tends to work better in more developed democracies. The modal choice, whether it is through a sophisticated alternatives analysis or the personal preference of the Mayor, usually ends up being made due to cost, modal bias, or in a more extensive network, the need for it to bridge the gap between local and ultra-fast service.

Finally, the table relates the contextual, implementation and decision making characteristics of the case studies to long term performance. Performance is expressed in terms of expansion speed, which is very important for the city's and mode's future; general performance, which is a qualitative assessment of how well the system operates from a user's perspective; and large scale impacts, such as the mitigation of city-wide congestion and emissions.

Putting everything together, it can be observed in general terms that higher scales and more inclusive integration tend to have the largest impacts at moderate expansion speeds. City size, density and economic development do not correlate well with sustained outcomes. This result tentatively confirms the concept of the wide urban character range under which BRT is competitive.

Overall, all the systems are expanding at much slower rates than predicted. This affects all public transportation modes and should not come as a surprise. Perhaps then, one of the major advantages indicated by the original BRT literature, implementation speed, should only be interpreted as construction speed, because overall system implementation speed through expansion, even with higher capital cost effectiveness, is not that much higher than for rail.

Implementing BRT might be cheaper and easier if the infrastructure is partially in place, but it is still not simple. Looking at the origins of the 13 systems analyzed explains it better. Table 7 shows how most systems failed to have their technology in place when operations were supposed to start. This could be attributed to political pressure and inexperience in some cases. The main other reason was most likely underestimating the complexity of the BRT's implementation due to the "bus" nature of the system.

Not only was the advanced technology not ready (after all the system ccould work without it), but something as basic as the number and type of buses was wrongly provided. Again, this happened for financial constraints in Santiago, but in most cases usually occurred because of late procurement. This situation occurred more in Latin American, not only because of a "procrastinating culture," but because of the multiple firms owning the buses. From a geographical perspective, systems in the highly developed, Anglo-speaking countries tended to perform better. Australia, in particular, implemented their systems better from the beginning, and still get some of the best press of all the systems studied.

The implementation analysis now moves on to the costs and revenues structure under which the BRT systems operated. This system breakdown is shown in Table 8.

Table 7. Initial system element conditions and effects

Original System Characteristics							Immediate Outcomes/Impacts on		
Name and location	*Year started*	*Infrastructure*	*Buses*	*Stations - FC*	*ITS -C. Control*	*Information*	*Ridership*	*IVTT*	*Acceptance*
Transmilenio I, Bogotá	2000	LQ, Incomplete	Insufficient	Provisional FC	Not ready	Sufficient and effective	High (Moderate Absolute growth)	High decrease	High for users, low for existing operators
Trolebús, Quito	1995	Poor Quality	Insufficient	Coin	N/A	Scarce	Moderate growth	Moderate decrease	Average for users, low for existing operators
Boqueirao, Curitiba	1974	OK	Insufficient	Coin	N/A	Sufficient	High (Moderate Absolute Growth)	Moderate decrease	High among users and existing operators
Passá-Rapido, Sao Paulo	2003	OK	Old-new mix	Problems	No C. control	Sufficient but ineffective	Small growth	Small decrease	Average for users and existing operators
Transantiago, Santiago	2007	Incomplete	Insufficient	Not operational	Not ready	Scarce	Major Decrease (Diverted)	Small decrease	Major rejection
Metrobus Insurgentes, Mexico D.F.	2005	Incomplete	Arrived late	Paper	Not ready	Scarce	Moderate Absolute Growth	High decrease	High for users
Transitway, Ottawa	1983	Good	Small	Manual -onboard	N/A		Moderate growth	Moderate decrease	High for users
Silver Line Washington St, Boston	2004	OK	Insufficient	Manual -onboard, OK	Problems	Sufficient	High growth	Moderate decrease	High for users
SMD Busway, Miami	1997	Good condition	Small	Manual -onboard	N/A		High (moderate absolute growth)		
South Busway, Pittsburgh	1983	Incomplete	Small	Manual -onboard	N/A		High (Moderate Absolute Growth)	High decrease	
Orange Line, Los Angeles	2005	Low Quality	Insufficient	OK	Ready	Sufficient	Outstanding growth (high absolute growth)	Small decrease	
O-bahn, Adelaide	1986	Good condition	Adequate	Manual -onboard	N/A		High (moderate absolute growth)	High decrease	High for users and operators
SE Busway, Brisbane	2001	Good condition	Adequate	Manual -onboard	Ready	Sufficient	High (moderate absolute growth)	Moderate decrease	High for users and operators

Source. Latin American Systems (Hidalgo, 2008). Rest from FTA (2003), and reporting agencies.

Table 8. Revenue management structure and policy

System	**Operating Costs and Revenues**	**Fare establishment mechanism**		**Operating contracts structure**	
Name and Location	Operational Subsidy Level	Formula	Ad-hoc	Direct Negotiation	Competitive Tendering
Transmilenio, Bogotá	None	X			X
Metrobús-Q, Quito	Low		X	X	
RIT, Curitiba	None	X			
Interligado, Sao Paulo	Low			X	
Transantiago, Santiago	Low	X			X
Metrobus, Mexico D.F.	Very Low		X		
Transitway, Ottawa	Medium		X	N/A	N/A
Silver Line , Boston	High		X	N/A	N/A
SMD Busway -Mbus, Miami	High		X	N/A	N/A
Busways, Pittsburgh	Medium		X	N/A	N/A
Orange Line, Los Angeles	High		X	N/A	N/A
O-bahn, Adelaide	High		X		X
Busways, Brisbane	Medium		X	X	

Operating costs tend to be high in developed countries due to high labor costs, leading to subsidized operations. However, the level of subsidy varies. Australian and North American systems tend to have high subsidies. Also, Australians are more willing to experiment with contracting out services, a practice Americans largely abandoned or limited with purchased transportation such as for paratransit. [10] There are many types of contracting practices, but competitive tendering and direct negotiation are the most common, and the success of each depends more on local conditions. Yet competitive tendering tends to work better when technical fares are market-calibrated.

Fare structure varied in developing countries between contractually provided usually through a formula based on service effectiveness[11] (metric explored in the next section of this thesis) or ad-hoc, ranging from pure electoral to social policy to financial distress. Developed countries mostly set their fares in an ad-hoc manner due to financial distress, but they maintain high subsidy levels for social policy and transit patronage reasons. This is the ad-hoc setting of a fare, due to financial trouble is what has happened in the US in the past year, when most agencies raised their fares as one of the many measures to close their increased revenue gap in FY 2009.

Ideally, fares should be determined technically with some market freedom allowing for innovation to at least cover operating costs, a very difficult goal in practice. However, BRT as a competitive mode in terms of costs and of promoting regulated competition for the market shows

[10] In the US, private involvement in public transportation in terms of funding and operating tends to be different in southern States.

[11] Currently, the Latin American model implements "pay-by-km" for operators. This has shown to be more beneficial than the However, experience and theory has also shown that a combination of both is more economically efficient and that is currently piloted in Curitiba.

cities in countries of various levels of development and market-friendliness that public transport does not need to be an ever growing source of subsidies.

Table 9. Success and Problems in BRT systems for different aspects

System Name and Location	Design and Operational		Costs/Financial		Institutional		User Perspective	
	Successes	*Problems*	*Successes*	*Problems*	*Successes*	*Problems*	*Successes*	*Problems*
Transmilenio, Bogotá	High capacity	Crowding at buses and stations	Pays for itself	No funds for maintenance	Clear contractual agreements, independent agency	Unfair intermodal competition, weakened government support	Faster and more comfortable service	High fares
Metrobús-Q, Quito	Low emissions	Not integrated, poor feeder service				No clear institutional independence	Low fares, faster IVTT	High transfer times
RIT, Curitiba	Transit hierarchy	Inefficient operations	Generates profit		Strong authority		Competitive with auto	Crowding
Interligado, Sao Paulo	Intermodal integration	Lane invasions	Pays for itself	Unclear revenue management		Centralized decision making, low pubic input	Seamless integration	Unreliable travel times
Transantiago, Santiago	High coverage	Insufficient fleet	Funding guaranteed	At first, strict finances compromised operations	Important involvement from central government		Faster than before	High transfer times
Metrobus, Mexico D.F.	Efficient operations	Not enough capacity for demand	Strong funding support	Still needs subsidies	High degree of agency independency	Unfair intermodal competition	Much faster than auto in corridor, good quality	Crowding
Transitway, Ottawa	Good capacity and coverage	Poor design downtown, Bus bunching at peak	Costs less than rail to build.	Costs more than rail to operate.	Continued government support	Politicians favoring LRT	Good coverage, few transfers	
Silver Line , Boston	Modern fleet and infrastructure	Low reliability		Expansion not approved for Federal Funding	Had strong support from FTA for first two phases	No strong backing outside MBTA for Phase III	Better than routes displaced	Not as good as subway
SMD Busway -Mbus, Miami	Fast	Design leads to crashes, long headways	Costs less than rail to build.				Effective as feeder service	Its own feeders problematic
Busways, Pittsburgh	Multiple routes	Inefficient operations	Costs less than rail to build.	High operating costs		Politicians favoring LRT		
Orange Line, Los Angeles	Good use of TSP	Not enough capacity for demand, high crash rate, pavement issues	Costs less than rail to build and operate				Serves crucial destinations	Perceived by some as unsafer and lower quaity than rail
O-bahn, Adelaide	Very fast, Guided	Insufficient integration	Costs less than rail to build and operate		Implemented successful operations contracting		Very fast, great option for suburbans	Not enough integration at stations.
Busways, Brisbane	Good integration, fast			High construction costs	Overcame state/local barriers		Well connected	Problems with access at stations, fare collection

Finally, the qualitative evaluation ends with a summary of the assessment of BRT implementation through design and operations, costs and finances, institutional and user perspective lenses. The results are shown in Table 9.

Every system faces challenges, but Curitiba's and Brisbane's systems seem a step above the rest. Judging from previous discussions, it should not come as a surprise. For the other systems, the most recurrent operational problem is crowding either at stations or buses. The lower the "value-of-comfort", the easier it is to maintain these levels without having a significant drop in ridership, so the issue is often overlooked in preference for higher profits. There is also major room for improvement in system integration and operational productivity gains. In terms of costs, funding, and finance, the cases show that BRT is competitive, but not at the same level that was promoted 8 years ago. On the other side, there is another mismatch between the users' perspective and costs. As discussed before, some cities often sacrifice revenues for increased user satisfaction, either for political or social benefit reasons.

In the end, institutional and political barriers should not be overlooked, since these could be one important reason for BRT being less successful than expected. Despite showing good impacts and performance, political support for it is often weak as compared to rail transit.

Judging from this evaluation, BRT has become a significant mode not only in terms of size, but performance as well. Its main problem is that putting together all of its characteristic elements in a way that achieves high performance at minimum cost has been proven to be more difficult than thought. This is because the system, flexible as it is, must adapt to local conditions, and often this is not done in the system optimal way. Yet the mode is relatively new to have a large room for improvement. So far, systems have been implemented mostly on a trial-and-error basis, with several missing elements: limited overall assessment, benchmarking, and a theoretical foundation for planning, design and operations. Hopefully, this thesis has provided some guidance on how these elements can be improved. The next step is to show a quantitative assessment.

4.5. Quantitative Evaluation[12]

So far, BRT performance has been presented in terms of categories, since that approach makes it easier to interpret complex data. Once such analysis has been been able to pinpoint key issues, it is important to complement it with quantitative analysis. To meet this need, a series of key performance indicators (KPI) were applied based on available data. Data availability is poor relative to other fields, so the analysis is somewhat limited in scope, detail and reliability, yet offers substantial information regarding BRT performance. Indicators are ordered by: operations, cost, and access. Some of these tell us more about the supply side (i.e., the service provider perspective) while others describe better the demand side (i.e., user experience perspective). The measures used in this analysis are not categorized as such because the overall picture of system performance is best shown with a set of related performance measures.

4.5.1 Operations

The first indicator shown is "peak load," which is the maximum observed in-vehicle passenger flow at a point along the route (i.e., a station). This is not to be confused with capacity, which is the theoretical value of the maximum flow that the facility can hold. Figure 7 shows the values

[12] Otherwise noted, data comes from: Hidalgo et al. (2008, 2008b, FTA, Transmilenio, Translink, Transantiago, CTS-Mexico, OC Transpo, ITDP, TRB, and MBTA.

for the 13 systems and what is striking is the variability. While the qualitative evaluation showed the systems more evenly paired - a valid assessment - this figure shows how much they differ in this important metric.

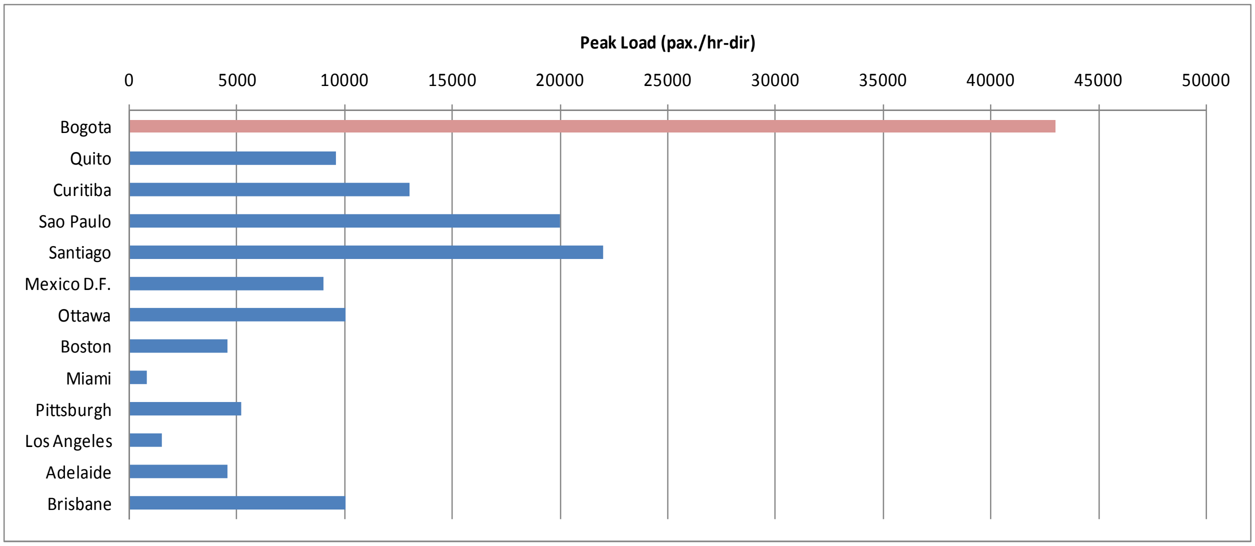

Figure 7. Peak load. Bogotá show in red (or lighter color)

Throughout the thesis, it has been mentioned that one of BRT's main strengths is that it can carry as many passengers as many of the highest ridership rail systems in the world. This claim is mostly due to Transmilenio, since it broke all paradigms of mode-capacity constraints by utilizing 4 lanes at stations (and sometimes for longer segments) providing various degrees of limited stops along a line. Thus, this station capacity is achieved due to the system's service flexibility, more than its vehicles' speed and capacity, as happens with heavy rail systems. While the value means the same for the agency, it has different implications on the type of service provided and the user experience.

One aspect of user experience related to peak load is how crowded the bus is. While Transmilenio's famous 43.000 pax/veh-dir was measured with buses in excess of 160 passengers, in the US a bus the same size cannot hold more than 120. From the agency's perspective, achieving such capacities is only important if there is demand for it. Many of these systems carry fewer passengers per day than TM in a peak-hour in one direction. The absolute number of vehicle capacity is important, but in terms of service quality and efficiency, more important is the relationship between peak load and capacity.

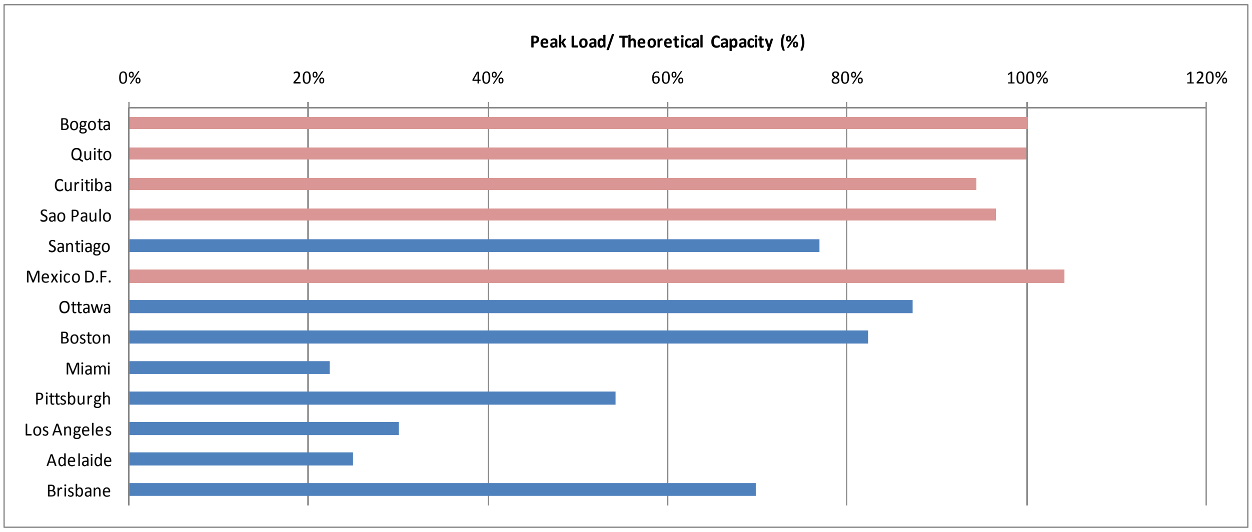

Figure 8. Ratio of Peak load to Estimated Capacity (systems at or near capacity in red).

Figure 8 shows this relationship through a ratio. Non-reported capacity was estimated by looking at the station with the highest ridership potential and making assumptions on traffic saturation rate. Aside from current station design, current fleet was also considered. Passenger capacity was calculated using maximum design levels for bus capacity based on each country's regulations. That is why Metrobús presents higher load than capacity, since it probably was holding more than 150 passengers per 18m bus. What is most important from this figure is that all systems in developing countries are operating at capacity except Santiago, which is just recovering from its implementation problems and could thus be considered an outlier. However, systems such as the Boston's Silver Line, Ottawa's Transitway, and Brisbane's South Busway also present good ratios. On the other hand, a system like Adelaide is sub-utilizing its capacity, but as will be shown later, at the expense of high speeds.

Next is a very important measure of cost effectiveness: operational productivity. Figure 9 shows this value for the 13 systems.

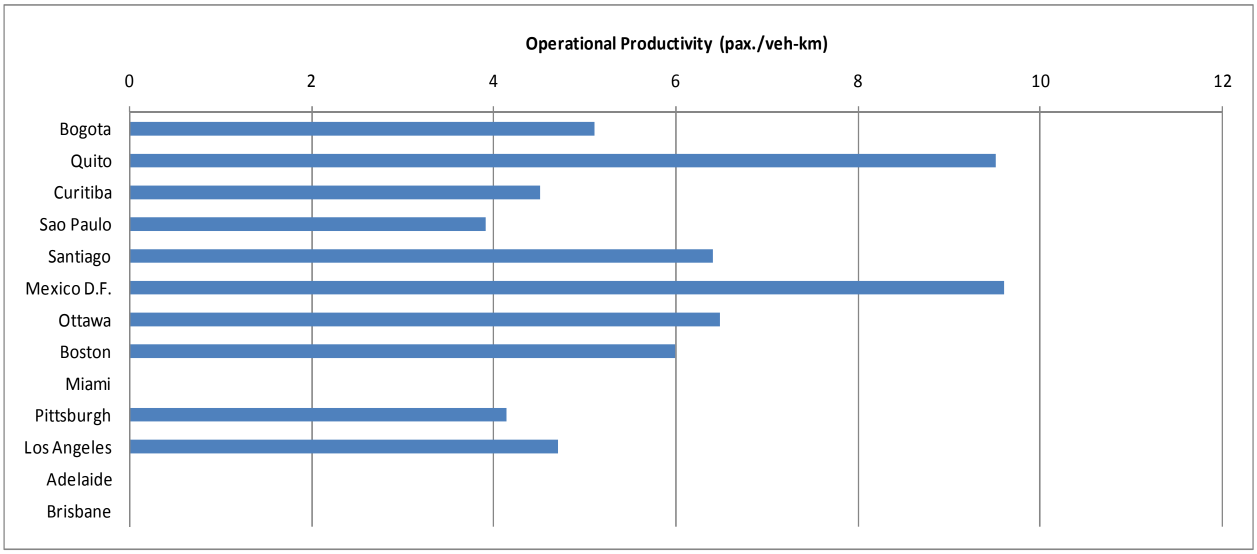

Figure 9. Operational Productivity. Data unavailable for Santiago.

Operational productivity is a key measure because it tells how efficiently a transit system is operating. It is easy to interpret because it basically means how many passenger boardings on average occupy a bus per unit of distance traveled. In the operating contracts in Bogota and Santiago, it is one of the most important variables affecting the fare. The higher the value, the better the system should be. However, from the user's perspective, a very high productivity could be detrimental in the case of bus and station crowding, with passengers often missing their trips. This low level of service is often not addressed and a larger focus is put on the agency's performance measures. Figure 9 shows that Transmilenio has a low productivity with respect to the average, and the main reason is that it operates almost empty on parts of the route. This could be easily improved with relatively inexpensive infrastructure improvements.

One performance measure that directly affects users is the commercial speed of the service. This represents the average speed, including stops, of a set of buses running through a corridor or system.

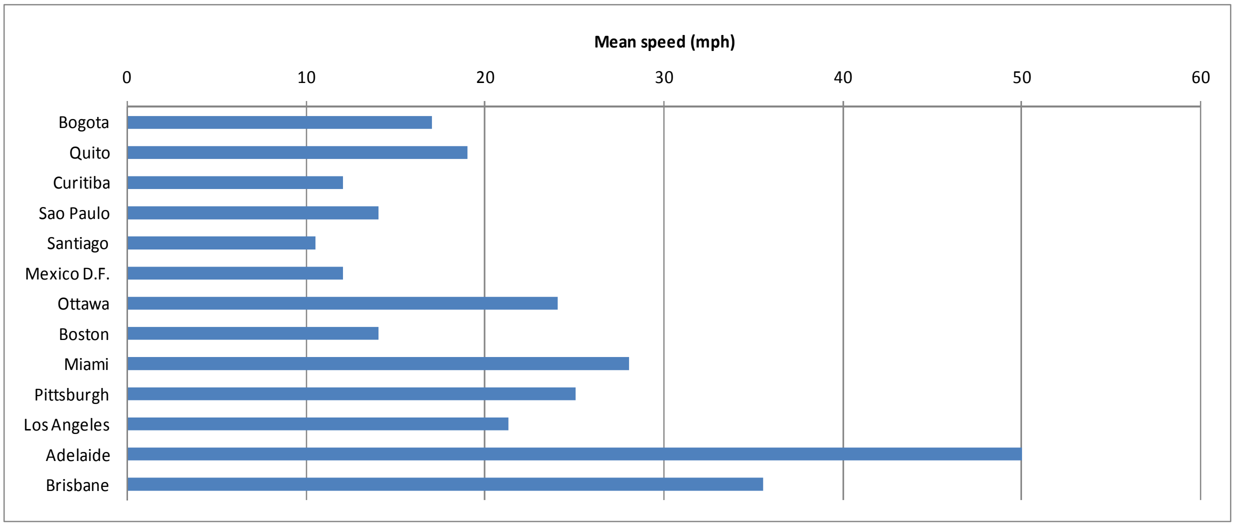

Figure 10. Commercial speed

Figure 10 compares this speed for the thirteen systems. All speeds in developing countries fall within the 10 to 18 mph range, while developed countries tend to show higher speeds. Commercial speed depends on many factors, especially the number of and distance between stops along a route. In terms of BRT elements, higher speeds result from highly segregated infrastructure, including grade separation at intersections. As developed countries usually have grade separation (or at least traffic signal priority) and long spacing between stations, their speeds are on average higher than in developing countries, where stations are closer together, lanes are often at grade, and no TSP is included. Nonetheless, in systems like Transmilenio, there are express services in which speeds are much higher than the average.

Dwell times also affect speed significantly. Dwell times for TM are 67% higher than in the Transitway or the Orange Line, which shows a tradeoff between speed and load. Finally, while commercial speed is important, focusing on it by itself is useless. The higher the access and connectivity of a system, the less important it becomes. Adelaide is remarkable in that it achieves speeds previously only displayed by rail systems, yet its design would not fit many other contexts.

4.5.2 Costs

Another set of performance indicators relates primarily to cost, and especially the cost efficiency and effectiveness of a system. From the operator's perspective, capital productivity is very important since it tells how efficiently the bus fleet is used. Figure 11 shows the values for the case studies. Although from a service effectiveness perspective Bogota's system needs improvement (Figure 9), in terms of how efficiently the fleet is utilized, it ranks high, along with Mexico City. Systems in developed countries struggle more with making the most out of their fleets, since they need to have a sufficient fleet size to provide a desired level of service. Peak-off peak patterns could be affecting these values too, so a dimensionless ratio of the average hourly ridership on the busiest line to the maximum hourly ridership on a segment would represent how intensively the fleet is being used. Data was not sufficient for all systems to calculate this value accurately.

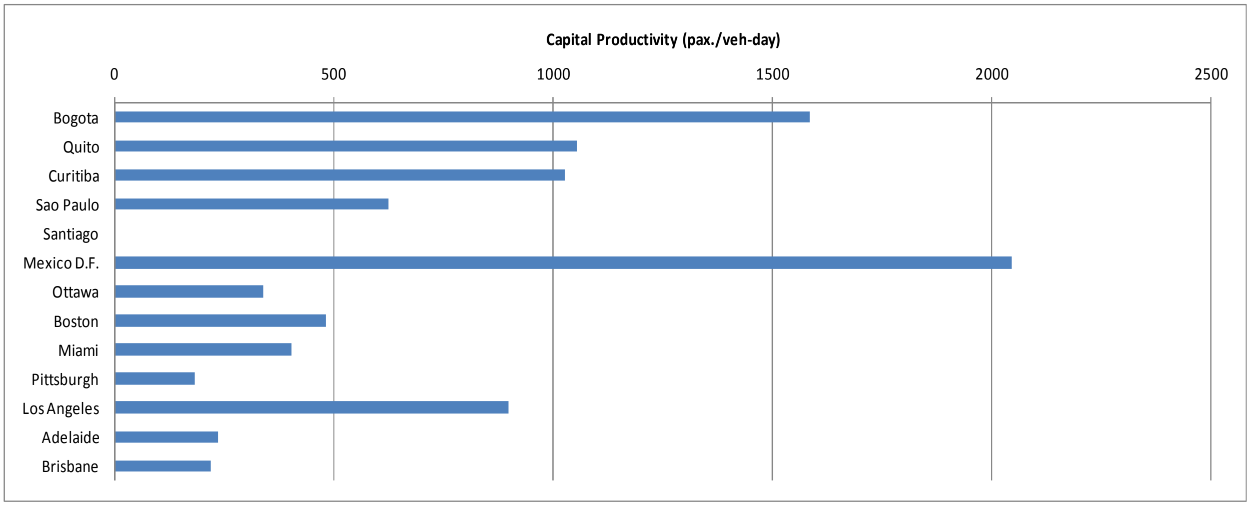

Figure 11. Capital productivity

Capital productivity considers fleet usage, but not the costs of operation or the cost of the infrastructure. Another measure of capital cost effectiveness is the annualized cost per passenger, which can be interpreted as a subsidy. It is the ratio of the annualized payments of the system's infrastructure costs in PV (2008) to the number of passenger boardings per year. If the annualized operating costs are added and the annualized revenues per passenger are subtracted from this value, the annualized subsidy results. To calculate the annualized capital cost, a 20 year life was assumed, since the durability and permanence of BRT is still debated, and the discount rate assumed 5% for US systems and applied a risk premium for the rest. Ridership was assumed constant for the built infrastructure. The results are shown in Figure 12, which shows that the variability between annualized costs per passenger is extremely high. Also notice that there is a noticeable difference between developed and underdeveloped countries, although Sao Paulo and Adelaide are very similar, and Ottawa is very similar to Bogotá.

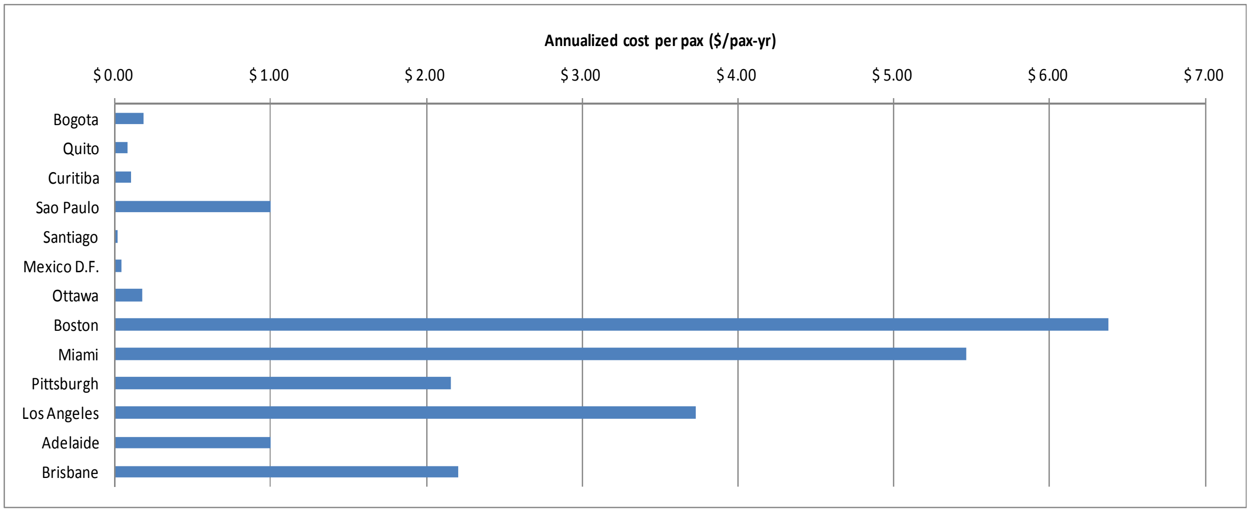

Figure 12. Annualized capital cost per passenger

Figure 12 shows that the variability between annualized costs per passenger is extremely high. Also notice that there is a noticeable difference between developed and underdeveloped countries, although Sao Paulo and Adelaide are very similar, and Ottawa is very similar to Bogotá. Ottawa is special because it has the highest ridership of all developed countries, and its costs could be underestimated given it was built many years ago and many of the costs could have been misrepresented in current dollars. Boston and Miami represent situations where systems are not cheap, even when they are portrayed as such. Boston made an enormous investment in its Waterfront line for only minimal levels of ridership, and it is doubtful that its benefits will ever justify this investment. Perhaps this result has contributed to putting Phase III on hold. Miami had a high cost because a busway was built almost from scratch to serve a low number of passengers. These results are important, because they show that BRT per se is not an inexpensive mode. It is competitive when the right of way is available for use, but when extensive new grade separation investments and transfer facilities are needed, and unless the system carries very high volumes, BRT loses its comparative advantage in terms of capital costs per rider.

Values for operating cost effectiveness are not available for most systems, so a comparative graph is not presented, but the available data shows that BRT is indeed competitive in terms of operational cost even when service effectiveness (Figure 9) is not very high. Since RBS is much less efficient, the numbers favor BRT. While the MBTA reports a 40% farebox recovery ratio (NTD, 2008), the number is closer to 70% for the Silver Line, as the average trip costs only $1.25. Pittsburgh, which also has a light rail line, reports $2.73 per trip for its West Busway, higher than for its LRT, and a $1.02 average for its East Busway, lower than its LRT (FTA, 2009; NTD, 2008). In Adelaide, costs are much higher, but an average busway trip is subsidized by 2.9 AUD compared to 8.8 AUD for the rail system[13]. This lower subsidy compared to rail could in fact be affected by the competitive tendering process that took place when contracting bus operations.

Finally, Latin American systems are known to have the capability to "break even", since their labor costs are much lower even in more developed cities like Curitiba and Santiago, and the ridership is so high. Bogotá has relatively high cost operations due to its low service effectiveness, while Mexico City and Quito take advantage of their high effectiveness to lower their fares. These services are subsidized, but not significantly.

Regarding fares, it is important to illustrate them from the users' perspective. Since income levels vary largely across the cities studied, fares should be normalized by median income in order to determine their impact on users. Figure 13 shows the share of fare–to-income.

[13] Source: Wikipedia. Retrieved October 6, 2010.

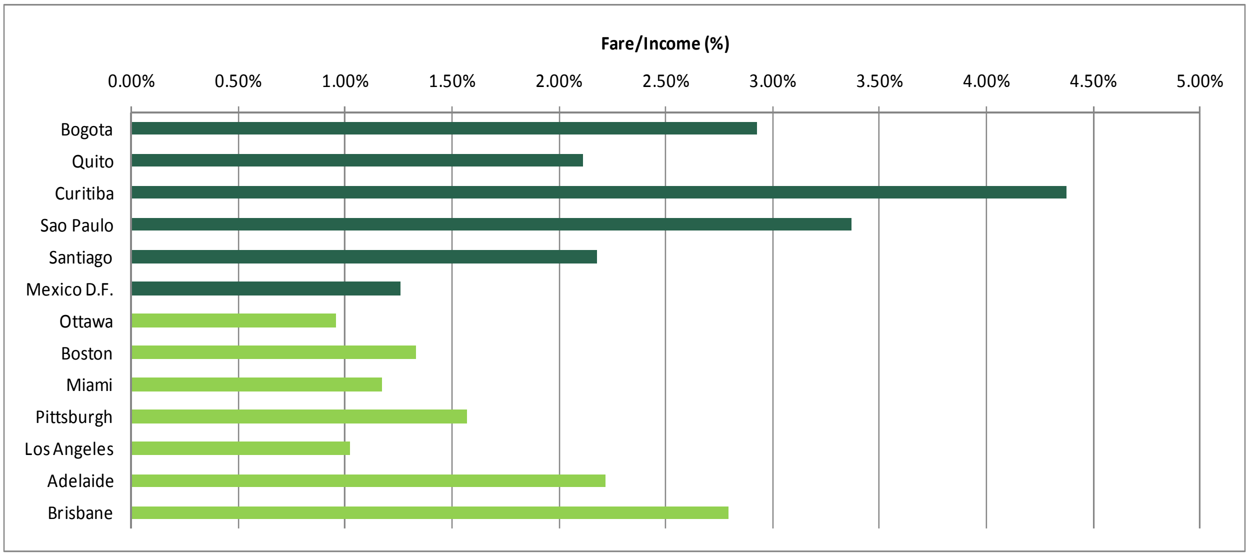

Figure 13. Fare impacts on user budget. (Low development cities in dark green)

From this perspective, values are not as different from region to region, although North American systems tend to have lower shares due to a combination of heavy subsidies and high incomes. Although people do not perceive the money they pay in taxes the same as they would pay with a token, most are aware of the subsidy. Curitiba shows the highest value, yet it remains competitive because of the high level of integration of its system. The fare is relatively high, but the system generates profits that go to reinvestment, and its impacts on urban form and quality of life are so noticeable, and contrasts so much with the congested streets, that people are willing to pay the fare.

Figure 14 looks at fares from a different perspective: the purchasing power and how it compares to the travel time cost, since passengers base their travel decision on the combination of both. This comparison allows us to put into perspective the fare across cities.

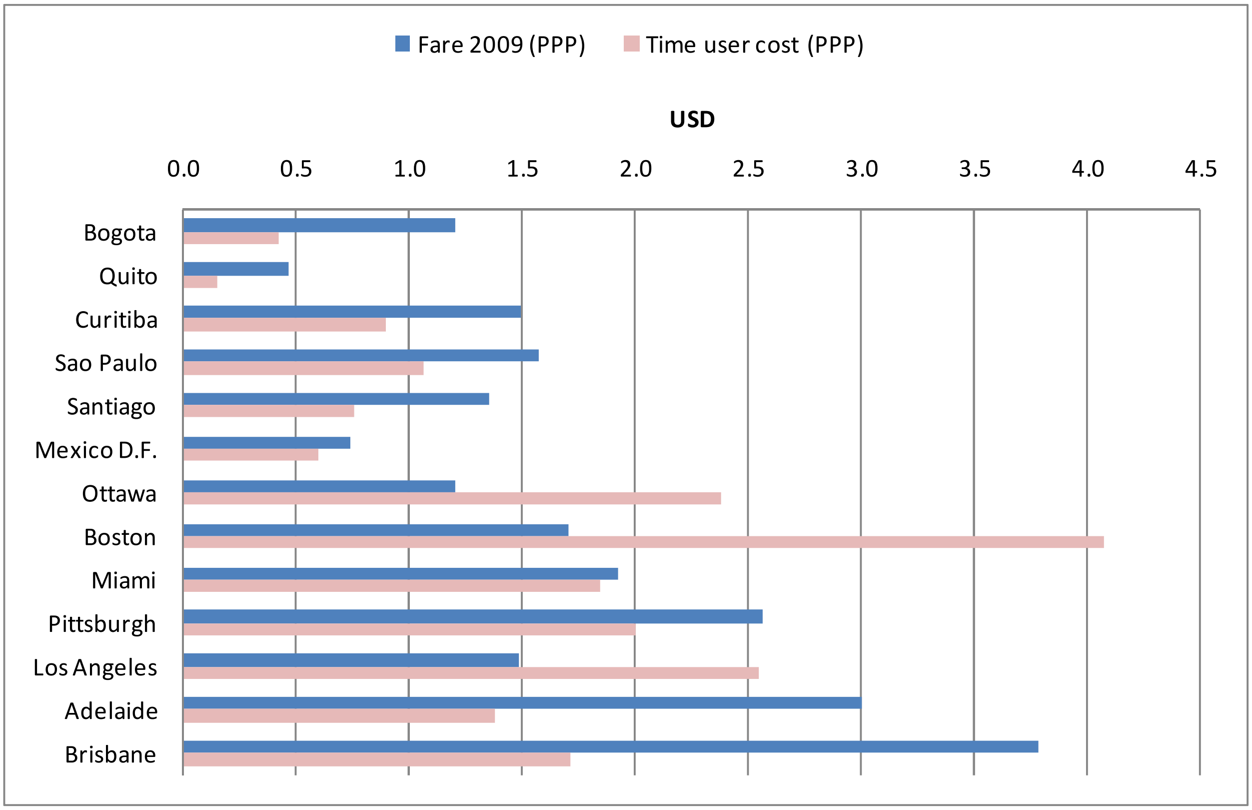

Figure 14. Fare and travel time cost for 5 mi trip, normalized by purchasing power.

Travel time cost was estimated for a 5 mile trip with no transfers, and a quarter-mile walking distance to a station. This cost is seen to be significant, similar to the fare or exceeding it in most cities, except in Bogota, Quito, Adelaide and Brisbane. Fares can be inelastic even for non-captive riders with increasing congestion. This could make it attractive for transit agencies to raise fares, if income equity is not considered. Investment in fully featured BRT systems could bring large benefits, and fares could be increased to reasonable levels if social benefits occur.

4.5.3 Access

Access is a complex concept that considers variables such as coverage, connectivity, and equity. A first approach in understanding the BRT system's impacts on the cities they serve is to look at how many people they effectively serve. Figure 15 shows the share of daily trips to population.

This is not equivalent to the share of population using transit since people make a different number of trips every day.[14] Yet it gives an order of magnitude estimate of how large and effective is the system. The results are not surprising given what has been discussed in this chapter. The top performing systems have a relatively high share, which also depends on the function of the system described earlier in the chapter. Ottawa stands out within North American systems, since BRT is the main mass transit mode in this small, low density city. Mexico DF has a great system, but by 2009 only had two lines while the subway had eleven.

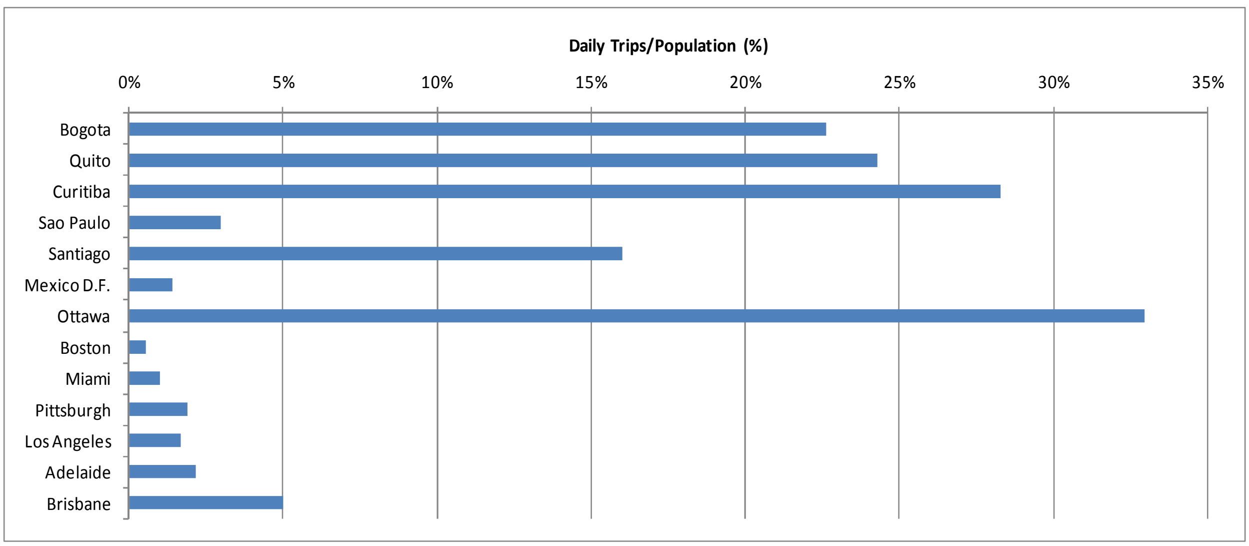

Figure 15. System coverage by population

Another way to look at coverage is from a spatial perspective. If we assume a transit supportive area and a BRT service area based on TCQSM (2003) criteria, we can come up with a ratio called THEMP (Theoretical Market Penetration). Figure 16 shows the results of calculating this new metric.

[14] The increased use of smartcards allow for a clearer distinction between trips and riders.

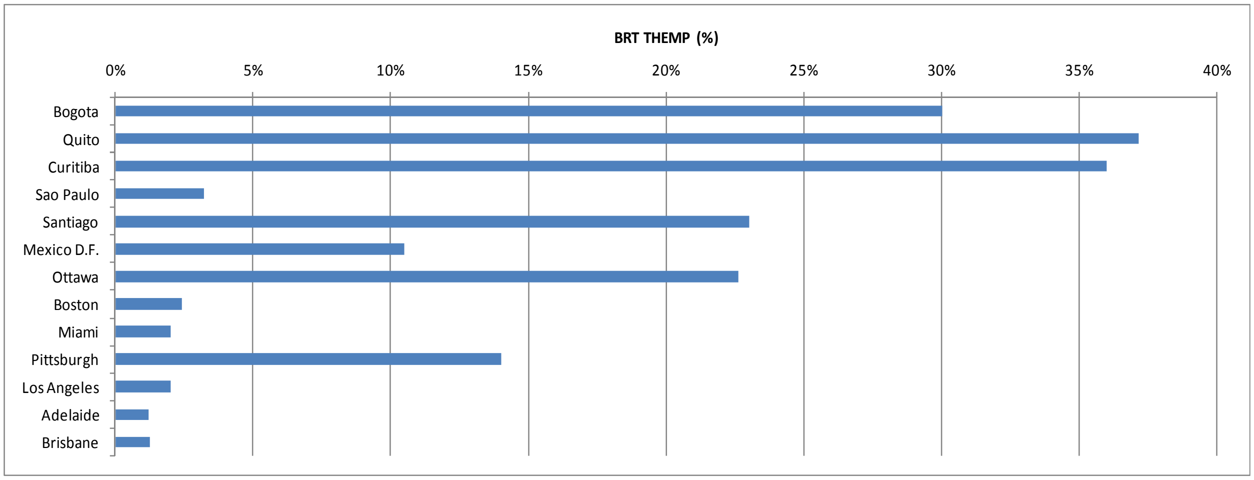

Figure 16. System coverage by theoretical service area

The figure shows that systems where BRT is the most important mode of mass transit already cover a significant amount of the metropolitan area and, in theory, the population. Using both Figures 15 and 16 one sees that Transmilenio consists of only 52 of the proposed 242 miles (21%), and covers 30% of the theoretical transit supportive area. It is expected that with increased expansion, the marginal coverage will decrease, but connectivity will increase.

To better understand how coverage interacts with population and space, another metric was developed, called the CII (Coverage Intensity Index). This index is the ratio of the share of transit trips made on BRT to the THEMP. It is basically the ratio of the real versus theoretical modal share. A value of one would represent equal attractiveness of BRT with respect to other modes. The index has its limitations, especially when the transit network is intermodally well connected (as in Sao Paulo, Santiago, Mexico), so it should be interpreted with caution.

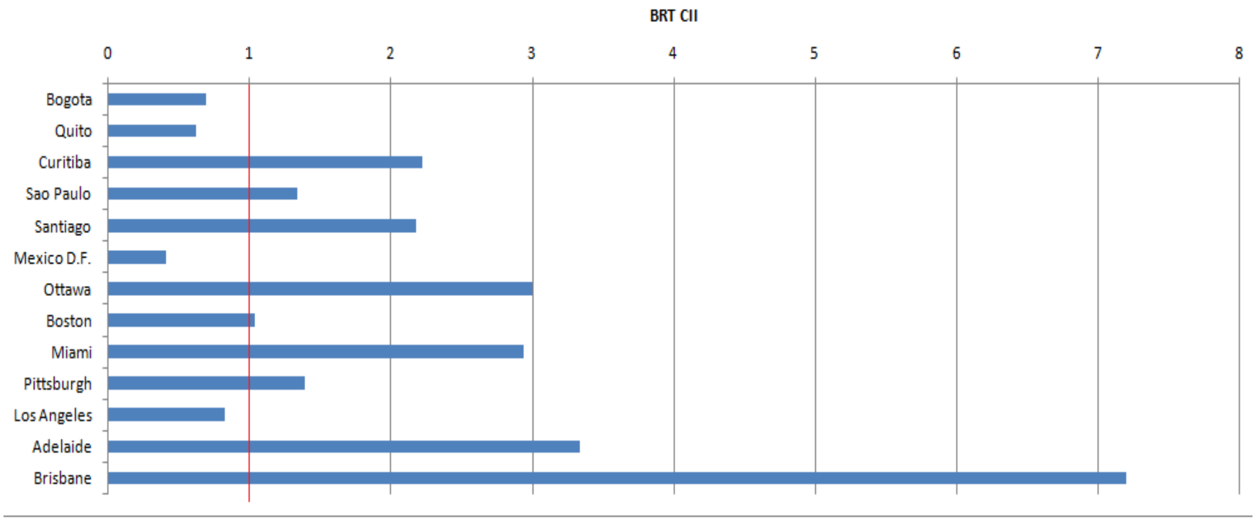

Figure 17. System coverage by BRT intensiveness

Ceteris paribus, Figure 17 suggests that systems that suffer from competition in the market with other bus systems (e.g. Bogotá, Quito, Mexico) fare less well than others who are either the dominant mode (e.g. Curitiba, Ottawa), or well integrated with other modes. The results are surprising for Adelaide and Brisbane, and could help explain the high user ratings for those systems.

4.6. Conclusions

This review, performed from both qualitative and quantitative perspectives, has largely agreed with previous literature in that it shows bus rapid transit as a relevant mode in a universal context that has not yet fulfilled its potential. Yet this study complements that literature by looking at some of the most representative BRT systems in the world and assessing them through objective and comprehensive criteria. From this review, the following conclusions can be extracted:

- Bus Rapid Transit is in fact a distinctive mode. A popular opinion within a large community including practitioners is that the name is just a rebranding used by the FTA and transit lobbyists to describe minor improvements in bus transit. That opinion is wrong; BRT describes a bundle of characteristics that make it fundamentally different to the still important local bus service (RBS in this thesis). These characteristics come in two forms: elements and interaction between them. A focus on just the elements does not necessarily constitute BRT. Despite BRT being part of a quasi-continuous range of bus transit, the discontinuity takes place when reliability and speed are significantly improved, and flexibility and direct access are significantly reduced.

- Bus Rapid Transit is cost-competitive, even in highly developed economies.

  Due to its service pattern, BRT can compensate its labor cost disadvantage with high productivities that allow it to be competitive under most economic and network size conditions.

- Bus Rapid Transit implementation is more complex and usually slower than originally thought. According to the special characteristics of BRT, in order to make it cost efficient, effective, and rapid, important decisions in terms of element design and implementation strategies need to be well defined with enough time. Otherwise, problems that even successful systems had will be repeated.

REFERENCES

Ardila, Arturo. How Public Transportation's Past is Haunting its Future in Bogotá, Colombia. In: Proceedings of the 2007 Annual Meeting of the Transportation Research Board – CDROM, January 2007, Washington, D.C.

Ardila, Arturo. Transit Planning in Curitiba and Bogotá: Roles in Interaction, Risk, and Change. MIT, September 2004, Cambridge, MA.

Bruun, Eric. Bus Rapid Transit and Light Rail: Comparing Operating Costs with a Parametric Cost Model. Transportation Research Record: Journal of the Transportation Research Board, Issue 1927, 2005, pp 11-21

Cain, A. and Hoffman, Alan. Advanced Network Planning for Bus Rapid Transit: The "Quickway" model as an alternative to "Light Rail Lite". Publication FTA-FL-26-7104-2007.4, FTA, US Department of Transportation, 2008.

Cain, Alasdair; Darido, Georges Bianco; Baltes, Michael R; Rodriguez, Pilar; Barrios, Johan. Applicability of TransMilenio Bus Rapid Transit System of Bogotá, Colombia, to the United States. Transportation Research Record: Journal of the Transportation Research Board, Issue 2034, 2007, pp 45-54

Callaghan, Lisa. Funding Bus Rapid Transit in the United States. Transportation Research Board 87th Annual Meeting; 2008, 19p

Callaghan, Lisa; Vincent, William. Preliminary Evaluation of Metro Orange Line Bus Rapid Transit Project. Transportation Research Record: Journal of the Transportation Research Board, Issue 2034, 2007, pp 37-44

Campo, Carlos A.. Bus Rapid Transit from a Sustainability Perspective: The Latin American Experience:. Accepted In: Proceedings of the 2011 Annual Meeting of the Transportation Research Board – CDROM, January 2011, Washington, D.C.

Chang, M; Darido, G; Kim, E; Schneck, D; Hardy, M; Bunch, J; Baltes, M; Hinebaugh, D; Wnuk, L; Silver, F; Zimmerman, S. CHARACTERISTICS OF BUS RAPID TRANSIT FOR DECISION-MAKING. Booz Allen Hamilton; Federal Transit Administration, 2004

Daganzo, Carlos F. Structure of Competitive Transit Networks. Transportation Research Part B: Methodological, Volume 44, Issue 4, 2010, pp. 434-446

Darido, G., Cain, A. Report on South American Bus Rapid Transit Field Visits: Tracking the TransMilenio Model. National BRT Institute. December 2007, Tampa, FL.

Diaz, R.B., D. Hinebaugh, , Characteristics of BRT for Decision Makers, Publication FTA-VA-26-7109-2009.1, FTA, US Department of Transportation, 2009.

EMBARQ. The WRI Center for Sustainable Transport. México City: Metrobús. [Online] http://www.embarq.org/en/project/México-city-Metrobús
Accessed: February 8, 2010

Grutter, Jurg. Transmilenio and CDM. Grutter Consulting, January 2008, Bogotá D.C.

GAO (2001). Mass Transit: Bus Rapid Transit Shows Promise. Washington, D.c.: United States Government Accountability Office.

Hensher, David A; Tirachini, Alejandro;Jara-Diaz, Sergio R. Restating Modal Investment Priority with an Improved Model for Public Transport Analysis. Transportation Research Part E: Logistics and Transportation Review, Volume 46, Issue 6, 2010, pp 1148-1168

Hensher, David A; Golob, Thomas F. Bus Rapid Transit Systems: A Comparative Assessment. Transportation: Planning, Policy, Research, Practice, Volume 35, Issue 4, 2008, pp 501-518

Hensher, David A. Sustainable Public Transport Systems: Moving Towards a Value for Money and Network-Based Approach and Away from Blind Commitment. Transport Policy, Volume 14, Issue 1, 2007, pp 98-102

Hensher, David A; Wallis, Ian P. Competitive Tendering as a Contracting Mechanism for Subsidising Transport: The Bus Experience. Journal of Transport Economics and Policy, Volume 39, Issue 3, 2005, pp 295-321

Hess, Daniel B; Taylor, Brian D; Yoh, Allison C. Light Rail Lite or Cost-Effective Improvements to Bus Service? Evaluating Costs of Implementing Bus Rapid Transit. Transportation Research Record: Journal of the Transportation Research Board, Issue 1927, 2005, pp 22-30

Hidalgo, D., Custodio, P., Grafiteaux, P., 2007. Planning, Implementation, and Operation of Bus Rapid Transit Systems: Cases of Quito, Bogotá, Leon, México City, Jakarta and Beijing. In: Proceedings of the 2007 Annual Meeting of the Transportation Research Board – CDROM, January 2007, Washington, D.C.

Hidalgo, Dario; Graftieaux, Pierre. Bus Rapid Transit Systems in Latin America and Asia: Results and Difficulties in 11 Cities. Transportation Research Record: Journal of the Transportation Research Board, Issue 2072, 2008, pp 77-88

Hidalgo, Dario, and Sandoval, Edgar. 2002. Transmilenio: A High Capacity – Low Cost Bus Rapid Transit System Developed for Bogotá, Colombia. Proceedings of the 2nd International Conference on Urban Public Transportation Systems. ASCE, 2004.

Echeverry et al. The Economics of Transmilenio, a Mass Transit System for Bogotá. CEDE, Universidad de Los Andes, August 2004, Bogotá D.C.

Karlaftis, M G; McCarthy, P. OPERATING SUBSIDIES AND PERFORMANCE IN PUBLIC TRANSIT: AN EMPIRICAL STUDY. Transportation Research Part A: Policy and Practice, Volume 32, Issue 5, 1998, p. 359-375

Levinson, Herbert, Danaher, Alan et al (2007). TCRP Report 118: Bus Rapid Transit Practitioners Guide. *Transit Cooperative Research Program,* 2007

Levinson, Herbert, Samuel Zimmerman et al (2003). TCRP Report 90: Bus Rapid Transit Volume 1: Case Studies in Bus Rapid Transit. *Transit Cooperative Research Program,* 2003

Light Rail Now! Mythbusters Weblog. "Free buses vs Expensive Rail" [Online] http://www.lightrailnow.org/myths/m_mythlog001.htm#STL_20070531 Accessed: April 4, 2009

Lleras, Germán (2003). *Bus Rapid Transit: Impacts on Travel Behavior in Bogotá*. MastersThesis. Department of Urban Studies and Planning. MIT. Boston, Massachusetts.

Mohan, Dinesh. Mythologies, Metros and Future Urban Transport. TRIPP Report 08-01. New Delhi: Transportation Research and Injury Prevention Program. 2008

Obeng, K; Sakano, R. TOTAL FACTOR PRODUCTIVITY DECOMPOSITION, INPUT PRICE INEFFICIENCIES, AND PUBLIC TRANSIT SYSTEMS. Transportation Research Part E: Logistics and Transportation Review, Volume 38, Issue 1, 2002, p. 19-36

Peñalosa, E. 2005. Comentarios al artículo "Una evaluación económica del sistema Transmilenio" de Juan Carlos Echeverry, Ana María Ibáñez y Andrés Moya. Revista de Ingeniería No. 21. Universidad de Los Andes. Bogotá D.C.

Puchalsky, Christopher M. Comparison of Emissions from Light Rail Transit and Bus Rapid Transit. Transportation Research Record: Journal of the Transportation Research Board, Issue 1927, 2005, pp 31-37

Rodríguez, D.A., and C. Mojica. 2008. Capitalization of BRT network expansions effects into prices of non-expansion areas". Transportation Research Part A, vol. 43. 560-571

Rodríguez, D. A., and F. Targa. 2004. Value of accessibility to Bogotá'sbus rapid transit system. *Transport Reviews* 24 (5):587–610

Schimek, Paul; Watkins, Kari; Chase, David; Smith, Karl; Gazillo, Stephen. Silver Line Waterfront Bus Rapid Transit (BRT) Project 2007 Evaluation. Washington Group International; Wilbur Smith Associates; Federal Transit Administration, 2007

Vincent, William; Jerram, Lisa Callaghan. The Potential for Bus Rapid Transit to Reduce Transportation-Related CO2 Emissions. Journal of Public Transportation, Volume 9, Issue 3, 2006, pp 219-238

Vuchic, Vukan R. Urban Transit Systems and Technology. John Wiley & Sons, Incorporated, 2007, 602p

Vuchic, Vukan R. Light Rail and BRT: Competitive or Complementary?. Public Transport International, Issue 5, 2005, pp 10-13

Vuchic, Vukan R. Urban Transit: Operations, Planning, and Economics. John Wiley & Sons, Incorporated, 2005, 660p

Vuchic, V R. BUS SEMIRAPID TRANSIT MODE DEVELOPMENT AND EVALUATION. Journal of Public Transportation, Volume 5, Issue 2, 2002, p. 71-95

Zhang, Ming, 2009. Bus Versus Rail: Meta-Analysis of Cost Characteristics, Carrying Capacities, and Land Use Impacts. In: Proceedings of the 2009 Annual Meeting of the Transportation Research Board – CDROM, January 2009, Washington, D.C.