SOCIAL, ENVIRONMENTAL AND ECONOMIC IMPACTS OF BRT SYSTEMS

Bus Rapid Transit Case Studies from Around the World

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CONTENTS

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EMBARQ catalyzes and helps implement environmentally, socially and financially sustainable urban mobility and urban planning solutions to improve people's quality of life in cities. Founded in 2002 as a program of the World Resources Institute (WRI), EMBARQ operates through a global network of centers in Brazil, China, India, Mexico, Turkey and the Andean region.

The EMBARQ network collaborates with local and national authorities, businesses, academics and civil society to reduce pollution, improve public health, and create safe, accessible and attractive urban public spaces and integrated transport systems. EMBARQ has built its global recognition on its local experience, and addressing national and international policies and finance. More information at www.EMBARQ.org

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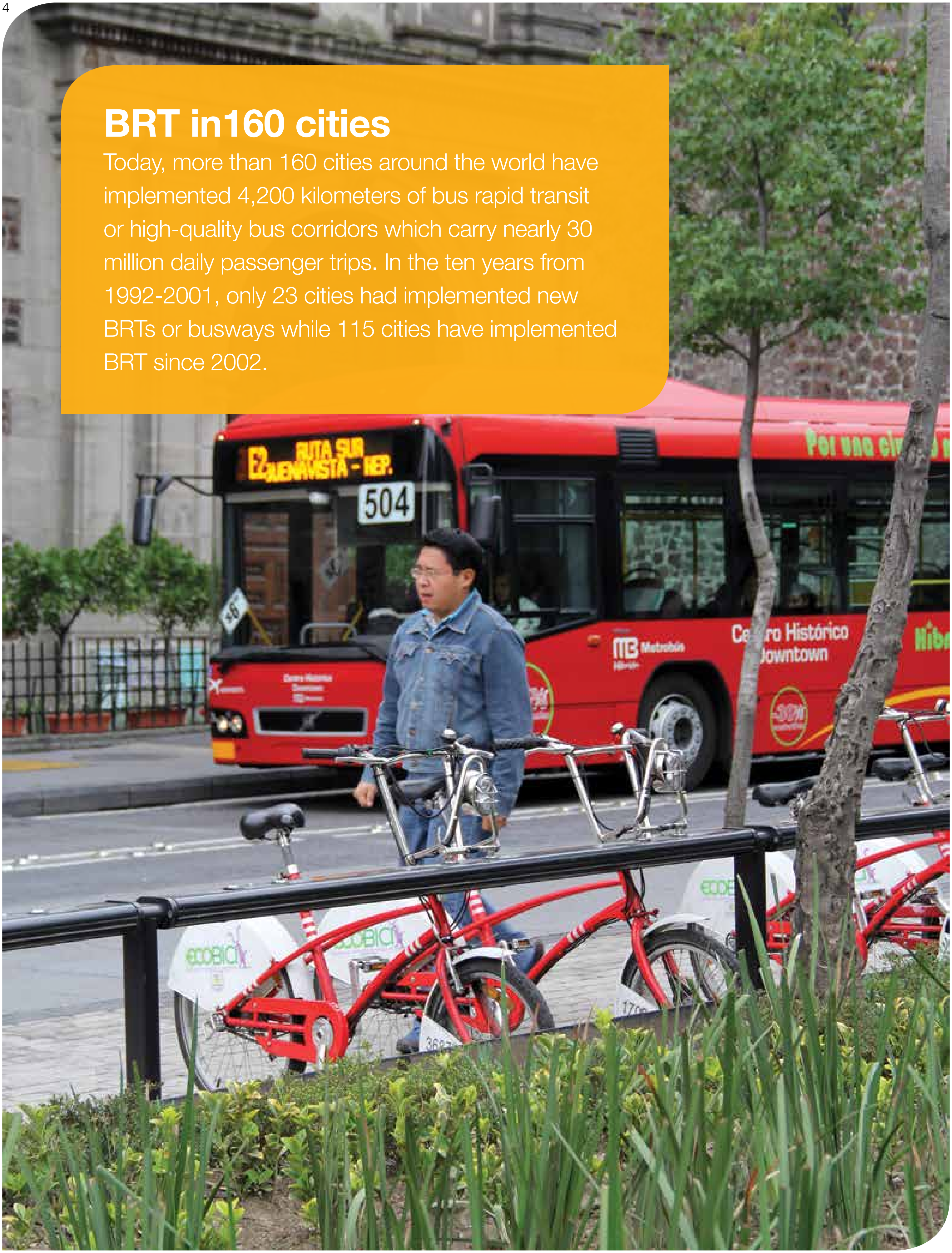
BRT in160 cities

Today, more than 160 cities around the world have implemented 4,200 kilometers of bus rapid transit or high-quality bus corridors which carry nearly 30 million daily passenger trips. In the ten years from 1992-2001, only 23 cities had implemented new BRTs or busways while 115 cities have implemented BRT since 2002.



EXECUTIVE SUMMARY

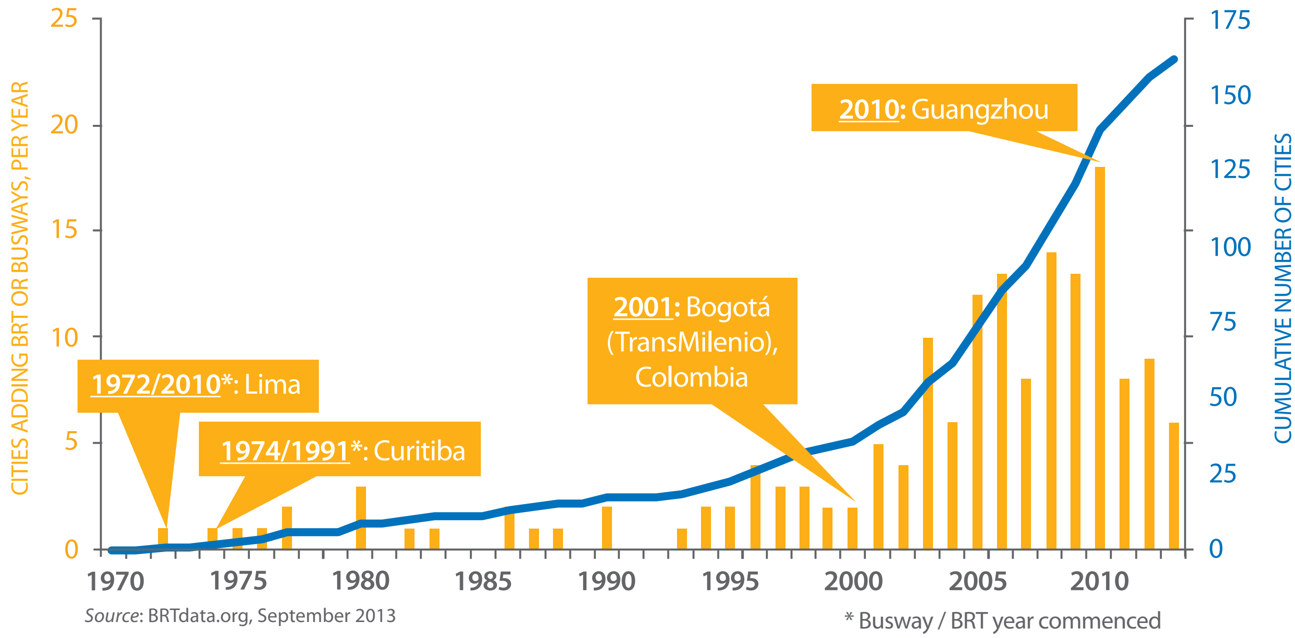
SOCIAL, ENVIRONMENTAL AND ECONOMIC IMPACTS OF BRT SYSTEMS

1.1 WHAT IS BUS RAPID TRANSIT (BRT)?

Bus rapid transit (BRT) is a high-quality, efficient mass transport mode, providing capacity and speed comparable with urban rail (light and heavy rail). Its insertion in urban transport systems is relatively recent and as a result there remains a need to introduce the concept to several audiences, particularly urban transport decision makers, and to better understand its cost, performance and impacts. To that end, this report provides a synthesis of existing literature and new data, and develops a detailed analysis on selected case studies to explore the economic, environmental and social impacts of BRT. BRT flexibly combines stations, buses, exclusive and segregated busways, and intelligent transportation system elements into an integrated transit system with a strong brand that evokes a unique identity (Hidalgo and Carrigan 2010). BRT provides higher quality of service than traditional urban bus operations because of reduced travel and waiting times, increased service reliability and improved user experience (Diaz *et. al.* 2004).

BRT has contributed to an urban transport transformation in the last decade. Today, more than 160 cities around the world have implemented 4,200 kilometers of bus rapid transit or high-quality bus corridors which carry nearly 30 million daily passenger trips (BRTdata.org 2013). The global growth of BRT has been tremendous in recent years. In the ten years from 1992-2001, only 23 cities had implemented new BRTs or busways while 115 cities have implemented BRT since 2002 (BRTdata.org 2013).

Figure ES-1 Growth of BRT Systems and Busways Around the World



Source: BRTdata.org, September 2013

1.2 AIM OF THIS STUDY

This report aims to synthesize available evidence regarding BRT performance, costs and impacts, and contribute new evidence from four case studies. A range of comparative performance and cost indicators for a variety of BRT systems based on literature review and direct data collection are presented in Sections 3.2 and 3.3. BRT performance and costs are compared with those of metros and light rail. Section 4 then summarizes a range of mobility, environmental, public health and urban development impacts that can be expected of BRT systems, informed by extensive literature review supplemented by additional EMBARQ data collection and analysis. The cost-benefit analysis methodology EMBARQ employs to analyze four case studies is presented in Section 5.

High-quality bus rapid transit systems, like all good urban transport, can impact the quality of life, productivity, health, and safety of people living in cities. These impacts have been explored in varying depth in the existing research in the form of travel time benefits, environmental impacts, public health and safety benefits, and urban development changes. A brief summary of the current research regarding these categories of benefits is provided in Section 1.4.

This report features four case studies that use available data to estimate the net benefit to society from a bus rapid transit project:

- **TransMilenio**, Bogota, Colombia;
- **Metrobús**, Mexico City, Mexico;
- **Rea Vaya**, Johannesburg, South Africa;
- **Metrobüs**, Istanbul, Turkey.

These case study BRT systems were selected on the basis of EMBARQ's strong relationship with the local transport authorities, and significant understanding of the projects, as well as a desire to have a geographically diverse set of cases. As a set, the cases provide a glimpse into the costs and benefits of BRT projects and shed light on the variance found among the over 160 cities around the world that

Table ES-1 Summary Characteristics of Selected Four Case Studies

	Bogota, Colombia	**Mexico City,** Mexico	**Johannesburg,** South Africa	**Istanbul,** Turkey
City Population[a]	7.3 million	9 million	4.4 million	10.9 million
BRT System	TransMilenio	Metrobús	Rea Vaya	Metrobüs
Scope of Case Study	Phases I and II	Line 3	Phase 1A	First 4 phases
Year of Operation	2000	2011	2009	2007
Daily Ridership[b]	1.6 million	123,000	40,000	600,000[c]

Notes:

[a] City, not metropolitan area population. Sources include Secretary of Planning, 2011; http://www.edomexico.gob.mx/sedeco/; CoJ 2013b; www.metropolis.org

[b] Daily ridership figures are for the portion of the BRT system analyzed in the case study, which is not necessarily the full system.

[c] IETT publishes system ridership figure of 750,000 passengers per day, but a more conservative estimate of 600,000 daily passenger trips is used in the Istanbul case study analysis.

have implemented BRT or high-quality bus corridors (BRTdata.org 2013).

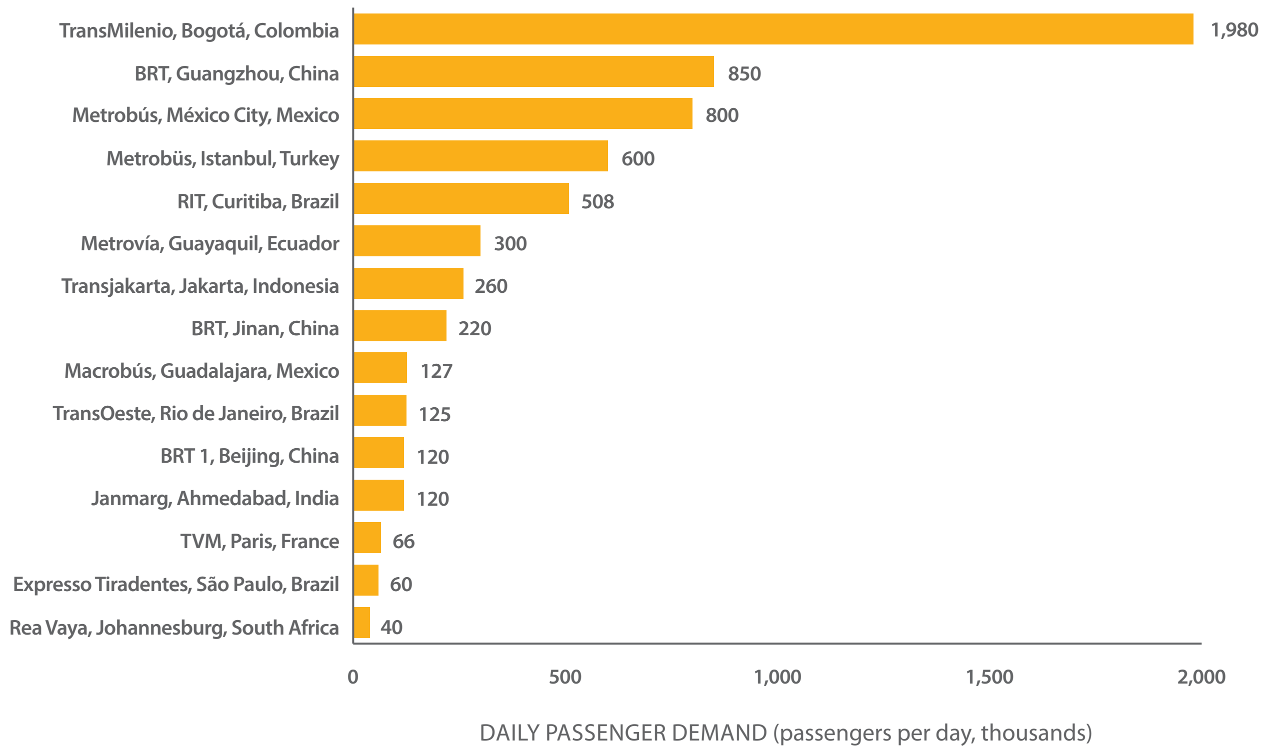
1.3 BRT COSTS AND PERFORMANCE

BRT system performance can vary significantly depending on design characteristics and level of integration with other transport modes. For instance, corridors with exclusive, segregated bus lanes will be able to move more passengers in an hour than a corridor where buses operate in bus-priority lanes, which also permit access to mixed traffic. Bypassing lanes at stations (which allow an arriving bus to pass those boarding passengers at the station) enable express routes to skip certain stations and reduce travel times for some passengers. Bus speeds will be higher on corridors with fewer intersections.

Not all corridors have the same travel demand and so there is not a one-size-fits-all BRT. A city should aim to implement the highest-quality BRT that meets the travel demand and mobility needs on a particular corridor. Understanding the range of performance that different BRTs have achieved may help decision-makers identify the right fit for their particular urban context.

Globally, the range of systems varies from very high-capacity to relatively low-volume corridors (Figure ES-2). Bogota's TransMilenio remains one of the highest-capacity BRT systems, with a **passenger demand** of 1.98 million per day. Mexico City's Metrobús and Istanbul's Metrobüs are medium-capacity BRTs, moving 600,000 – 800,000 passengers daily, while low-capacity systems in Paris and Johannesburg move fewer than 70,000 daily passengers. The highest-volume systems are designed to maximize capacity, while systems with lower throughput have been tailored for the needs of a lower-demand corridor, or may not yet have reached their carrying capacity.

Figure ES-2 Passenger Demand of Select BRTs



Sources: BRTdata.org 2013; data published by transit agencies; McCaul 2012; Wilson and Attanucci 2010

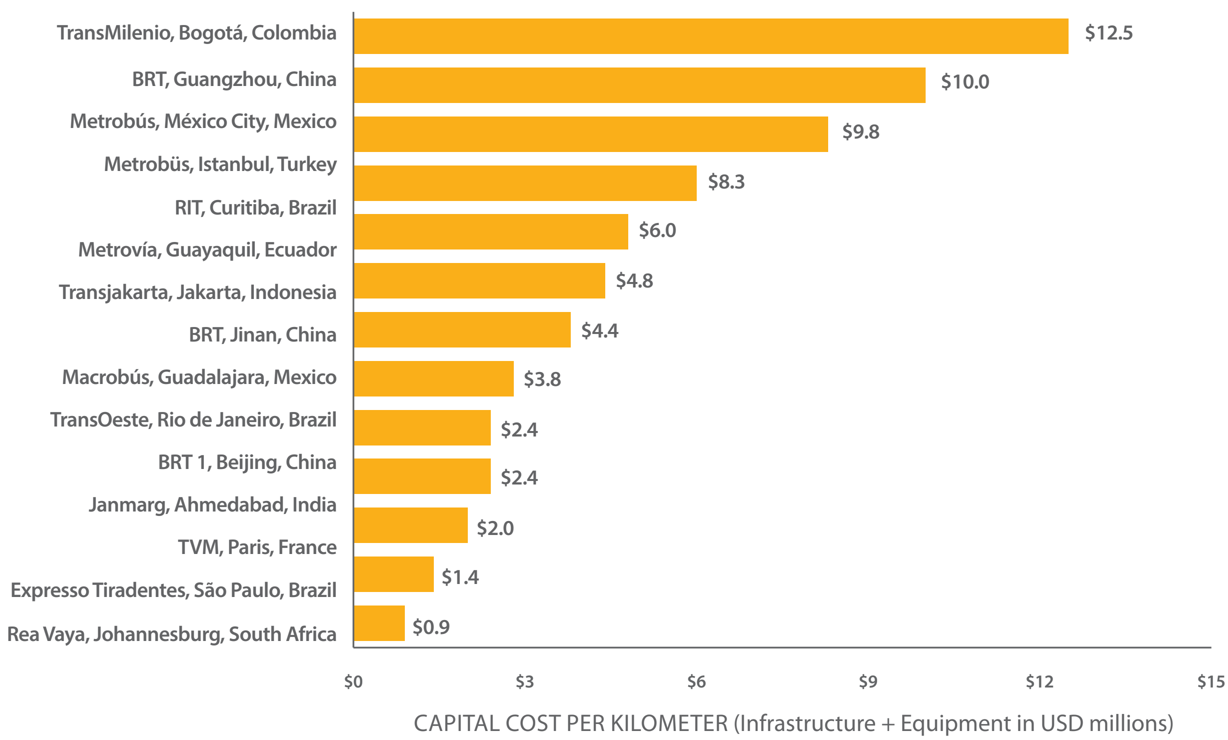
TransMilenio's Avenida Caracas in Bogota has achieved the highest **peak loads** on a single BRT corridor, carrying 45,000 passengers per hour in each direction. Particularly high-capacity corridors have by-pass lanes, which are additional bus-only lanes at stations to allow buses to overtake each other. Istanbul's TUYAP - Sogutlucesme Metrobüs Corridor also carries relatively high volumes, with 24,000 per hour per direction (BRTdata.org 2013). It achieves this capacity without bus passing lanes because it operates at high speeds in a highway median. Other BRT corridors carrying fewer than 20,000 passengers per hour per direction typically have much lower travel demand and only one bus lane at stations, which limits directional capacity.

Average **commercial speeds** of BRT systems vary from 14 to 40 km/hr. Higher speeds are typically achieved as more BRT design components are integrated, such as segregated bus lanes, level platform boarding, pre-boarding fare collection, high-capacity buses, express services and centralized operational controls. Istanbul's Metrobüs achieves an average speed of 40km/hr by operating primarily in segregated lanes on a freeway, with no signalized intersections.

As with BRT performance, project costs vary significantly across systems depending on the extent of the roadworks required (e.g., bridge or tunnel construction), corridor capacity (e.g., inclusion of bypass lanes at stations), obligatory simultaneous repair or upgrading of urban utilities (e.g., water, sanitation and electric services along the BRT corridor) and the quantity and type of equipment used (e.g., articulated or bi-articulated buses, automatic fare collection, passenger information systems, advanced traffic control), among other factors. Local conditions, such as cost of labor and capital, will also have an impact on total system costs. Where BRTs are used as a vehicle for broader urban transport reform, such as formalizing an informal transport industry, there are added costs associated with that transformation.

While capital costs per kilometer and operating costs can vary significantly among BRTs, data from existing systems help to define an indicative range of BRT costs. Total BRT **capital costs** include busway infrastructure, stations, buses and technology systems such as passenger information and fare collection systems. These costs can vary from around USD 1 million per kilometer to USD 12 million per kilometer or more (Figure ES-3). The range of cost indicates the extent of the roadway improvements needed as well as the relative cost of labor and materials in each country. New transit systems requiring only minor physical improvements to the roadway cost in the range of USD 1–3.50 million per kilometer to implement while major reconstruction of corridor roadways (i.e., tunnels, extensive simultaneous utility upgrades or station bypass lanes) require capital investment in the range of US$3.8–12.5 million per kilometer. These costs are one third to one fifth of those of alternative rail technologies (UN HABITAT 2013).

Figure ES-3 Capital Cost per kilometer (USD/km) for Select BRT Systems



Sources:
BRTdata.org 2013; data published by transit agencies; McCaul 2012; Wilson and Attanucci 2010

1.4 BRT IMPACTS

Beyond singular performance indicators, high-quality bus rapid transit systems can impact the quality of life, productivity, health, and safety of people living in cities. These impacts have been explored in varying depth in the existing research as travel time benefits, environmental impacts, and public health and safety benefits (Table ES-2).

BRT systems can **reduce travel times** for their passengers by moving BRT buses out of mixed traffic and into exclusive, segregated lanes. Level and pre-paid boarding at stations along with high-capacity buses with multiple boarding doors help speed passenger boarding and alighting. Sophisticated traffic signal management and high-frequency bus service can help to minimize passenger waiting and transit times.

Bus rapid transit systems can have **positive environmental impacts** by reducing greenhouse gases (GHG) that contribute to global climate change as well as local air pollutants, which lead to citywide air pollution and smog. Emissions reductions can be achieved by reducing vehicle-kilometers travelled (VKT), and replacing older technology and smaller vehicles with newer, cleaner high-capacity BRT buses.

Bus rapid transit systems also provide valuable **public health benefits** by reducing road fatalities, crashes and injuries; reducing personal exposure to harmful air pollutants; and increasing physical activity for BRT users.

Table ES-2 Summary of Typical Impacts of BRT Systems

Impact	How does BRT achieve the benefit?	Empirical Evidence
Travel time savings	• Segregated busways separate BRT buses from mixed traffic; • Pre-paid level boarding and high-capacity buses speed passenger boarding; • Traffic signal management and high-frequency bus service minimize waiting times	• Johannesburg BRT users save on average 13 minutes each way (Venter and Vaz 2011) • The typical Metrobüs passenger in Istanbul saves 52 minutes per day (Alpkokin and Ergun 2012)
GHG and local air pollutant emissions reductions	• Reduce VKT by shifting passengers to high-capacity BRT buses • Replace/scrap older, more polluting traditional vehicles • Introduce newer technology BRT buses • Better driver training leads to improved driving cycles which have lower fuel consumption and emissions	• In **Bogota**, the implementation of TransMilenio combined with new regulations on fuel quality is estimated to save nearly 1 million tCO_2 per year (Turner *et. al.* 2012). • **Mexico City's** Metrobús Line 1 achieved significant reductions in carbon monoxide, benzene and particulate matter (PM2.5) inside BRT buses, traditional buses and mini-buses (Wöhrnschimmel *et. al.*. 2008)
Road safety improvements – reductions in fatalities and crashes	• Improve pedestrian crossings • Reduce VKT by shifting passengers to high-capacity BRT buses • Reduces interaction with other vehicles by segregating buses from mixed traffic • BRT can change drivers' behaviors by reducing on-the-road competition and improving training	• **Bogota's** TransMilenio has contributed to reductions in crashes and injuries on two of the system's main corridors (Bocarejo *et. al.* 2012) • On average, BRTs in the Latin American context have contributed to a reduction in fatalities and injuries of over 40% on the streets where they were implemented.
Reduced exposure to air pollutants	• Cleaner vehicle technologies and fuels lower **concentration** of ambient air pollution citywide or inside the BRT vehicles; • Reduce **time** passengers are exposed to air pollution at stations or inside the bus by reducing travel times.	• After the implementation of TransMilenio, **Bogota** reported a 43% decline in SO2 emissions, 18% decline in NOx, and a 12% decline in particulate matter (Turner *et. al*. 2012). • By reducing emissions of local air pollutants, especially of particulate matter, Metrobús Line 1 in Mexico City would eliminate more than 6,000 days of lost work, 12 new cases of chronic bronchitis, and three deaths per year saving an estimated USD $3 million per year (INE 2006).
Increased physical activity	• Spacing of BRT stations tend to require longer walking distances than all other motorized modes with the exception of Metro • Higher operation speeds increases passengers' willingness to walk to stations	• Mexico City's Metrobús passengers walk on average an additional 2.75 minutes per day than previously • Users of the Beijing BRT have added 8.5 minutes of daily walking as a result of the BRT system

By reducing local air pollution and emissions, **Metrobús Line 3** in Mexico City has **prevented more than 2,000 days of lost work due to illness**, 4 new cases of chronic bronchitis, and two deaths per year, saving an estimated USD $4.5 million.

1.5 COST-BENEFIT ANALYSIS METHODOLOGY

Bus rapid transit projects have the potential to provide travel time, public health, environmental, land use, and other benefits to society (see Section 4 for more detail). However, like all transport options, BRT systems can also impose social costs from construction, operation, and maintenance. In order for policymakers to make an informed decision regarding the development or expansion of a BRT project, the project should be evaluated in terms of total benefits compared to total costs. Ideally, an analysis of alternatives should be done comparing alternative solutions in a preconstruction phase. Often, however, little or no analysis is done.

Cost-benefit analysis (CBA) is used to capture both public and private costs and benefits for society as a whole (Harberger and Jenkins 2002; Gramlich 1997; Boardman *et. al*. 2006). In addition to the financial or market costs, it also considers externalities and indirect or intangible costs to capture social effects. Cost-benefit analysis therefore provides policymakers with a valuable tool for comparing net benefits (benefits minus costs).

For each of the four case studies, EMBARQ applied a consistent CBA methodology to analyze the effects of BRT. We have provided as comprehensive an analysis as possible based on available data, and have striven to be transparent in our assumptions. Where data is incomplete, we have extrapolated trends from existing data to estimate key inputs. We acknowledge limitations in this approach, but remain confident in its usefulness, given the broad professional acceptance of cost-benefit analysis. (A detailed discussion of EMBARQ's cost-benefit methodology and assumptions for each case may be found in Appendix A – EMBARQ's BRT Impact Evaluation Methodology. Assumptions used in the analysis of each case are presented in Appendices B-E).

Three summary indicators are used in the cost-benefit analysis:

- **Net present value.** Because the costs and benefits of transportation projects will continue over many years, the future costs and benefits are often discounted over the life of a project, in the form of an estimated net present value (NPV). A positive NPV implies that a project offers net benefits.

Table ES-3 BRT Costs and Benefits Considered in EMBARQ's CBA Methodology

BRT Costs	BRT Benefits

• Planning and design
• Capital costs
  • Infrastructure (e.g. busways, stations, depots)
  • Equipment (e.g. fleet acquisition, fare collection, passenger information, control center)
• Bus operations and maintenance
• Infrastructure operations and maintenance
• Negotiations with existing transit operators
	• Changes in travel time (BRT users and others)
	• Changes in vehicle operating costs (private vehicles and public transit)
	• Changes in CO_2 emissions
	• Changes to exposure to local air pollutants
	• Road safety benefits (fatalities, injuries, property damage)
	• Changes in physical activity

- **Benefit-cost ratio.** A ratio of the net present benefits and costs greater than one indicates that the total benefits to society exceed the costs.

- **Internal rate of return (IRR).** The IRR is the discount rate at which the net present value of costs equals the net present value of the benefits and indicates the attractiveness of the investment. The IRR of a public investment should exceed the cost of capital.

EMBARQ's CBA methodology considers a set of typical BRT project costs and many of the common transport, environmental, public health and safety benefits described earlier (See Table ES-2). Where sufficient reliable data is available, each of the four case studies incorporates these elements into its CBA.

While CBA is a powerful tool to guide decisions, the methodology does not typically include a distributional analysis. EMBARQ's methodology goes beyond traditional CBA, evaluating the distribution of benefits and costs across society to identify which income groups are winners and losers. We consider the benefit-cost ratio by income strata as well as how net benefits (benefits minus costs) are distributed across socioeconomic groups.

Table ES-4 Summary of Case Study Cost-Benefit Analyses

BRT System	Scope of Case Study	Net Present Benefits (2012 million USD)	Benefit-Cost Ratio	Social IRR
TransMilenio, Bogota	Phase 1 & 2	$1,400	1.6	23%
Metrobús, Mexico City	Line 3	$36	1.2	14%
Rea Vaya, Johannesburg	Phase 1A	$143	1.2	12%
Metrobüs, Istanbul	Phases 1-4	$6,407	2.8	66%

1.6 CASE STUDY FINDINGS

The four BRTs presented in the case studies represent a variety of projects with a range of infrastructure and service designs, implemented and operated in different urban and political contexts. All of the projects have positive net present benefits and benefits exceeding costs. The internal rates of return indicate each of the investments was at least as socially profitable as the opportunity cost of public funds (Table ES-4).

Key findings from each case study include:

Bogota's TransMilenio

- The two largest benefits are travel time savings for transit users, and savings on the operation of traditional buses removed from service following the implementation of the TransMilenio system.
- The largest proportion of users of the BRT system is in the lower- and middle-income groups.
- TransMilenio benefits are biased towards the lower income strata, and with costs biased towards the highest socioeconomic stratum, reflecting the profile of users and the structure of the Colombian tax structure.

Mexico City's Metrobús

- The largest benefits were travel time savings for public transport users, due to the segregated bus lane allowing buses to achieve high operation speeds.
- Savings in operation costs of public transport vehicles are the second largest benefits. This is the result of larger, newer buses that operate at higher speeds. This also helps the system to achieve lower emissions.
- The largest proportion of users of the BRT system is in the lower- and middle-income groups.
- The largest proportion of benefits accrue to those of modest income (monthly income = MXN $4500-7500)—representing the second quintile of the income distribution.
- The largest losses accrue to those at the top of the income distribution.

Johannesburg's Rea Vaya

- Together the bus operation and maintenance contract and the capital costs constitute 96 percent of the total project costs.
- The high cost of the bus operating contract reflects, in part, the cost of formalizing and empowering the minibus taxi industry.
- The largest portion (37 percent) of benefits comes from travel time reductions followed by improved road safety (28 percent).
- Phase 1A has been a progressive project; the upper income quintile bears the majority of the costs, while the project benefits accrue to lower quintiles, predominately the 4th highest income quintile.

- The city's poorest residents are underrepresented in BRT users and therefore are not significant beneficiaries of the project. They do share in 4% of the project benefits, while only contributing to 2% of the costs.

Istanbul's Metrobüs

- The largest proportion (64 percent) of benefits comes from travel time reductions, followed by vehicle operating cost reductions (23 percent) and traffic safety (9 percent).
- Metrobüs costs are driven primarily by operating and maintenance costs.
- The largest proportion of users of the BRT system are in the lower- and middle-income groups, though benefits exceeded costs in all income groups.

The four cases suggest several general conclusions about BRT costs and benefits:

- **Travel time savings** dominate the BRT benefits as a result of segregated bus lanes and other design features that minimize waiting and in-vehicle times.
- Shifting from informal/unregulated service with smaller vehicles operating in mixed traffic, to newer, larger buses operating at higher speeds results in significant **reductions in vehicle operating costs** with BRT (Bogota, Mexico City and Istanbul).
- **Capital costs** and **bus operating costs** were the most significant portion of project costs in the cities.
- BRT projects can be a mechanism for broader **urban infrastructure or transport reform**. They can be used to facilitate formalization of an informal public transport industry (Bogota, Mexico City, Johannesburg) and simultaneously improve complementary urban services (Johannesburg). This can come at an extra cost to the BRT implementing agency, or at the same time as the BRT implementation. In any case, such reform has a broader purpose than the BRT itself.

For the most part, the largest proportion of users from the case study BRT systems is in the lower- and middle-income groups. The lowest and the highest income groups are not well represented among the BRT passengers, a fact which influences how the project benefits are distributed across society (See Table ES-5). Because the majority of the BRT costs in the cases are paid with public revenue derived from taxes, the project costs typically accrue to the highest

Table ES-5 Summary of Distribution of Net Present Benefits for Four Cases

Distribution of Net Benefits by Income Strata (2012 million USD)					
BRT System	1 (Lowest)	2	3	4	5 & 6 (Highest)
TransMilenio, Bogota	$ 92	$ 642	$ 603	$ 238	$ (176)
Metrobús, Mexico City	$ 11.4	$ 37.9	$$ 12.2	$ (9.5)	$ (16.4)
Rea Vaya, Johannesburg	$ 18.6	$ 8.2	$ 35.2	$ 353.9	$ (273.3)
Metrobüs, Istanbul	$ 765.9	$ 2,308.5	$ 1,414.0	$ 969.0	$ 952.1

Legend: Gain least/Lose | Gain most

Travel Time

$142m saved

in Metrobus Line 3 in Mexico City

Traffic Safety

$288m saved

in avoided traffic injuries and fatalities in Bogota's Transmilenio

Greenhouse Gases

$392m saved

from Metrobüs in Istanbul

income strata. Since the dominant benefit is travel time savings, the majority of benefits tend to accrue to the strata most represented by BRT users — typically lower- and middle-income. While the BRT projects tend to be progressive and beneficial to lower-income strata, the lowest-income residents are not benefitting the most from the four projects.

Ensuring that the poorest residents are well represented among BRT users is key to their benefiting more from BRT projects. This may require special attention during project planning to make BRTs accessible to the poorest residents; it also requires careful structuring of user fares compared to existing transport modes and may necessitate targeted fare subsidies.

1.7 LOOKING AHEAD

The four cases reinforce the conclusion that BRT projects can provide net positive benefits to society and can be socially profitable investments. Trends at the local, national and international levels suggest continued growth of BRT worldwide. Data collected by EMBARQ show that 143 cities are currently constructing 1,000 kilometers of new or expanded BRT corridors and planning 1,600 more kilometers (EMBARQ Brasil 2013).

Supportive national and international transport policies are helping to drive this growth. Several national transit investment programs facilitate funding for mass transit including BRT, and some explicitly earmark funds for BRT. Under PROTRAM, Mexico's national mass transit funding program, there are 35 BRTs approved or in final planning across Mexico. Brazil's development acceleration program (PAC) has earmarked USD7.7 billion for BRT systems in 32 cities, doubling the kilometers of BRT in Latin America by the 2016 Olympic Games. India's second national urban renewal program is expected to earmark USD12 billion for implementation of urban rail and bus systems over the next ten years. A policy directive of China's Ministry of Transport establishes a national goal of 5000 kilometers of BRT implemented by 2020 (China MoT 2013). At the international level, donor commitments that prioritize sustainable transport solutions to address urban development challenges are also spurring interest in BRT.

1.8 RECOMMENDATIONS

Lessons from TransMilenio, Metrobús, Rea Vaya and Metrobüs inform generalized recommendations for how policy, infrastructure and operations design, and project financing can maximize the net social benefits of BRT projects.

National and municipal urban transport policies dictate the type and quality of urban transport infrastructure cities implement. These policies can be structured in such a way to encourage transparent and objective assessment of the merits of a particular investment based on the societal impacts.

- National and local investment decisions should be predicated on objective and transparent evaluation of alternatives, including an assessment of social costs and benefits (such as a Cost Benefit Analysis) to determine whether proposed projects represent a good use of limited resources.
- Where possible, project evaluation should consider the distributive impacts — which segments of society benefit and which lose.
- National transit investment schemes can help catalyze widespread adoption of BRT as an urban transport solution.

Physical design, service plans and institutional arrangements dictate many of the benefits and costs analyzed in the case studies. Decisions made during the BRT project planning phases affect which segments of society gain and lose the most as a result of the project. The four cases suggest key recommendations for cities planning BRTs:

- BRT systems should be designed to best accommodate the local travel demand and urban context. Choices about expanding capacity with station by-pass lanes, larger stations, or bi-articulated buses should be driven by corridor demand and available funding.
- Travel time savings are often the most significant social benefits resulting from BRT systems. Design of routes, services and infrastructure should aim to minimize passenger waiting, transfer and in-vehicle transit times to maximize the travel time savings and to deliver a system that is attractive to users. Exclusive, segregated BRT lanes are a key design element.
- User fares should be defined based on technical methods and the actual cost of operations, to reduce the need for operational subsides and political interference (Hidalgo and Carrigan 2010).
- Engagement with existing bus operators early in the project planning phase can build buy-in and ensure inclusion. Be aware that negotiated operator contracts are often more costly than competitive contracts.

- To attract more users from the lowest income quintiles, cities should consider accessibility of the BRT service to poor residents and the price of user fares compared to other transport options. Targeted subsidies for particular income strata may be warranted.
- The implementation and operation of BRT systems provide an opportunity to strengthen the capacity of institutions at the local level and to improve urban transport regulation.
- BRT systems should be part of fully integrated transportation networks.

The four case studies demonstrate positive social benefits of BRT, and banks that have been involved in BRT have identified positive commercial and financial results from the projects. Banks assess BRT investments considering the financial returns for the operator, as well as the social and environmental impacts. Doing so requires those who arrange BRT financing to have an informed understanding of the complexities of both the bus and BRT industries, as well as the scope of impacts of urban transport reform. Specific recommendations for **facilitating finance of BRT systems** include:

- Loans are typically required and should be adapted to the specific conditions of each BRT project. This may include analyzing the concession contract to permit advancing lines of credit to previously informal operators.
- Financial institutions should be brought into the project planning process early, and can support cities and other project stakeholders in the project planning and preparation.
- Trust funds are a good mechanism for facilitating debt repayment by earmarking funds, but conditions need to be assessed carefully so as not to negatively affect the bus operations. They can also ensure transparency of financial transactions.
- Special teams for bus and BRT finance that understand the industry (manufacturers, operators, government) can be very effective, as they have typically followed a large number of projects through all their phases (planning, implementation, adjustment, maturity).
- On-going dialogue with development institutions and non-governmental organizations is also advisable.

CHAPTER 2

INTRODUCTION

2.1 BUS RAPID TRANSIT: AN EMERGING TRANSPORT OPTION

Bus rapid transit (BRT) is a high-quality, efficient mass transport mode, providing capacity and speed comparable with urban rail (light and heavy rail). Its insertion in urban transport systems is relatively recent and as a result there remains a need to introduce the concept to several audiences—particularly urban transport decision makers—and to better understand its cost, performance and impacts. To that end, this report provides a synthesis of existing literature and new data, and develops a detailed analysis on selected case studies to explore the economic, environmental and social impacts of BRT.

BRT flexibly combines stations, buses, exclusive and segregated busways, and intelligent transportation system elements into an integrated transit system with a strong brand that evokes a unique identity (Hidalgo and Carrigan 2010). BRT provides a higher quality of service than traditional urban bus operations because of reduced travel and waiting times, increased service reliability and an improved user experience (Diaz *et. al.* 2004).

Examples of BRT Systems in Action. Note the dedicated lanes and above-grade, high-quality stations with level passenger boarding.

Higher quality of service than traditional urban buses

BRT provides a higher quality of service than traditional urban bus operations because of reduced travel and waiting times, increased service reliability and an improved user experience (Diaz et. al. 2004). BRT flexibly combines stations, buses, exclusive and segregated busways, and intelligent transportation system elements into an integrated transit system with a strong brand that evokes a unique identity (Hidalgo and Carrigan 2010).

BRT has contributed to an urban transport transformation in the last decade. Today, more than 160 cities around the world have established 4,200 kilometers of bus rapid transit or high-quality bus corridors which carry nearly 30 million daily passenger trips (BRTdata.org 2013). The global growth of BRT has been tremendous in recent years. In the ten years from 1992 to 2001, only 23 cities had implemented new BRTs or busways, while 115 cities have implemented BRT since 2002 (BRTdata.org 2013).

The future of BRT continues to look bright. EMBARQ estimates that 143 cities are currently constructing 1,000 km of new or expanded BRT corridors and planning an additional 1,600 km (EMBARQ Brazil 2013). The national governments of China, Brazil, Mexico and India continue to make significant investments in mass transit and BRT in excess of USD12 billion.

This anticipated growth is positive, given BRT's potential to address pressing transport and environmental challenges. Rapid urbanization, motorization, and climate change require urban transport solutions that can be implemented quickly at a massive scale. Bus rapid transit uniquely meets this global imperative. BRT systems can move high passenger volumes efficiently and can be implemented at a fraction of the cost of metro or light rail. For many cities, in developed and developing countries alike, BRT is an effective and affordable solution that improves residents' accessibility, quality of life and the urban environment. It is not surprising then that UN HABITAT includes BRT as an important component of mobility improvements worldwide in its 2013 Global Report of Human Settlements (UN HABITAT 2013).

The explosive growth of BRT in recent years and its clear potential for an even larger role in future global transport solutions – as suggested by UN HABITAT – signal a significant opportunity for cities and for the BRT industry itself.

2.2 ABOUT THE REPORT

If cities continue to choose to invest in BRT systems, what is the need for a report on the impacts and benefits of BRT? While many cities have elected to implement BRT, urban infrastructure investment decisions continue to be highly politicized and face public scrutiny. Decisionmakers need to evaluate and select public transport investments through an objective and informed process.

This report aims to synthesize available evidence regarding BRT performance, costs and impacts, and contribute new evidence from four case studies. A range of comparative performance and costs indicators for a variety of BRT systems based on literature review and direct data collection are presented in Chapter 3. In addition, BRT performance and costs are compared with that of metros and light rail. Chapter 4 then summarizes a range of mobility, environmental, public health and urban development impacts that can be expected of BRT systems, informed by extensive literature review supplemented by additional EMBARQ data collection and analysis. The cost-benefit analysis methodology EMBARQ employs to analyze its four case studies is presented in Chapter 5.

Chapters 6-9 present the report's case studies, which estimate the net benefits (benefits minus costs) of four globally significant BRTs: Bogota, Colombia's TransMilenio; Mexico City's Metrobús; Johannesburg, South Africa's Rea Vaya; and Istanbul, Turkey's Metrobus. The four cases study cities were selected because their operational BRTs incorporate many of the key elements indicative of high-quality systems, yet they represent a diverse mix of system maturity, physical design and urban contexts. These systems are pioneer and iconic applications in their own countries, and have been influential in the advancement of BRT around the world. Their diversity of conditions and experience shed light on the variance among the more than 160 cities that have implemented BRT or high-quality bus corridors to date (BRTdata.org 2013).

The selection of case studies was limited by the public availability of data. Estimates of costs and benefits rely on accurate and comprehensive data collection and transparent data management practices that provide data to the public. For each selected city and BRT system, sufficient data was publically available to complete the cost-benefit analysis. EMBARQ has a relationship with each city or at least a strong familiarity with the BRT system that improved our ability to make appropriate and reasonable estimates and assumptions in the analysis.

The cases present the results of detailed cost-benefit analysis and consider how these net benefits are distributed among the population, by income. Detailed project costs analyzed include planning, infrastructure and equipment, and operations and maintenance. Project benefits include transport, environmental, road safety and public health impacts (see Table). Furthermore, the cases consider the socioeconomic distribution of these costs and benefits, offering additional insights into the equity of the BRT projects. The results confirm the potential of BRT as an effective tool in advancing urban mobility in a progressive way: it provides significant net benefits to middle- and lower-income people while reducing environmental impacts.

Table 6 BRT Costs and Benefits Considered in Four Case Studies

BRT Costs	BRT Benefits
• Planning and design	• Changes in travel time (BRT users and others)
• Capital costs	• Changes in vehicle operating costs (private vehicles and public transit)
• Infrastructure (e.g. busways, stations, depots)	• Changes in CO_2 emissions
• Equipment (e.g. fleet acquisition, fare collection, passenger information, control center)	• Changes to exposure to local air pollutants
• Bus operations and maintenance	• Road safety benefits (fatalities, injuries, property damage)
• Infrastructure operations and maintenance	• Changes in physical activity
• Negotiations with incumbent operators	


DESCENSO

CHAPTER 3

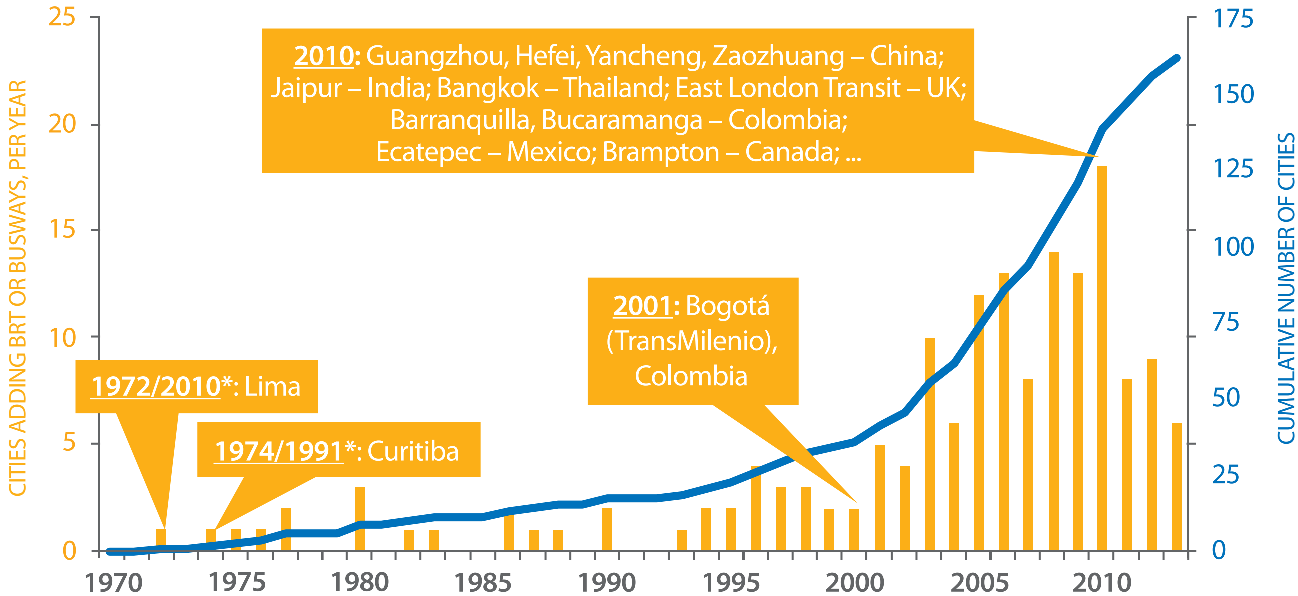
OVERVIEW OF BUS RAPID TRANSIT

3.1 GLOBAL BRT INDUSTRY

There are currently 163 cities in the world with some version of BRT, collectively making nearly 26 million daily passenger trips (Global BRT Data 2013). Latin America is not only where BRT was invented, but also the source of ongoing innovation[1]. The region is home to many of the world's highest-capacity systems, including Bogota, Sao Paulo, Curitiba and Mexico City. 34 percent of the world's cities with BRT are in Latin America, and together they are responsible for 62 percent of the global BRT passenger trips. Brazil leads the world both in number of cities with BRT (32) and daily passenger demand (11 million trips or approximately 38 percent of the global total). Nearly 21 percent of the cities with BRT are in Asia, and are responsible for 8.1 million daily passenger trips, or a quarter of the global total. Africa's megacities have been slow to adopt BRT; only 3 African cities have operational BRTs, and they account for less than one percent of the global BRT passenger demand.

There has been a rapid expansion of the BRT industry between 2000, when there were 35 BRT or high-quality bus corridors in operation, and mid-2013, when there are more than four times that many. Several noteworthy systems were launched during this period, including several which became iconic regionally or globally: Bogota's TransMilenio, Mexico City's Metrobús, Ahmedabad's Janmarg and Johannesburg's Rea Vaya.

Figure 1 Growth of BRT Systems and Busways Around the World



Source: BRTdata.org, September 2013

* Busway / BRT year commenced

As cities consider implementing BRTs, decisionmakers will be confronted with a difficult and highly politicized decision: is BRT the best infrastructure investment for the community? Will BRT meet the transport demand while providing other important public benefits? How much will a new BRT corridor cost? While the design specifications of a particular BRT must be worked out to accurately answer many of these questions, it can be helpful for decisionmakers to have an understanding of how other BRT systems have performed, how much they cost and what benefits they achieved. Thus, sections 3.2 and 3.3 compare the performance and costs of currently operational BRTs as a benchmark for cities considering a new BRT system or corridor. A deeper analysis of alternatives, comparing the costs and benefits of different transport solutions, is beyond the scope of this paper, but should be prepared by any city deciding upon its transportation investments.

3.2 BRT PERFORMANCE

BRT system performance can vary significantly depending on design characteristics and level of integration with other transport modes. For instance, a BRT corridor with exclusive, segregated bus lanes will be able to move more passengers in an hour than a corridor where buses operate in bus-priority lanes, which also permit access to mixed traffic. Bypassing lanes at stations (which allows an arriving bus to pass buses in the process of boarding passengers at the station) enable express routes to skip certain stations and reduce travel times for some passengers. Bus speeds will also be higher on corridors with fewer intersections.

Not all corridors have the same travel demand and so there is not a one-size-fits-all BRT. Not all cities need the high capacity of Bogota's TransMilenio. A city should aim to implement the highest quality BRT that meets the travel demand and mobility needs on a particular corridor. Understanding the range of performance that different BRTs have able to achieve may help decisionmakers identify the right fit for their particular urban context.

This section compares a variety of BRT systems according to several common BRT performance indicators:

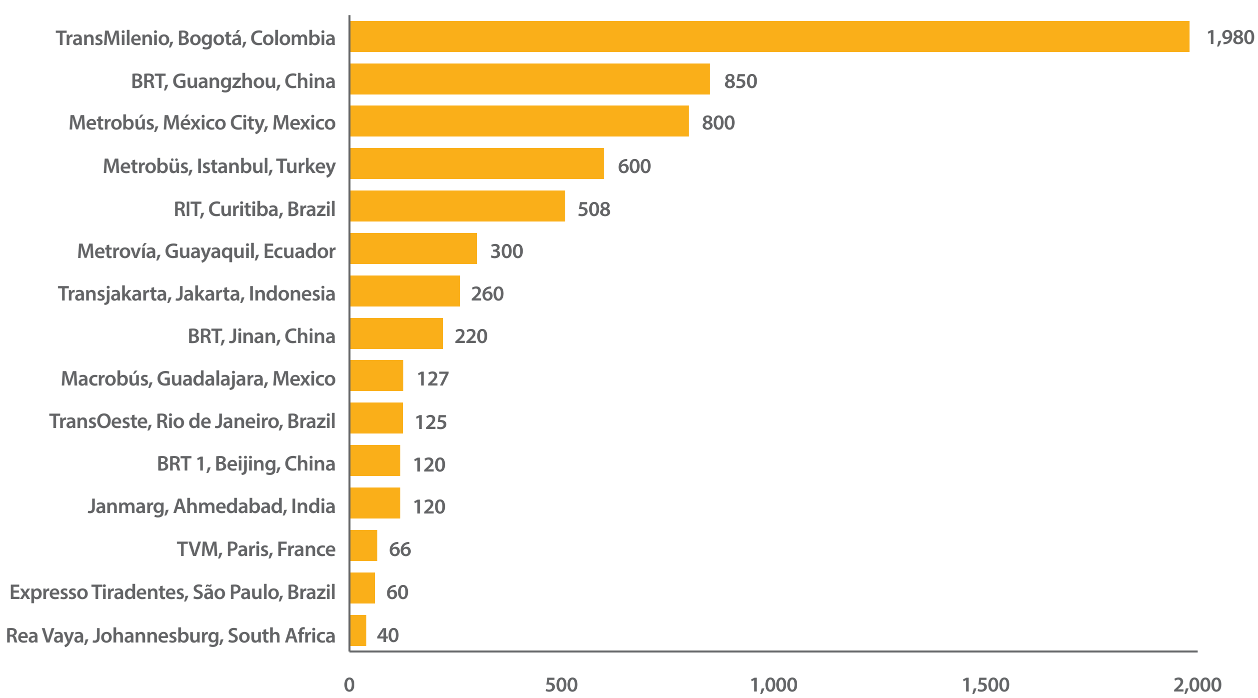
- **Passenger demand:** the number of passenger trips per day carried on the system. Linked passenger trips are used rather than boardings, so a transfer between a feeder route and trunk corridor is counted once.

- **Peak load:** the maximum number of passengers carried in one direction between two stations in an hour.
- **Commercial speed:** the average bus operating speed on the corridor.
- **Operational productivity:** the number of daily passenger boardings (output) for every bus' daily operated kilometers (input); a measure of service efficiency.
- **Capital productivity:** the number of passenger boardings per bus per day; a measure of the fleet efficiency.

Globally, the range of systems varies from very high-capacity to relatively low-volume corridors (Figure 2). Bogota's TransMilenio BRT system remains one of the highest capacity systems, with a **passenger demand** of 1.98 million per day. Mexico City's Metrobús is a medium-capacity BRT, moving 800,000 passengers daily, while low-capacity systems in Paris and Johannesburg move fewer than 70,000 passengers per day. The highest-volume systems are designed to maximize capacity. The lower-capacity systems have been tailored for needs of a lower-demand corridor, or may not yet have reached their carrying capacity.

On a single BRT corridor, TransMilenio's Avenida Caracas in Bogota has achieved the highest peak loads, carrying 45,000 passengers per hour in each direction (Figure 2). TransMilenio corridors with particularly high capacity have by-pass lanes as well as additional bus-only lanes at stations to allow buses to overtake each other. Istanbul's TUYAP - Sogutlucesme Metrobüs Corridor also carries relatively high passenger volumes with 24,000 per hour per direction (Excellence 2013); it achieves this capacity

Figure 5 Daily Passenger Demand of Select BRTs



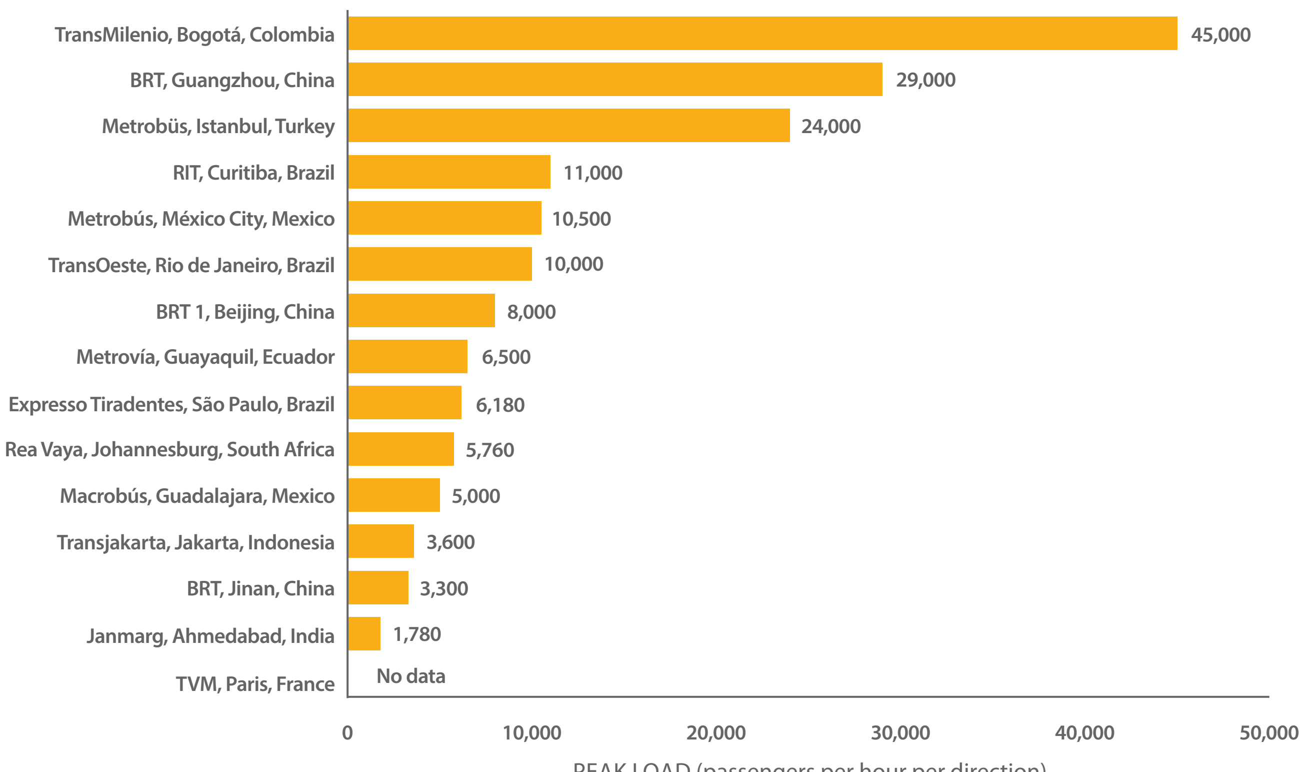
Sources:
BRTdata.org 2013; data published by transit agencies; McCaul 2012; Wilson and Attanucci 2010

without bus passing lanes because it operates at high speeds in a highway median. Other BRT corridors carrying fewer than 20,000 passengers per hour per direction typically have much lower travel demand and only single bus lanes at stations, limiting their directional capacity.

Average **commercial speeds** of BRT systems vary from Jinan's low speed of 14 km/hr to highs of 40 km/hr in Istanbul and Rio de Janeiro (Figure 4). Higher speeds are typically achieved as more BRT design components are integrated, such as segregated bus lanes, level platform boarding, pre-boarding fare collection, high-capacity buses, express services and centralized operational controls. Istanbul's Metrobüs achieves its average speed of 40km/hr by operating primarily in segregated lanes on a freeway, with no signalized intersections. A comparison with speeds of rail systems is provided in Section 3.4, which compares the performance and costs of alternative transportation modes.

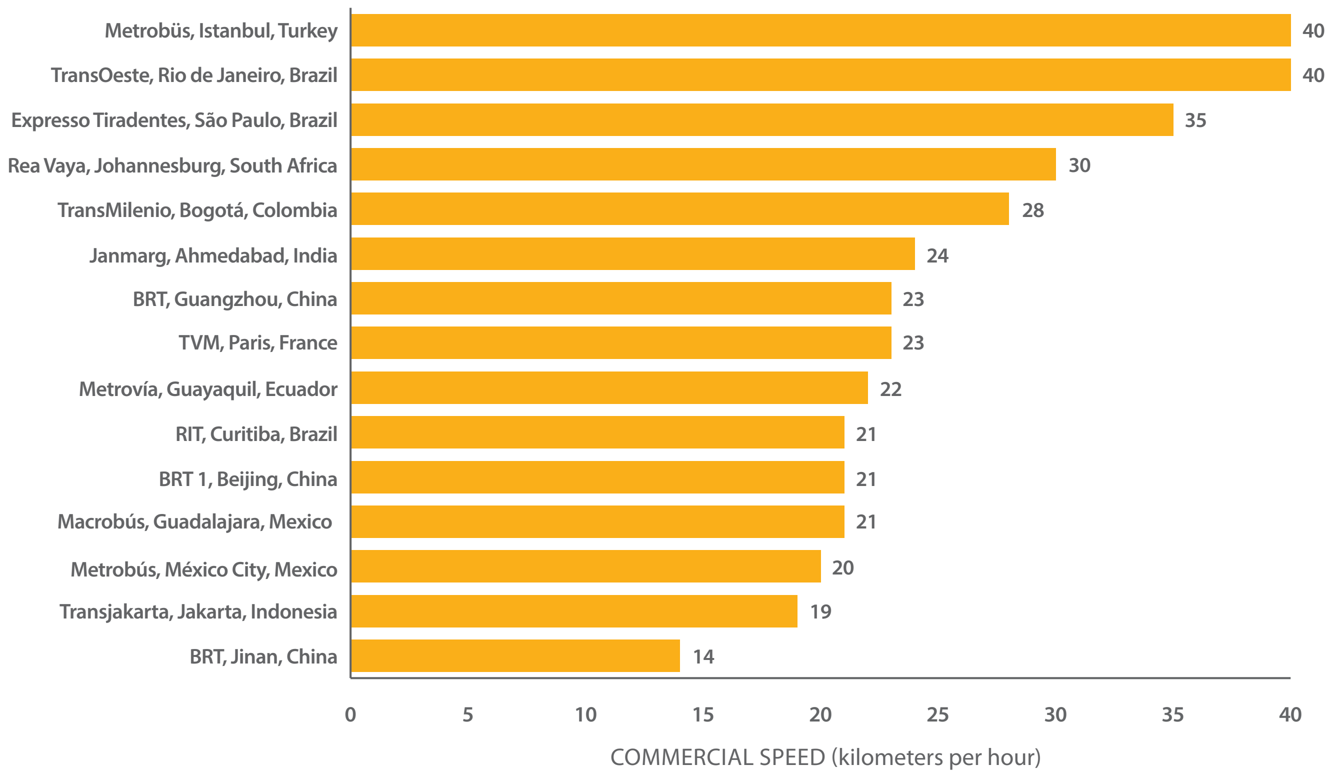
The highest **operational productivity** was achieved in Guayaquil, Ecuador where Metrovía reported 13 passenger boardings per bus-km. The lowest levels of productivity were reported in Johannesburg, with two passenger boardings per bus-km (Figure 5). Even this relatively low level of operational productivity is still twice that observed in traditional bus systems operating in mixed traffic. There are external factors affecting operational productivity such as corridor

Figure 3 Peak Load (passengers per hour per direction) of Select BRT systems



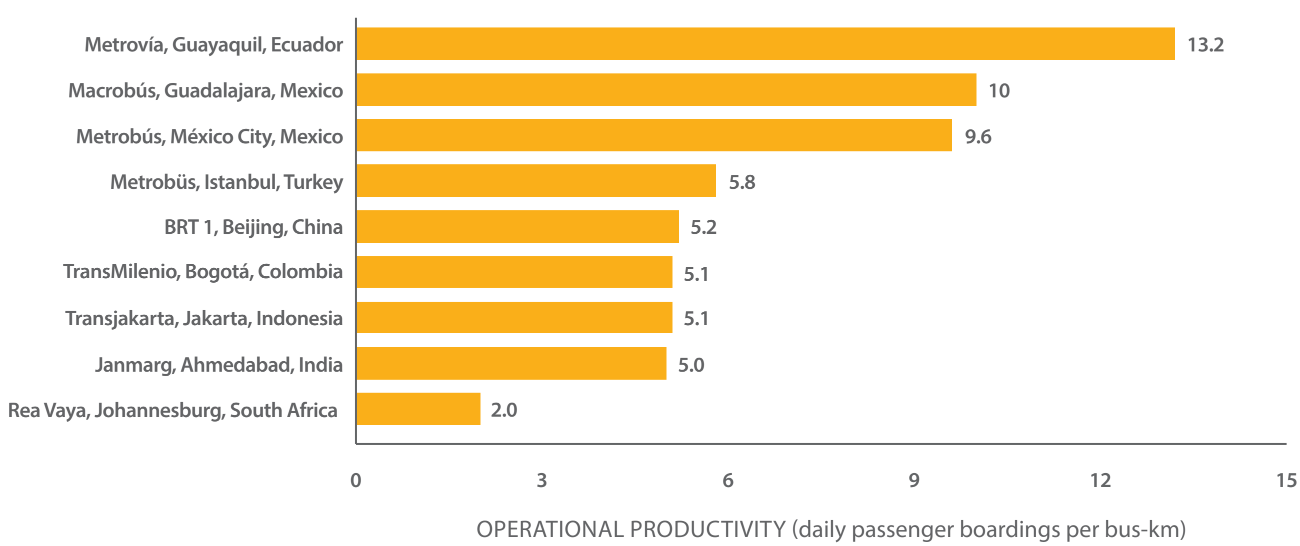
Sources:
BRTdata.org 2013; data published by transit agencies; McCaul 2012; Wilson and Attanucci 2010

Figure 4 Commercial Speed (km/hr) of Select BRT Systems



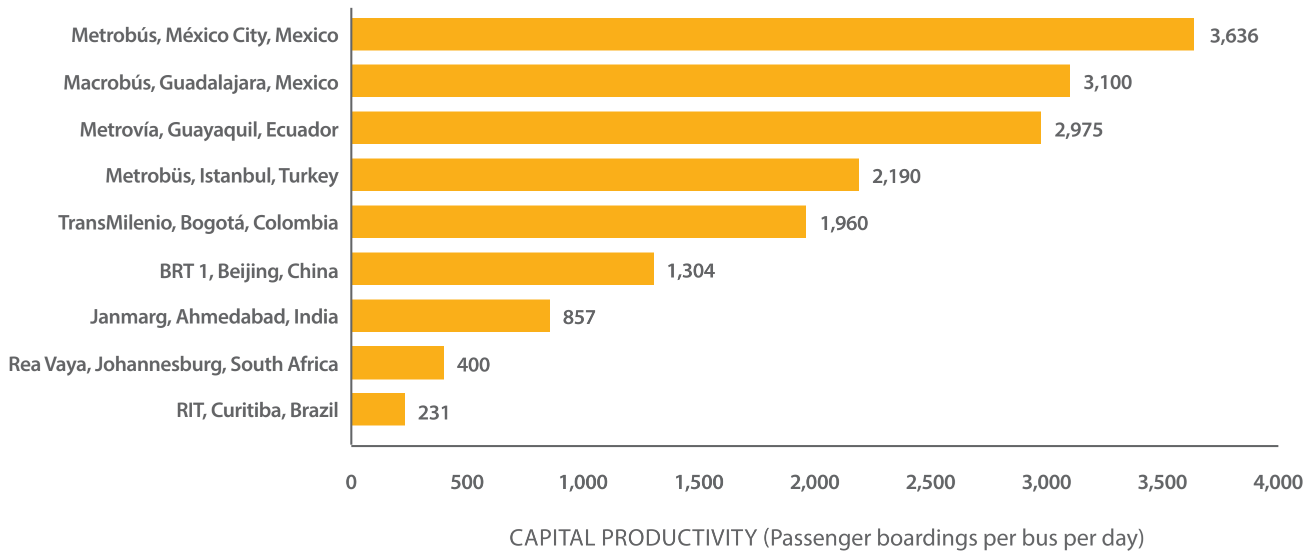
Sources:
BRTdata.org 2013; data published by transit agencies; McCaul 2012; Wilson and Attanucci 2010

Figure 5 Operational Productivity (passenger boardings per bus-km) of Select BRT Systems



Sources:
BRTdata.org 2013; data published by transit agencies; McCaul 2012; Wilson and Attanucci 2010

Figure 6 Capital Productivity (boardings per bus per day) of Select BRT Systems



Sources:
BRTdata.org 2013; data published by transit agencies; McCaul 2012; Wilson and Attanucci 2010

density, trip length, and availability and characteristics of transport alternatives. Conversely, there are also internal factors, such as the way routes are programmed (radial/diametric, short/long, local/express), minimum headways, and occupancy evels, among others.

In terms of **capital productivity** (average number of daily passengers per bus), Guadalajara's Macrobús and Guayaquil's Metrovía report more than 3,000 passengers per bus per weekday. Capital productivities of less than 1000 passengers per bus per weekday are found in Ahmedabad, Johannesburg and Curitiba (Figure 6).

3.3 BRT COSTS

As with BRT performance, BRT costs vary significantly across systems depending on the extent of the roadworks undertaken (e.g., if bridges or tunnels were constructed), the corridor capacity (e.g., inclusion of bypass lanes at stations), obligatory simultaneous repair or upgrading of other urban utilities (e.g., water, sanitation and electric services along the BRT corridor) and the quantity and type of equipment used (e.g., articulated or bi-articulated buses, automatic fare collection, passenger information systems, advanced traffic control), among other factors. Local conditions, such as cost of labor and capital, will also have an impact on total system costs. Where BRTs are used as a vehicle for broader urban transport reform, such as formalizing an informal transport industry, there are added costs associated with that transformation as well.

While capital cost per kilometer and operating costs can vary significantly from BRT to BRT, existing systems can help to define an expected range for BRT costs. Local context, technical design and policy decisions will ultimately determine the final cost of any system, but decisionmakers can consider the expected range of BRT costs when evaluating BRT against other alternative modes.

Several common indicators are often used to assess the cost of a BRT system:

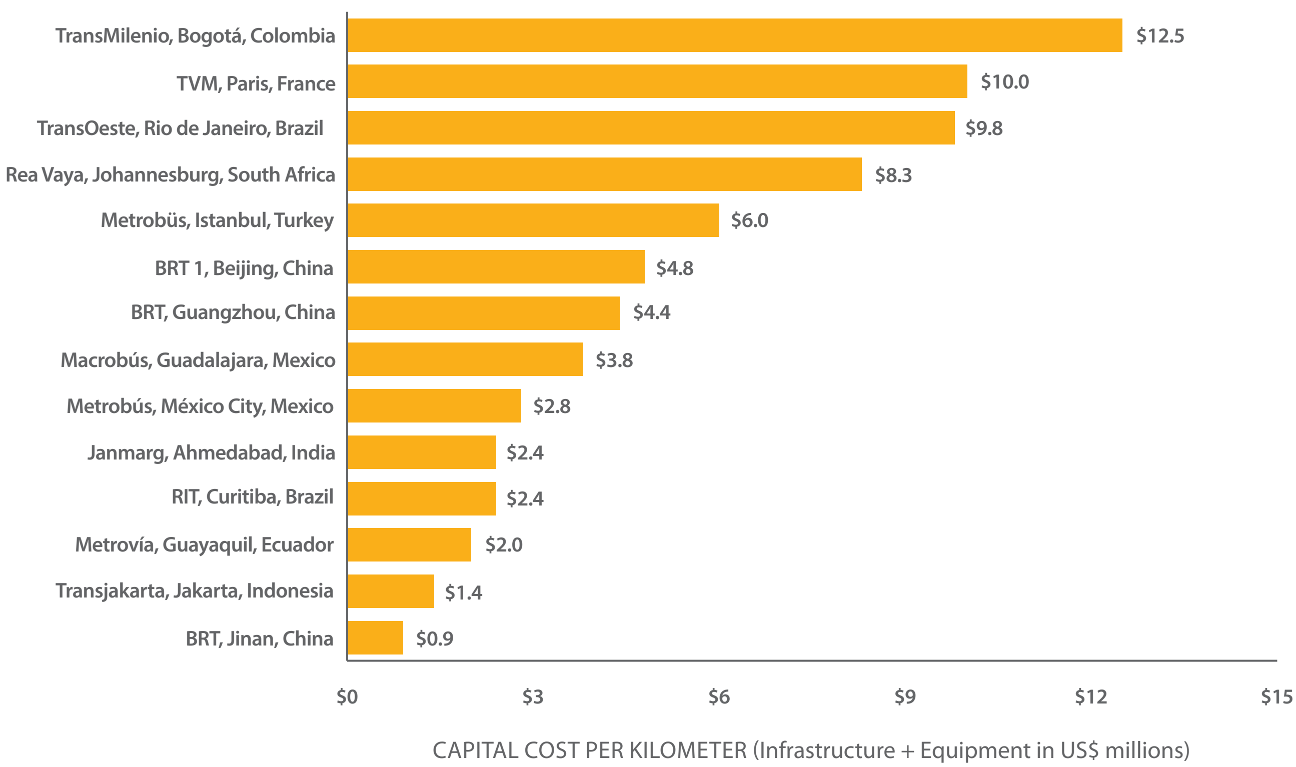
- **Capital cost:** includes the cost of infrastructure (lanes, stations), equipment (passenger information, fare collection) and fleet, normalized by the length of the segregated lane infrastructure in the system. It is typically measured on a per kilometer basis.

- **Operational cost:** includes the cost of operating and often maintaining the buses, depots, stations and infrastructure (i.e., maintaining the busways). This information is often not published by transit operators and therefore no comparative charts are presented here.
- **Average user fare** or **annual fare revenue:** the average user fare indicates the affordability of the BRT service. Total annual fare revenue can be estimated by multiplying average user fare by annual passengers.

Total BRT **capital costs** include lane infrastructure, stations, buses and technology systems such as passenger information and fare collection systems. These costs can vary from less than US$1 million per kilometer (Jinan) to US$12.5 million per kilometer (Bogota) or more (Figure 7). The range of costs indicates the extent of the roadway improvements needed as well as the relative cost of labor and materials in each country. New transit systems requiring only minor physical improvements to the roadway cost in the range of US$1–3.50 million per kilometer to implement while major reconstruction of corridor roadways (e.g., tunnels, extensive simultaneous utility upgrades or station bypass lanes) require more capital investment: US$3.8–12.5 million per kilometer. These costs are one third to one fifth of those of alternative rail technologies (UN HABITAT 2013). A comparison with speeds of rail systems is provided in Section 3.4.

BRT infrastructure may be funded with a combination of public or private funding. Many BRT systems are built by local agencies with local and external (state or national government) funds. Jakarta and Beijing purchased their buses with public funds and the México City municipality directly acquired 20

Figure 7 Capital Cost per Kilometer (USD/km) for Select BRT Systems



Sources:
BRTdata.org 2013; data published by transit agencies; McCaul 2012; Wilson and Attanucci 2010

percent of the bus fleet. México City also attracted private capital through concession contracts for the construction or improvement of stations and bus stops. México City procured fare collection equipment with public funds. In other systems, equipment has been provided by the private sector, which is paid back with revenue from user fares.

Average user fares in most systems were below US$0.80 per trip as of 2009, with the exception of Curitiba and São Paulo whose fares are US$1.27 and 1.33 respectively. Most systems with fares below US$0.40 (Beijing, Ahmedabad, Jakarta, Quito, and México City) either received subsidies or were financially strained. If operational costs exceed farebox revenues, there is a need for an operational subsidy. In most cases in developing countries subsidies are not allowed, placing pressure on the transit system's finances. One way cities have resolved this is through productivity increases and reductions in the perceived level of service for users. Increasing service quality usually involves creating operational subsidies.

3.4 COMPARISON OF PERFORMANCE AND COSTS OF ALTERNATIVE TRANSIT MODES

It is common for urban transport decisionmakers to compare the costs and benefits of alternative transit modes before opting to implement any given solution. It is therefore useful to frame the costs and performance of BRT systems relative to metro and light rail systems[2].

3.4.1 PERFORMANCE COMPARISON OF ALTERNATIVE TRANSIT MODES

There is considerable variation in passenger carrying capacity between different examples of the same transit mode. Capacity is very dependent on the exact operational design of each system, so when comparing performance of different modes, it is more useful to consider a capacity range rather than a single value. Many heavy rail systems can carry passenger loads significantly higher than BRT and light rail systems (LRT) (Table 2). However high-quality BRT systems that include key design and operational features can also carry high passenger loads. In fact, in the middle of the

Table 2 Typical Peak Load Capacity Ranges by Mode

Type of transit mode	Capacity range (pphpd)	Source
Standard bus	3,180 – 6,373	Vuchic 2005
Bus Rapid Transit (single lane, no overtaking, e.g. Metrobus, Mexico City)	Up to 13,000	Adapted from Wright and Hook 2007
Bus Rapid Transit (overtaking lanes and multiple sub-stops at stations, e.g. TransMilenio, Bogota)	43,000 – 55,710	Hidalgo *et. al.* 2011
Light rail transit (LRT)	Up to 30,760	Adapted from Vuchic 2005
Rapid Rail (e.g. Metro) and regional rail	52,500 – 89,950	Vuchic 2005

capacity range, below 30,000 passengers per hour per direction, there is a lot of overlap between modes, and BRT can match or exceed the capacity of rail (Figure 8). Which mode is best, ultimately depends on the corridor demand, system and operational design and budget availability (whether key BRT design and operational features can be included).

3.4.2 COST COMPARISON OF ALTERNATIVE TRANSIT MODES

In the range of performance (i.e., peak load) where transit modes overlap, another critical consideration when comparing alternative transit solutions is cost.

Table 3 Range of Commercial Speeds by Transit Mode and Alignment Type

Type of transit mode	Operating speed (km/h)	Source
Standard bus	varies with traffic conditions	
Bus Rapid Transit on urban arterial and no express service (e.g. Metrobus Mexico City)	18 – 28	Metrobus 2010
Bus Rapid Transit on suburban arterial with predominantly express service (e.g. Transoeste, Rio de Janeiro)	28 – 35	Rio Onibus 2012
Bus Rapid Transit on expressway (no intersections and no express service, e.g. Metrobus Istanbul)	40 +	IETT, Istanbul
Light rail	18 – 40	Vuchic 2007, p. 302
Rapid Rail (Metro, subway)	20 – 60	Vuchic 2007, p. 305
Regional rail (e.g. Tren Suburbano, Mexico City)	30 – 75	Vuchic 2007, p. 307

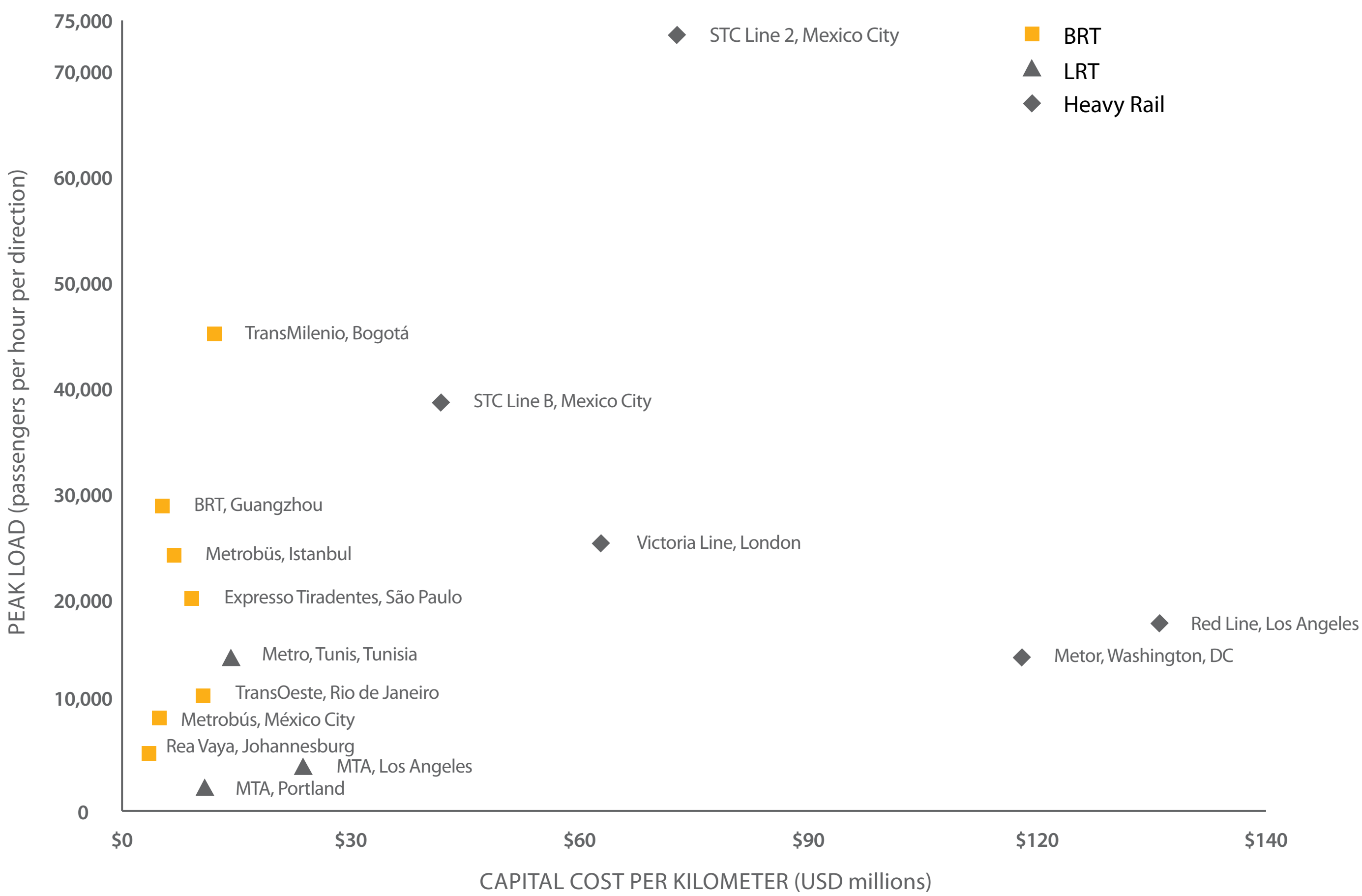
Table 4 Comparison of Capital Costs of BRT and rail systems, 2006-2012 US FTA Grantees

Mode	Capital Costs, Range (million USD)	Capital Costs, Median (million USD)
BRT	$3.5 – 567	$36.1
Rail	$117 – 7,000	$575.1

Sources: GAO 2012

Here, BRT performs quite well, as even the most costly BRT systems have lower capital costs per kilometer than most heavy or light rail systems (Figure 8). A US Government Accountability Office report noted that among projects receiving a Federal Transit Administration grant between 2006 and 2012, BRT generally had lower capital costs than rail projects (GAO 2012) (Table 4). This is attributed to the relatively simple right of way improvements needed for BRT – no tracks must be laid – as well as the less expensive bus fleet.

Figure 8 Comparison of Capital Cost/Km and Peak Load of Select Heavy Rail, Light Rail and BRT Systems



Sources:
BRTdata.org 2013; data published by transit agencies; Flyvbjerg *et.al.* 2008; Parkinson and Fisher 1996

CHAPTER 4

BRT IMPACTS ON CITIES

High-quality bus rapid transit systems, like all urban transport, can affect the quality of life, productivity, health, and safety of people living in cities. These impacts have been explored in varying depth in the existing research as travel time benefits, environmental impacts, public health and safety benefits, and urban development changes. A brief summary of the current research regarding these categories of benefits is provided here.

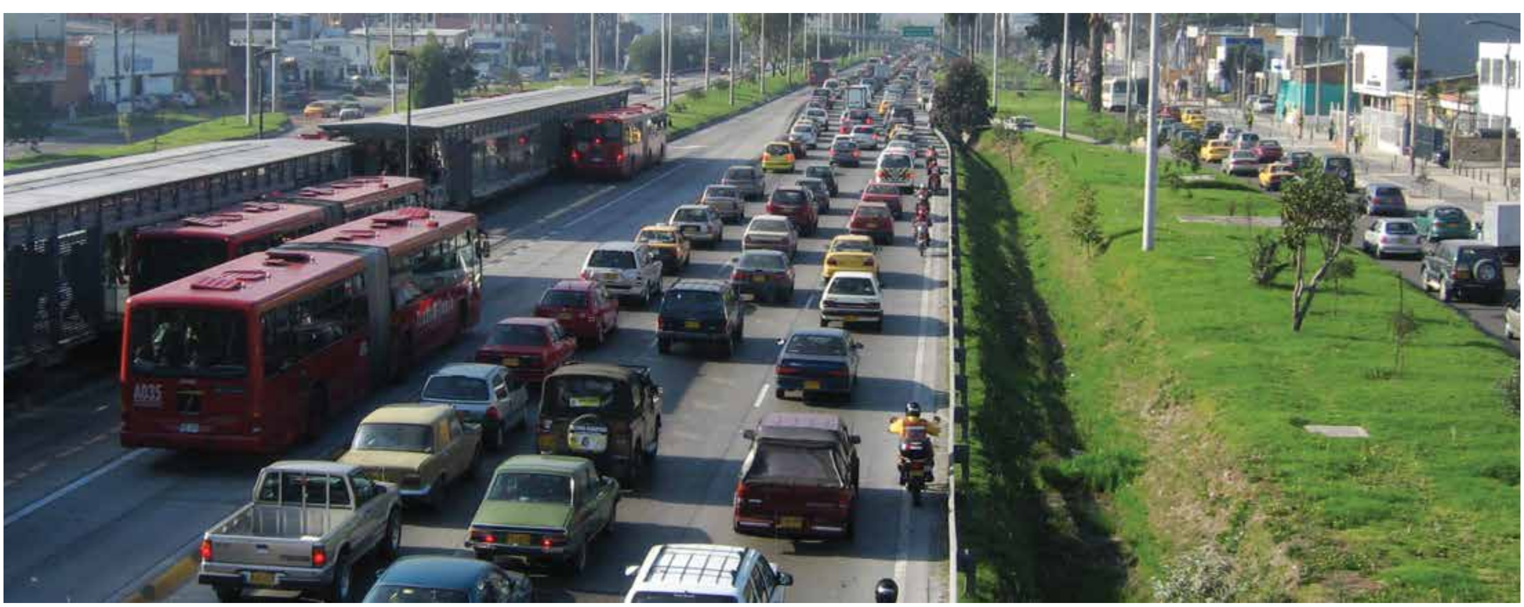
The travel time, environmental and public health impacts presented here are included in EMBARQ's cost-benefit analysis methodology (see Table 8 and Table 9 in Chapter 5) and analyzed in the context of the four case study BRT systems.

4.1 TRAVEL TIME IMPACTS

Several design elements of high-quality BRT systems can help to quicken passenger boarding and alighting times, reducing overall travel times:

- Level boarding: station platforms level with bus floors; no bus stairs to walk up or down;
- Pre-paid boarding: fares collected off-board the buses, typically at the station entrance;
- High-capacity buses with multiple doors: several, often wide, doors for boarding.

Furthermore, a physically segregated lane for BRT services separates buses from mixed



traffic and raises commercial speeds. Sophisticated traffic signal management can help minimize delays by holding green signals for BRT buses approaching an intersection. Finally, high-frequency bus service (sometimes more than 60 buses per hour) minimizes passenger waiting time.

Other vehicles traveling alongside the BRT corridor may also experience changes in travel times. First and foremost, all users of the corridor are likely to experience travel delays during BRT construction. It is common to replace a general traffic lane with a BRT-only lane, which effectively reduces the roadway capacity for non-BRT users, and may result in slower travel times for vehicles in the mixed-use traffic lanes. However, BRT services often replace more chaotic, informal transit along the corridor. Shifting from many buses or minibuses jockeying to pick-up passengers at curbside bus stops to fewer high-capacity articulated or bi-articulated buses operating in segregated median bus lanes may relieve some congestion in the general traffic lanes, resulting in an overall improvement in travel times.

Empirical data supports this. In Johannesburg, for example, a survey of Rea Vaya passengers revealed that BRT users saved 13 minutes each one-way trip to the same destination when using Rea Vaya compare to their previous form of transportation. On average, this represents a travel time savings to users of 10 to 20 percent (Venter and Vaz 2011). This is partly attributable to the relatively high operating speeds (30 km/hr) that Rea Vaya achieves. An increase in operating speeds also contributed to increased service frequency and attracted 134 percent higher ridership on Paris' 20-–kilometer Trans-Val-de-Marne BRT (Heddebau *et. al.* 2010). Ahmedabad's Janmarg reports average speeds in the 25 km/hr range, substantially higher than the 13-15 km/hr reported by the normal city buses (Zimmerman 2012, CEPT monthly reports).

The travel time savings achieved by the BRT system in Istanbul are also notable. The Istanbul Metrobüs operates at 40 km/hr along the median of a highway, the D-100 Expressway, connecting the Asian and European sides of the city across the Istanbul Strait Bridge. The typical Metrobüs passenger saves 52 minutes per day (Alpkokin and Ergun 2012). Data from the Guangzhou Transport Research Institute reveals that the BRT in Guangzhou, China considerably reduced travel times as well (Guangzhou Transport Research Institute 2012). With the BRT system's exclusive, segregated bus lanes, average bus speeds have increased 84 percent, from 14 km/hr to 23km/hr. These higher speeds have reduced BRT passengers' in-vehicle travel times by 29 percent. The extremely high frequency of service (350 buses per hour) has also reduced passengers' waiting times by 15 percent. Removing buses from the mixed traffic lanes has improved travel times for non-BRT users on the corridor as well; the speed of other vehicles on the corridor has increased from 13.9 km/hour to 7.8 km/hour with the BRT.

Travel time savings is not just about spending less time on public transport. More efficient travel options allow commuting passengers to get to work faster and either work more hours, enjoy more leisure time, or both. In addition to overall travel time savings, high-quality BRT services improve travel time reliability as well. BRT buses operating at high frequencies (low headways) in exclusive segregated lanes will have more consistent run times. Passengers can more reliably predict their travel times, reducing commuter stress and making an on-time arrival at their destination or connections to other transport modes a more common occurrence. Furthermore, technologically advanced BRT systems that incorporate passenger information systems and push notifications of next bus arrival times to customers help to minimize passengers' perceived waiting times and relieve stress on transit operators for on-time arrivals. This may lead to fewer accidents and increase user confidence in the BRT system.

4.2 ENVIRONMENTAL IMPACTS

Bus rapid transit systems can have positive environmental impacts by reducing greenhouse gases that contribute to global climate change as well as local air pollutants, which lead to citywide air pollution and smog. Reductions in vehicle emissions can be achieved in several ways, including reducing vehicle-kilometers travelled (VKT) and improving the fuel efficiency and technology of the buses. Passengers shifting from single-occupancy vehicles to high-occupancy BRT buses reduce overall VKT in the city. Likewise, many BRT systems consolidate informal systems comprised of low-occupancy vans that may use older and more polluting fuels and vehicle technologies. New articulated or bi-articulated BRT buses can carry many more passengers per bus kilometer and many are capable of meeting the most stringent emissions standards[3].

4.2.1 REDUCTIONS IN GREENHOUSE GASES

Eleven BRT systems across Mexico, Colombia, China, India and South Africa have registered their carbon dioxide equivalent (CO_2e) emissions reductions through the United Nations Framework Convention on Climate Change's (UNFCCC) Clean Development Mechanism or other emissions verification schemes.

High-quality bus rapid transit systems, like all urban transport, can affect the quality of life, productivity, **health, and safety of people living in cities.**

These impacts have been explored in varying depth in the existing research as travel time benefits, environmental impacts, public health and safety benefits, and urban development changes.

Over the course of ten to twenty years of the systems' operations, starting as early as 2000, these registered BRT projects are forecast to reduce emissions by 31.4 million tCO_2e (Nelson, Nelson and Kruijne 2012), an amount equivalent to the annual greenhouse gas emissions from more than 6.5 million passenger cars (EPA 2013).

Studies from several cities substantiate the magnitude of greenhouse gas emissions reductions possible from a BRT system:

- In **Bogota**, the implementation of TransMilenio combined with new regulations on fuel quality is estimated to reduce emissions by nearly 1 million tCO_2 per year (Turner *et. al.* 2012).
- Together Phase 1A and 1B of **Johannesburg's** Rea Vaya BRT system are expected to reduce emissions by 40,000 tCO_2e annually (JIKE 2012).
- When **Mexico City's** Metrobus Line 1 first opened it was estimated to reduce emissions by nearly 27,000 tCO_2e per year (INE 2006).
- By reorganizing and consolidating informal transit and conventional buses, **Istanbul's** Metrobüs BRT system is estimated to reduce CO_2 emissions by 167 tons/day and cut daily fuel consumption by more than 240 ton-liters (Alpkokin and Ergun 2012).

4.2.2 REDUCTIONS IN LOCAL AIR POLLUTANTS

Local air pollutants, such as carbon monoxide and particulate matter, pose environmental and public health concerns. By forcing the retirement of less-efficient, older transport vehicles, BRT systems can have a positive impact on smog, local pollution, and the health of city residents. Because local air pollutants primarily impact individual health, this benefit is treated as a public health impact in this report in section 4.3 below.

4.3 PUBLIC HEALTH IMPACTS

Bus rapid transit systems also provide valuable public health benefits to society in three key ways: reduced road fatalities and injuries, reduced personal exposure

Table 5 Safety impacts of select BRT systems

	Type of transit service		Corridor and length (km)	Safety impacts with BRT, per year, per km (percent change in parenthesis)		
City	Before	After		Property Damage Only Crashes	Injuries	Fatalities
Mexico City[a]	Informal transit	Single lane BRT	Metrobus Line 3 (17 km)	+7.5 (+11%)	-6.7 (-38%)	- 0.3 (-38%)
Guadalajara[b]	Bus priority lane	BRT with overtaking lane	Macrobus (16 km)	-83.19 (-56%)	-4.1 (-69%)	-0.2 (-68%)
Bogota[c]	Busway	Multi-lane BRT	Av. Caracas (28 km)	n/a	-12.1 (-39%)	-0.9 (-48%)
Ahmedabad[d]	Informal transit	Single lane BRT	Janmarg system (49 km)	-2.8 (-32%)	-1.5 (-28%)	-1.3 (-55%)
Melbourne[e]	Conventional bus	Queue jumpers, signal priority	SmartBus Routes 900, 903 (88.5 km)	-0.09 (-11%)	-0.1 (-25%)	-0.03 (-100%)

Notes[a]: EMBARQ analysis, based on data provided by the Government of the Federal District of Mexico; [b] EMBARQ analysis, based on data provided by the Jalisco State Secretariat for Roadways and Transport and the Department of Public Health at the University of Guadalajara; c EMBARQ analysis, based on data provided by TRANSMILENIO S.A. and based on data from Bocarejo *et. al.*. 2012; d EMBARQ analysis, based on data provided by the Center for Environmental Planning and Technology (CEPT) Ahmedabad; e source: Goh *et. al.*. 2013;

Table 6 Weighted MeanSafety Effect of BRT Implementation

	Best estimate	95% confidence interval
Arterial BRT (Latin American examples)		
Fatalities	-47%	(-21%; -64%)
Injuries	-41%	(-35%; -46%)
All crashes	-33%	(-29%; -36%)
Arterial BRT (Latin American and Indian examples)		
Fatalities	-52%	(-39%; -63%)
Injuries	-39%	(-33%; -43%)
All crashes	-33%	(-30%; -36%)

to harmful air pollutants, and increased physical activity for BRT users.

4.3.1 ROAD SAFETY IMPACTS

While research on the road safety impacts of BRT systems is less developed than some of the other impact areas, recent studies have shown that BRT corridors can have a positive impact on traffic safety by reducing the frequency of traffic incidents, injuries and fatalities, even when controlling for citywide trends in accidents. Bocarejo *et. al.* (2012) found that the **Bogota's** TransMilenio has contributed to reductions in crashes and injuries on two of the system's main corridors. Duduta *et. al.* (2012) confirm these findings for Bogota and present additional evidence of positive safety impacts associated with the Macrobus BRT in **Guadalajara**, Mexico. Literature also shows road safety improvements from BRT systems in Australia: **Melbourne's** SmartBus BRT contributed to reductions in crashes at all severity levels on the streets where it was implemented (Goh *et. al.* 2013).

Table 5 summarizes results of safety impact assessments based on before and after data for four BRT systems in Latin America, India and Australia, as well as an additional analysis of crash data undertaken for this report. All four BRTs show significant positive safety impacts after their implementation. There were reductions in injuries and fatalities observed on all four corridors, and all but one (Mexico City) also witnessed reductions in crashes that resulted in property damage only (PDO crashes).

On average, BRTs in the Latin American context have contributed to a reduction in fatalities and injuries of over 40 percent, and a reduction in PDO crashes of 33 percent on the streets where they were implemented. The mean effect is quite consistent across different regions of the world, as evidenced by the similar impacts of the Janmarg BRT in **Ahmedabad**, India. Table 6 shows a mean estimate of safety impacts from the different examples in Table 5. The methodology used to derive these estimates is shown in detail in Appendix A.

The reductions in crashes after BRT implementation yield significant economic benefits by reducing the costs associated with traffic accidents, including fatal crashes, injury crashes, and property damage only (PDO) crashes. The largest benefits accrue from

EMBARQ's cost-benefit methodology includes

- TRAVEL TIME IMPACTS
- REDUCTIONS IN GREENHOUSE GASES
- REDUCTIONS IN LOCAL AIR POLLUTANTS
- ROAD SAFETY IMPACTS
- PHYSICAL ACTIVITY BENEFITS

the reductions in fatal crashes, both because fatal accidents are reduced at a higher rate than other types of crashes and because the cost of a fatal crash is considerably higher than that of an injury or PDO crash. EMBARQ's cost-benefit analysis methodology includes the economic benefits of road safety and other public health impacts. The approach is discussed in further detail in Section 13.1.2.1.

4.3.2 AIR QUALITY IMPACTS

The impact of exposure to harmful air pollution is a function of both the concentration of the pollutant in the environment as well as the duration of the exposure. BRT systems can therefore help reduce personal exposure to air pollution of passengers who switch to BRT from other modes in two ways:

- **Lowering the concentration** of ambient air pollution citywide or inside the BRT vehicles;
- **Reducing the amount of time** BRT passengers are exposed to air pollution at stations or inside the bus by reducing travel times.

The majority of BRT passengers switch to BRT from the existing bus and minibus services (Investigaciones Sociales Aplicadas & CTS Mexico 2007). In some cases, especially in Latin America, the implementation of the BRT is part of a larger transit reorganization scheme that involves eliminating the private minibus service and integrating the operators into the newly formed BRT operating agency. The replacement of older vehicles with newer buses is likely to also contribute to reducing emissions of local air pollutants on the corridor, which can have health benefits by reducing premature deaths and lost work days associated with pulmonary diseases.

Empirical data supports this. Along Insurgentes Avenue, **Mexico City's** Metrobús Line 1 has brought significant reductions in the concentration of carbon monoxide, benzene and particulate matter (PM2.5) inside BRT buses, traditional buses and mini-buses (Wöhrnschimmel *et. al.*. 2008). Similarly, after the implementation of TransMilenio, **Bogota** reported a 43 percent decline in SO2 emissions, 18 percent decline in NOx, and a 12 percent decline in particulate matter (Turner *et. al.* 2012). Metrobús not only reduced the concentration of carbon monoxide, benzene and PM2.5 inside the buses (compared to minibuses and traditional buses), but also reduced exposure by reducing in-vehicle travel times (Wöhrnschimmel *et. al.* 2008). It is estimated that such pollution reductions along Metrobús Line 1,especially of particulate matter, would eliminate more than 6,000 days of lost work, 12 new cases of chronic bronchitis, and three deaths per year, saving an estimated USD $3 million per year (INE 2006).

4.3.3 PHYSICAL ACTIVITY IMPACTS

BRT passenger surveys have shown that the vast majority of BRT passengers switch to BRT from the existing bus or minibus services (Investigaciones Sociales Aplicadas & CTS Mexico 2007). In addition, a small percentage of passengers shift from private cars and metered taxis, and an even smaller percentage from modes with a higher level of physical activity (i.e., walking, cycling, and metro). There is evidence indicating that a trip on a BRT involves a higher level of physical activity (due to longer walking distances) than all other motorized modes with the exception of a Metro (Mexico City Household Travel Survey 2007). In other words, BRT passengers tend to walk considerably more per trip than people who rely on private cars or taxis for transportation, and also slightly more than people who use regular buses or minibuses. This is primarily due to the fact that BRT stations are set relatively further apart compared with regular bus stops. Overall, because more passengers switch to BRTs from more sedentary modes (bus, minibus, car, taxi) than from more active modes (walking, cycling, Metro), BRT implementation typically results in higher rates of physical activity for BRT users as a whole.

Data from **Mexico City** and **Beijing** illustrates the potential physical activity benefits of BRT systems. Metrobús passengers walk, on average, an additional 2.75 minutes per day, while users of the Beijing BRT have added 8.5 minutes as a result of the BRT system (Mexico City Household Travel Survey, 2007; EMBARQ Analysis of Peking University data and Beijing Transport Annual Report 2007)

This increased physical activity results in health benefits for BRT users. A higher level of physical activity is strongly correlated with better health outcomes (CDC 1999). As people become more physically active across a population, there is an expected reduction in premature deaths due to diseases related to physical inactivity, such as diabetes, high blood pressure, cardiovascular diseases, and various types of cancers. EMBARQ's cost-benefit analysis methodology quantifies the mortality reductions from increased physical activity using the World Health Organization's Health and Economic Assessment Tool (HEAT) model[4] and monetizes those impacts using the concept of value of a statistical life (VSL) (see Sections 5.1 and 13.1.3 for more discussion).

4.4 OTHER BRT IMPACTS

In addition to the travel time, environmental and public health benefits, there are other important impacts of BRT systems related to urban development and land use, employment, crime rates, and even public

BRT systems have additional impacts related to urban development and land use, employment, crime rates, and even public tax revenues.

tax revenues. These impacts, detailed below, are important to acknowledge but are difficult to quantify in a traditional cost-benefit analysis. Thus, they are excluded from EMBARQ's CBA methodology and not considered in the case studies.

4.4.1 URBAN DEVELOPMENT AND PROPERTY IMPACTS

Extensive research has confirmed that urban properties respond positively to transportation improvements. This typically takes the form of higher property values and, if zoning allows, land-use intensification (Cervero and Kang 2011). In the short term, benefits of transportation infrastructure investments get capitalized in land values, while over the longer term, land uses may change (Cervero and Kang 2011).

There are clear examples where increased accessibility conferred by rail systems is reflected in increased land values and land use patterns (Cervero and Kang 2011, Rodríguez and Mojica 2009). However, for some time, conventional wisdom has suggested that urban bus systems, which do not include the same permanent infrastructure investments nor improve accessibility to the same degree as a rail system, would not influence urban development to the same degree as rail infrastructure.

Nonetheless, research shows that, to the extent that BRT systems include segregated bus lanes, enclosed stations and high-capacity buses, and are implemented as part of a citywide integrated transport system, BRT systems do have the potential to influence property values and land uses.

4.4.1.1 LAND VALUE CHANGES

The reductions in travel time and the improvements in quality of service associated with the implementation of a new transit line often get capitalized into land values, as residents and businesses are willing to pay a premium to be closer to transit stations[5]. The magnitude of the impact tends to vary considerably with market dynamics, property types, and across different regions of the world. Despite the variations, several trends can be observed in the literature:

- Proximity to BRT stations has a positive impact on land values, while proximity to a transit line (but

Table 7 Results of Hedonic Price Models Analyzing the Impact of Proximity to BRT Stations on Property Values

	Effect on property values (absolute value, 2012 USD)		Effect on property values (%)		Definition of "station area"	Source
City	Commercial	Residential	Commercial	Residential		
Pittsburgh	+ 9,745	n/a	n/a		A property within 30 meters of a BRT station, compared to one 300 meters away	Perk and Catala 2009
Seoul	+16.65 to +10,110 /m2	+1.8 to +732.5 /m2	+3% to +26%	+5% to +10%	150 m radius (commercial) and 300 m radius (residential)	Cervero and Kang 2011
Boston	+525 /m2		+7.6%		Not specified	Perk *et. al.*. 2012
Bogota	+0.02 /m2		+0.05%		For each meter closer to station	Perdomo 2011
Bogota	+1704 to +1861	+26.6 to +84.8	+268.7%	+5.8% to +17%	Area with BRT access	Pedromo Calvo *et. al.*. 2007
Bogota	n/a		n/a	- 4.50%	10 min walk around stations	Munoz-Raskin 2010

not a station) occasionally showed a disamenity effect on residential properties (see Table 7); this could be interpreted to mean that residents value proximity to transit stations, but not the traffic and pollution associated with major roadways.

- The impacts of station proximity on commercial properties were considerably higher than on residential properties, both in absolute value and in percent increase, suggesting that businesses (especially retail) value proximity to transit stations more than residents.
- Most studies on this topic have relied on hedonic price models – a cross-sectional model that does not track property values over time. A limited number of studies have tracked property values before and after BRT implementation; they show results consistent with the hedonic price models, but lower coefficients (i.e., less impact on property values).

Several studies tracking the impact of BRT on property values over time in Beijing and Bogota show an increase in property values in the vicinity of stations in the range of 1.8 to 2.3 percent (Deng and Nelson 2010; Rodriguez and Mojica 2008). Table 7 summarizes studies relying on the more common method of assessing property value impacts– hedonic price models – which show generally positive and considerably higher impacts on property values than time series studies[6].

In **Seoul**, Korea, Cervero and Kang (2011) found that new BRT services produced highly localized land value premiums. Land markets capitalized the BRT's accessibility benefits particularly for higher-density residential uses. Residences within 300 meters of the BRT stations experienced land price premiums of 5 to 10 percent, while retail and other non-residential uses within 150 m of the BRT stations benefitted from premiums of 3 to 25 percent. In **Bogota**, research examining the impacts of TransMilenio Phase 2 found that multi-family residential properties near the BRT stations rented for more per square meter than housing further away, and for every five minutes of additional walking time to a station, property values decreased between 6.8 and 9.3 percent (Rodriguez and Targa 2004). Levinson *et. al.* (2002) point out that **Brisbane's** South East Busway, with its high-quality station design and Busway infrastructure, catalyzed several major development projects and increased residential property values near stations 20 percent compared to similar areas beyond walking distance of stations.

While the vast majority of studies found that proximity to BRT stations had a positive impact on property values, one study in **Bogota** found the opposite. Munoz-Raskin (2010) found that, while controlling for confounding factors, the advertised price for properties located within a 10-minute walk to TransMilenio was, on average, 4.5percent lower price than properties located elsewhere in Bogota.

4.4.1.2 LAND USE CHANGES

BRT systems may also catalyze changes in the types of development – residential, retail, office, industrial – or the density of development near stations. In addition to accommodating existing travel demand on a corridor, a BRT may induce higher-density development around stations as a result of increased accessibility and higher pedestrian volumes. New BRT services in **Seoul** resulted in market demand for higher-density residential land uses (Cervero and Kang 2011). Increased accessibility in Seoul spurred the conversion of single-family residences to higher-density apartments and condos near BRT stations. After implementation of the median-lane BRT corridor, parcels within half a kilometer of a BRT stop were more likely to convert to more intensive land uses (i.e., from single family residential to multifamily residential) than parcels beyond half a kilometer. Within 400 meters of a BRT stop, the most likely land use conversion was from single family to multifamily residential uses.

Many of the largest benefits of urban transport projects, and perhaps the most important long-term, transformational benefits such as increased connectivity and increased access possibilities, are difficult to capture and quantify. These are especially difficult to capture in areas of rapid change where the informal sector dominates economic activity and data availability is poor. For example, **Ahmedabad's** Janmarg BRT network represents an excellent chance to help shape a more inclusive city around cost-effective public transit integrated into a broader transport network that includes safe access, non-motorized transport (NMT) networks, and pleasant and inviting public spaces.

4.4.2 EMPLOYMENT IMPACTS

Construction, operation and maintenance of BRT systems can create jobs. This may result in a net increase in the number of employed people, or merely a shift of workers from one job or sector to another. In many cases, BRT systems create new jobs in the formal economy that replace informal jobs from the existing traditional transport system.

The employment impact due to the implementation of TransMilenio was positive. The BRT system resulted in a net gain of 1,900 to 2,900 permanent jobs in operations, plus 1,400 to 1,800 temporary jobs per month during construction. This net gain occured despite the requirement for elimination of traditional buses between Phase I and Phase II. It is also worth noting that these were new jobs in the formal sector replacing informal jobs from the traditional system.

Phase 1A of Johannesburg's Rea Vaya BRT system helped move former minibus taxi drivers from the informal sector to formal employment as Rea Vaya bus drivers. Annual earnings for these drivers increased more than two-fold and they benefited from formal employment arrangements (McCaul 2012). Rea Vaya employs more than 780 people between the bus operating company (as drivers and admin staff), stations (as customer service ambassadors, cashiers, cleaners and security), and the city's BRT business unit offices (McCaul 2012). During construction of Phase 1A, more than 15,000 construction jobs (defined as at least 55 days of continuous work per person) were created.

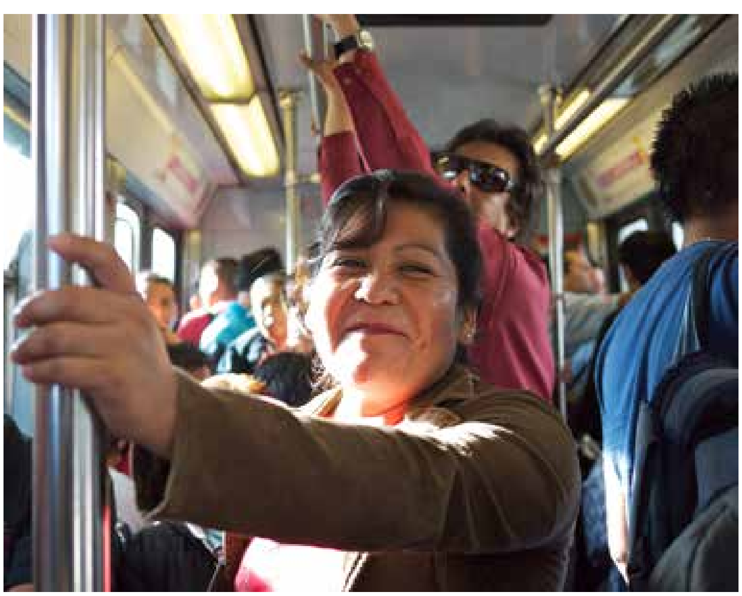
4.4.3 CRIME IMPACTS

By providing well-lit stations staffed with security personel, security cameras on buses and in stations and pedestrian-scale lighting around stations, BRT systems can create a safer environment in those areas they serve. According to statistics from the Center for Criminal Investigations of the Bogota Metropolitan Police, aggregate crime in the area around Av. Caracas dropped 85 percent between the period prior to (1999–2000) and following (2001–2002) the implementation of the TransMilenio system (TransMilenio, 2008). Analysts credit this to increased and better organized economic activity and movement.

On the other hand, crowded stations and buses may increase petty crime such as pick-pocketing within the the BRT system. In Bogota, petty crime in the TransMilenio system is still a big and growing concern for users.

4.4.4 TAX REVENUE IMPACTS

The formalization of Bogota's transportation industry through concession contracts resulted in increased tax revenues for the national and local goverments. The financial statements from the TransMilenio system private operators show that between 2005 and 2008 these operators made income tax payments of 32.158 billion 2008 pesos, and 17.476 billion pesos in other tax payments, such as unrecovered VAT, sales, and industry taxes, as well as vehicle taxes. These revenues were not captured under the traditional bus system that predated the TransMilenio BRT.

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CHAPTER 5

EMBARQ'S BRT IMPACT EVALUATION APPROACH

As detailed in Chapter 4, bus rapid transit projects have the potential to provide travel time, public health, environmental, land use, and other benefits to society. At the same time, BRT systems, like all transport options, can impose social costs from construction, operation, and maintenance. In order for policymakers to make an informed decision regarding the development or expansion of a BRT project, the project should be evaluated in terms of total benefits compared to total costs. Ideally, an analysis of transit alternatives should be done comparing alternative solutions in a pre-construction phase. Often, however, little or no analysis is done. Some government and multilateral funding programs suggest or require impact analysis[7], most often a cost-benefit analysis, and this report adopts this approach.

5.1 COST-BENEFIT ANALYSIS

Cost-benefit analysis (CBA) is used to capture both public and private costs and benefits for society as a whole (Harberger and Jenkins 2002, Gramlich 1997, and Boardman et. al. 2006). In addition to the financial or market costs, it also considers externalities and indirect or intangible costs to capture social effects. Cost-benefit analysis therefore provides policymakers with a valuable tool for comparing net benefits (benefits minus costs), and is well accepted in the transportation policy community. Several insightful alternative project evaluation methods have been proposed, such as social impact assessment (Thynell *et. al.* 2009; Arora 2007) and multi-criteria analysis (Department for Communities and Local Government 2009 and Munior 2011). Yet these have failed to make major inroads, and cost-benefit analysis remains the principal approach in transportation policy analysis, and thus will be used in this report.

For each of the four case studies, EMBARQ has applied a CBA methodology which incorporates well-accepted transportation planning and analysis methods to analyze the effects of BRT. Based on available data, we provide as comprehensive an analysis as possible and strive to be transparent in our assumptions. Where data is incomplete, we extrapolate trends from existing data to estimate key inputs. We acknowledge limitations in this approach, but adopt it in light of the broad professional acceptance of cost-benefit analysis. (A detailed discussion of EMBARQ's cost-benefit methodology and assumptions for each case may be found in Appendix A – EMBARQ's BRT Impact Evaluation Methodology. Assumptions used in the analysis of each case are presented in Appendices B-E).

Three summary indicators are used in the cost-benefit analysis:

- **Net present value:** Because the costs and benefits of transportation projects will continue over many years, the future costs and benefits are often discounted over the life of a project, in the form of an estimated net present value (NPV). A positive NPV implies that a project offers net benefits.
- **Benefit-cost ratio:** A ratio of the net present benefits and costs greater than one indicates that the total benefits to society exceed the costs.
- **Internal rate of return (IRR)**: The IRR is the discount rate at which the net present value of costs equals the net present value of the benefits, indicating the attractiveness of the investment. The IRR of a public investment should exceed the cost of capital.

Table 8 Summary of Costs Considered in Each Case Study

	Bogota	Mexico City	Johannesburg	Istanbul
Planning Costs	X	X	X	
Land Acquisition	X			
Infrastructure Construction Costs	X	X	X	X
Equipment Costs (Fleet, fare collection)	X	X	X	X
Bus Operations & Maintenance Costs	X	X	X	X
Infrastructure Operations & Maintenance	X	X	X	X
Fleet Salvage	X	X	X	X
Incumbent operator negotiations			X	X

Table 9 Summary of Benefits Considered in Each Case Study

	Bogota	Mexico City	Johannesburg	Istanbul
Changes in Travel Time	X	X	X	X
Private Vehicle Operating Cost Changes			X	X
Transit Operating Cost Changes	X	X	X	
Travel Cost Changes	X	X		
CO_2 Emissions Changes	X	X	X	X
Road Safety Impacts	X	X	X	X
Changes in Exposure to Air Pollutants	X	X		
Changes in Physical Activity	X	X	X	X

EMBARQ's CBA methodology considers a set of typical BRT project costs and many of the benefits described in Chapter 4. Where reliable data is available, each of the four case studies incorporates these elements into its CBA (see Table 8 and Table 9).

5.2 DISTRIBUTIONAL ANALYSIS

While CBA is a powerful tool to guide decisions, the methodology does not typically include a distributional analysis. EMBARQ's methodology goes beyond traditional CBA, evaluating the distribution of benefits and costs across society to identify which income groups are winners and losers. We consider the benefit-cost ratio by income strata as well as how net benefits (benefits minus costs) are distributed across socioeconomic groups. Additional details about EMBARQ's distributional analysis methodology are included in Appendix A, Section 13.1.4.

Some analysts have recognized the need to expand CBA to look at distributional impacts as well as the more aggregate effects of projects and policy interventions (see, for example, Government of Australia 2006 or Jenkins, Kuo, and Harberger 2011). In this report, we focus on one narrow lens – benefits of a BRT line accruing to different income groups – based on available information. However, we are aware that a broader and more detailed look is warranted. Nonethless, this approach is a dramatic step forward compared to current practice, since we are explicitly acknowledging the importance of the distributional aspects of BRT costs and benefits and attempting to quantify them.

5.3 SELECTION OF CASE STUDIES

This report features case studies which use available data to estimate the net benefit to society from bus rapid transit projects in Bogota, Colombia; Mexico City, Mexico; Johannesburg, South Africa; and Istanbul, Turkey (Table 10). The case study BRT systems were selected based on EMBARQ's strong relationship with local transport authorities and significant understanding of the projects, as well as a desire to have a geographically diverse set of cases. As a set, the four case studies provide a window into the costs and benefits of BRT projects in developed and developing cities on four different continents, and shed light on the variance found among the more than 160 cities across the world that have implemented BRT or high-quality bus corridors (BRTdata.org 2013).

The selection of case studies was also limited by the public availability of data. Estimates of costs and benefits rely on accurate and comprehensive data collection and transparent data management practices that push data to the public. In each case, some data on the inputs to costs and benefits were collected by the implementing transport authority and made publically available.

Table 10 Summary Characteristics of Selected Four Case Studies

	Bogota, Colombia	Mexico City, Mexico	Johannesburg, South Africa	Istanbul, Turkey
City Population[a]	7.3 million	9 million	4.4 million	10.9 million
BRT System	TransMilenio	Metrobús	Rea Vaya	Metrobüs
Scope of Case Study	Phases I and II	Line 3	Phase 1A	First 4 phases
Year of Operation	2000	2011	2009	2007
Daily Ridership[b]	1.6 million	123,000	40,000	600,000[c]

Notes: [a] City, not metropolitan area population. Sources include Secretary of Planning, 2011; http://www.edomexico.gob.mx/sedeco/; CoJ 2013b; www.metropolis.org

[b] Daily ridership figures are for the portion of the BRT system analyzed in the case study, which is not necessarily the full system.

[c] IETT publishes system ridership figure of 750,000 passengers per day, but a more conservative estimate of 600,000 daily passenger trips is used in the Istanbul case study analysis.

CHAPTER 6

CASE STUDY: BOGOTA, COLOMBIA'S TRANSMILENIO PHASES 1 AND 2

6.1 KEY FINDINGS: TRANSMILENIO PHASES 1 AND 2

EMBARQ's analysis of the costs and benefits of the first two phases of Bogota's TransMilenio BRT reveal the following key findings:

- The two largest benefits are travel time savings for transit users and savings on the operation of traditional buses that were removed from service following the implementation of the TransMilenio system.
- Lower- and middle-income groups make up the largest proportion of users of the BRT system.
- TransMilenio benefits are biased towards the lower income strata, while costs are biased towards the highest socioeconomic stratum, reflecting the profile of users and the structure of Colombian tax policy.

6.2 BOGOTA AND TRANSMILENIO BACKGROUND

Bogota, the capital city of Colombia, is home to 7.3 million inhabitants and has one of the highest population densities in the region, with 21.3 inhabitants per square kilometer (Secretary of Planning 2011). Traditionally, Bogota's public transport system has been operated by private bus companies. The local authority, the Secretary for Traffic and Transport (STT), issues individual licenses to private firms to operate the different bus routes. However, the licenses are mere authorizations to run buses on a given route; they do not specify operational requirements and do not establish a contractual relationship between the city and the companies. The STT lacks the institutional capacity to properly regulate the transport system and the private companies have obtained increasing political influence in the city (Ardila 2004).

These firms do not necessarily operate their own fleets. Instead, they charge a lump sum and a fixed monthly rent to independent bus owners, allowing them to run their buses on the routes and profit from them (Bogota Chamber of Commerce 2006). This leads to a persistent bus oversupply since license-holding companies have an incentive to rent their routes to as many bus owners as possible in order to maximize their revenues.

On the other hand, bus owners do not have a formal contractual relationship with their bus drivers. They agree that the driver is to operate the bus on a specific route and will make a percentage commission on any ticket sold. Occasionally, some bus owners drive their own bus. This provides an incentive for drivers to carry as many passengers each day as possible, competing for passengers with other buses in a "guerra del centavo" or "penny war." This, combined with the high bus oversupply, reduces profits for drivers and owners alike. There are a number of other side-effects as well, including unsafe driving conditions, low ridership per bus, traffic congestion, long journey times, high air pollutant emissions, unnecessary road wear and tear and lower-than-expected returns on investments. For instance, even though the number of legal buses remained at 16,500 from 1999 to 2005, the number of daily passengers carried dropped from approximately 5 to 4 million (Cal y Mayor and Duarte Guterman 2006; Ardila 2007).

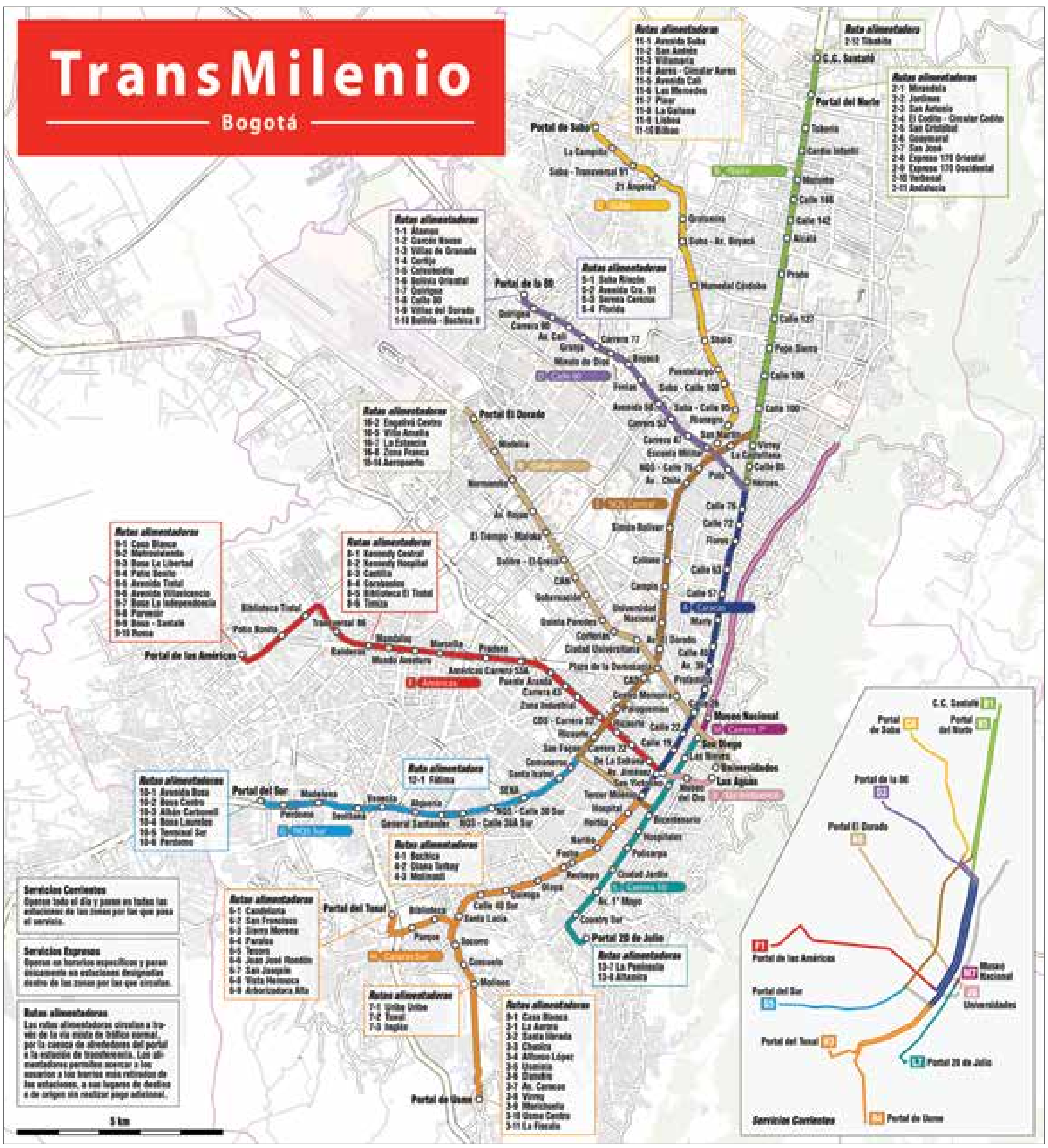
Between 2000 and 2001, the TransMilenio system opened in the most important public transport corridor of the city, the Avenida Caracas, along with two other corridors. The new system represented a radical change from the previous situation, and a new institutional arrangement was put in place. A shareholding company, TransMilenio S.A., was created by the city council, with the city owning 100 percent of the shares. This provided a fresh start at regulating public transport. As a shareholding company, TransMilenio S.A. was allowed to pay higher salaries than its partner STT. Consequently, it was able to attract better-trained staff and build a stronger organization that was able to properly regulate the system, although there is no direct competition in the TransMilenio trunk lines. Currently, TransMilenio S.A. regulates the BRT system while the STT regulates the coexisting traditional bus system.

The TransMilenio system was also part of a wider package of urban transport reforms that included limiting the use of private cars at peak hours, establishing parking restrictions, and increasing gasoline taxes to finance road maintenance and

mass transit development. The package also included enhancing pedestrian facilities and building extensive bicycle infrastructure.

TransMilenio Phase III is currently in operation, expanding the system to 120 km of segregated bus lanes, 1,400 articulated and bi-articulated buses, 600 feeder buses and 1.9 million passengers per day. A 5.5 km extension of Phase II into the municipality of Soacha is currently under construction and the first 34-km line of Phase IV is being planned. Other existing corridors will likely be expanded as well in coming years. Additionally, the city is undergoing a transition to an integrated public transport system that will completely replace traditional buses.

Figure 9: Bogota TransMilenio Map, September 2013



Source: http://en.wikipedia.org/wiki/File:TransMilenio_Bogota_Map.png

Bogota Case Study

SCOPE OF ANALYSIS
Phases 1 and 2

LINE LENGTH
84 km

DAILY RIDERSHIP
1.6 m

PLANNING/CONSTRUCTION BEGAN
1999

OPERATIONS BEGAN
2000

6.3 COST-BENEFIT ANALYSIS OF TRANSMILENIO PHASES I AND II

This cost-benefit analysis of TransMilenio considers the costs and benefits associated with Phase 1 and 2 of the system over a 20-year time horizon (1998-2017). The assessment incorporates all implementation and operating costs and estimates of benefits according to EMBARQ CBA methodology (see Chapter 5).

As shown in Table 11, the TransMilenio BRT has a positive present net value, a benefit-cost ratio greater than one, and an internal rate of return greater than 12 percent, which indicates that the benefits of the project exceed total costs. The flow of socioeconomic costs and benefits show a significant volume of investment in the initial years and a new cycle of expenses in 2012 through 2017 as a result of the need to rehabilitate and replace fleet vehicles. We also note a gradual increase in benefits over time. As a result, the net value of benefits is likely to grow in 2017 as a result of the realization of the salvage value of infrastructure and equipment with remaining service life. The net flow is negative in the first years, when phases I and II are under construction or implementation, with a significant excess being produced by 2008 (equal to or greater than 1 trillion 2012 pesos).

Table 11 TransMilenio CBA Summary Indicators

	COP billion (2012)	USD million (2012)
Present Value 1998-2017 Costs	$4,239	$2,359
Present Value 1998-2017 Benefits	$6,755	$3,759
1998 – 2017 Benefit/Cost ratio	**1.59**	
1998 – 2017 Internal Rate of Return	**23.2%**	

Table 12 Present Value of Costs, TransMilenio Phases I and II (12% Discount Rate)

	COP billion (2012)	USD million (2012)
PUBLIC COSTS	**$2,585.01**	**$1,438.59**
Studies and project preparation costs	$28.80	$16.03
Real estate purchase and resettlement	$332.46	$185.02
Infrastructure Construction and/or Rehabilitation	$2,014.01	$1,120.83
Infrastructure Maintenance	$102.80	$57.21
Implementation of Control Center	$34.19	$19.03
Control Center Operation	$7.53	$4.19
Costs of the Public Project Management Agency	$65.21	$36.29
Salvage Value	-$743,874	-$413.98
PRIVATE COSTS	**$1,654.74**	**$920.89**
Bus Fleet Acquisition	$509.52	$283.55
Bus Fleet Operation	$878.30	$488.79
Implementation of Collection System	$23.08	$12.85
Collection System Operation	$243.84	$135.70
TOTAL	**$4,239.75**	**$2,359.48**

Source: Prepared by EMBARQ, based on data provided by TRANSMILENIO S.A.

6.3.1 TRANSMILENIO COSTS

The present value of project costs was 4.2 trillion 2012 pesos (USD 2.4 billion) (economic prices), of which 61 percent reflected public costs and 39 percent reflected private costs. This includes infrastructure rehabilitation budgets for 2010 through 2018, fleet replacement at year 10, and fleet growth in line with expected demand increases.

The net present value of the economic benefit-cost flow between 1998 and 2017, using a 12 percent annual discount rate, is 2.52 trillion 2012 pesos (USD 1.4 billion) (Table 12). The benefit-cost ratio is 1.59, and the flow of benefits minus costs over the 20 years yields an internal rate of return of 23.2 percent, higher than the 12 percent recommended by the Colombian National Planning Department.

Public funding came from the national and city governments in almost equal parts through a joint funding agreement. Private companies financed their investments in part with loans obtained from the local financial sector.

TransMilenio's net present value of the economic **benefit is USD 1.4 billion for 1998—2017**

The benefit-cost ratio is 1.59, and the flow of benefits minus costs over the 20 years yields an internal rate of return of 23.2 percent, higher than the 12 percent recommended by the Colombian National Planning Department.

6.3.2 TRANSMILENIO BENEFITS

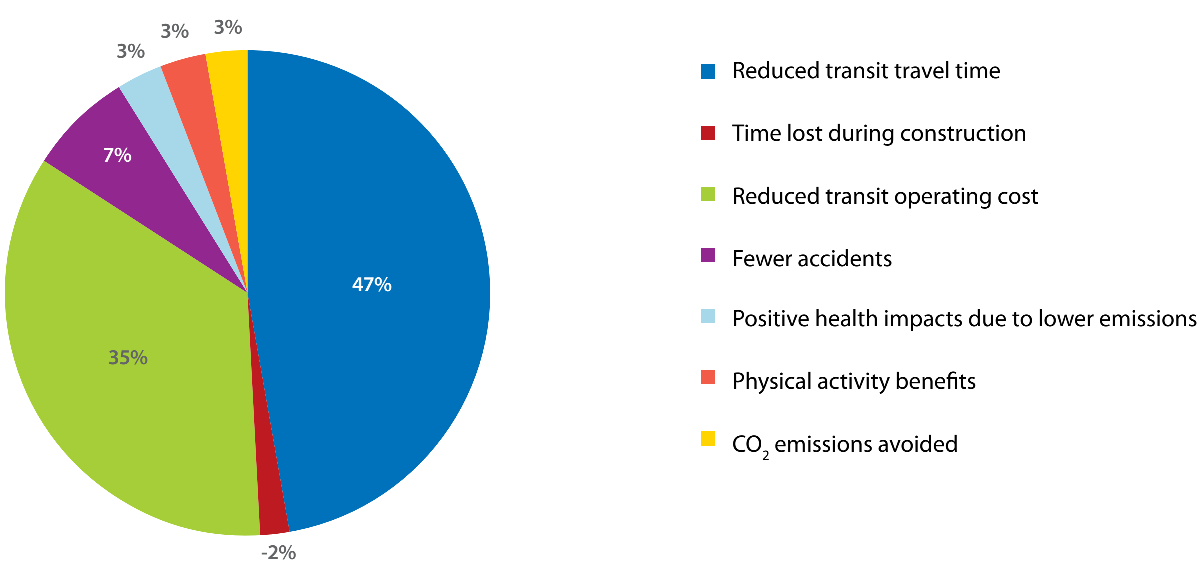
The present value of the estimated benefits from the project amounts to 6.76 trillion 2012 pesos (USD 3.76 billion) (Table 13), of which 70 percent reflect Phase I benefits and 30 percent reflect Phase II benefits. Figure 10 shows the relative size of the various TransMilenio benefits. The two largest benefits are travel time savings for transit users and savings on the operation of traditional buses removed from service following the implementation of the TransMilenio system. Segregated lanes allow TransMilenio to achieve operational speeds of about 28 km/hr, which is significantly higher than the 18 km/hr traditional bus system, yielding travel time savings for transit users. Additionally, the number of BRT buses was optimized, reducing bus oversupply and leading to significant savings in operation costs. Reduced oversupply also drives the reduction in emissions of pollutants and greenhouse gases. The cost-benefit analysis includes lost time during construction but does not incorporate impacts on overall city-wide traffic after the project was implemented (i.e., reduced travel times and reduced operating costs due to reduced traffic congestion), thus yielding a conservative evaluation.

Table 13 Present Value of Benefits, TransMilenio Phases I and II (12% Discount Rate)

	Total COP billion (2012)	Total USD million (2012)
Reduced transit travel time	$3,287,721	$1,830
Time lost during construction	(-$160,157)	(-$89)
Reduced transit operating cost	$2,503,937	$1,393
Fewer accidents	$517,520	$288
Positive health impacts due to lower emissions	$235,068	$131
Physical Activity Benefits	$177,310	$99
CO_2eq emissions avoided	$193,877	$108
TOTAL	**$6,755,276**	**$3,759**

Source: Prepared by EMBARQ. Base information supplied by TransMilenio S.A.

Figure 10 Distribution of TransMilenio's Present Benefits

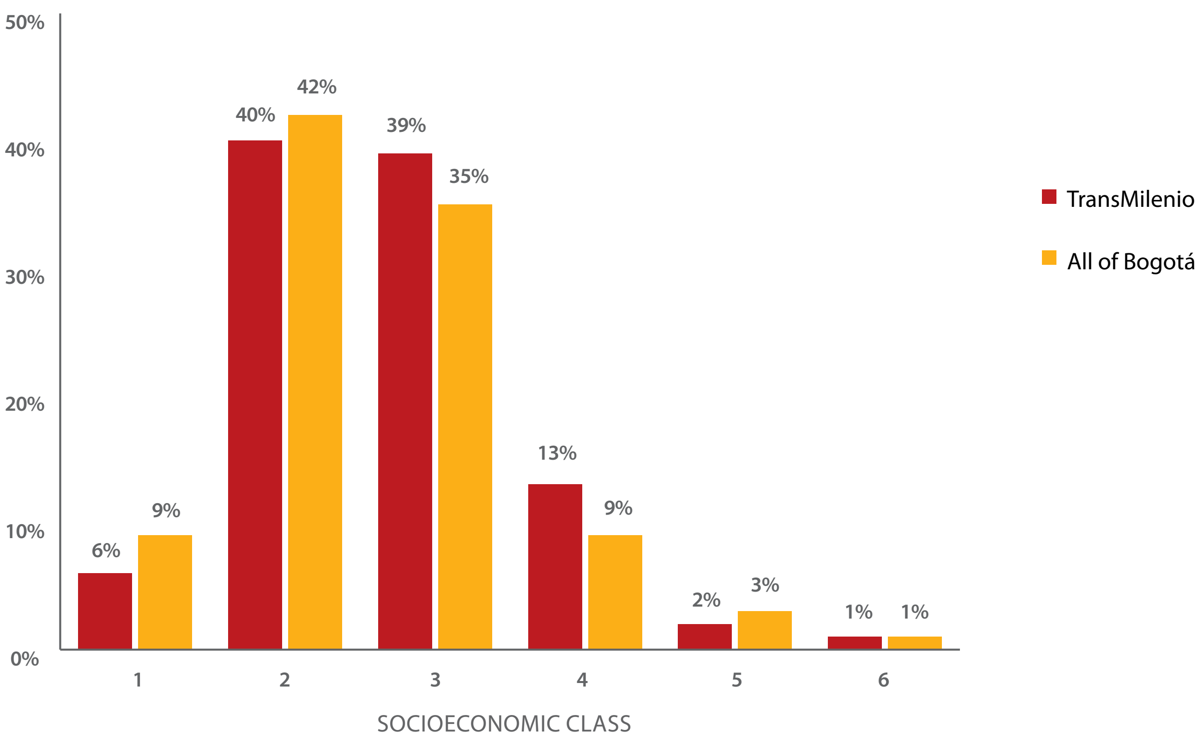


Source: Prepared by EMBARQ, based on data supplied by TransMilenio S.A.

6.3.3 TRANSMILENIO DISTRIBUTIONAL ANALYSIS

TransMilenio captures 27 percent of total public transit trips in Bogota, with an additional 2 percent accounted for by those who use only its feeder lines. The class distribution of mass transit trips, seen in Figure 11 below, is different from the socioeconomic distribution of the city as a whole. The largest proportion of riders comes from middle and lower-middle socioeconomic classes, reflecting the city's demographics. The highest and the lowest income groups make up a relatively small percentage of the riders, although this could change with improved quality of service or more extensive coverage. It should be noted that TransMilenio currently captures more than 20 percent of transit users in each strata. For all motorized trips, TransMilenio captures 18 percent for the general population, but at least 10 percent of each of the lowest three socioeconomic groups.

Figure 11 Distribution by Socioeconomic Class, TransMilenio Users vs. All of Bogota (2011)



Source:
Authors based on Steer Davies Gleave and Centro Nacional de Consultoria, Bogota Mobility Survey 2011 and TransMilenio S.A.

Applying the distributional cost benefit analysis approach where costs and benefits are allocated among socioeconomic classes reveals that TransMilenio benefits are biased towards the lower income strata, while costs are biased towards the highest socioeconomic stratum. Patronage is high in low-income strata because of the extensive feeder bus coverage in low-income areas. Table 14 presents the relationship between discounted costs and benefits by stratum. The numbers above one indicate benefits greater than costs, with larger numbers showing greater benefits. The highest

Table 14 TransMilenio Benefit-Cost Ratios by Income Stratum

Benefit-Cost Ratio by Income Stratum (average monthly income 2012 COP)					
Total	1 (191,038)	2 (273,367)	3 (539,925)	4 (1,335,515)	5 and 6 (2,561,290)
1.59	1.42	3.12	2.56	1.50	0.82

Figure 12 TransMilenio Net Present Values by Income Stratum

category, representing the richest socioeconomic group, is the only one where costs are higher than benefits, and the most benefits accrue to groups two and three.

Figure 12 demonstrates the benefits of BRT systems to lower socioeconomic strata, with most benefits accruing to lower-middle income groups, and the top income group having costs dominating benefits.

CHAPTER 7

CASE STUDY: MEXICO CITY, MEXICO'S METROBÚS LINE 3

7.1 KEY FINDINGS: METROBÚS LINE 3

EMBARQ's analysis of the costs and benefits of Line 3 of Mexico City's Metrobus BRT system reveals the following key findings:

- The largest benefits were travel time savings for public transport users, which is explained by the segregated bus lane allowing buses to achieve high operation speeds.
- Savings in operation costs of public transport vehicles are the second largest benefits. This is the result of larger, newer buses that operate at higher speeds. This also helps the system to have lower emissions.
- The largest proportion of users of the BRT system is in the lower and middle income groups.
- The largest benefits also accrue to users in the lower- and middle-income groups, particularly the quintile representing those in the 20-40 percent portion of the income distribution.
- The largest losses accrue to the top stratum of income earners.

7.2 MEXICO CITY AND METROBÚS BACKGROUND

Mexico City is home to 18 million people and 6 million cars spread over an area of 1,485 km^2, making it one of the largest, most polluted and congested cities in the world (EMBARQ n.d.). Solving the twin problems of congestion and air pollution requires de-emphasizing individual motorized transport and providing a clean, affordable and

Metrobús Case Study

SCOPE OF ANALYSIS

Line 3

LINE LENGTH

17 km

DAILY RIDERSHIP

123,000

PLANNING/CONSTRUCTION BEGAN

2009

OPERATIONS BEGAN

2011

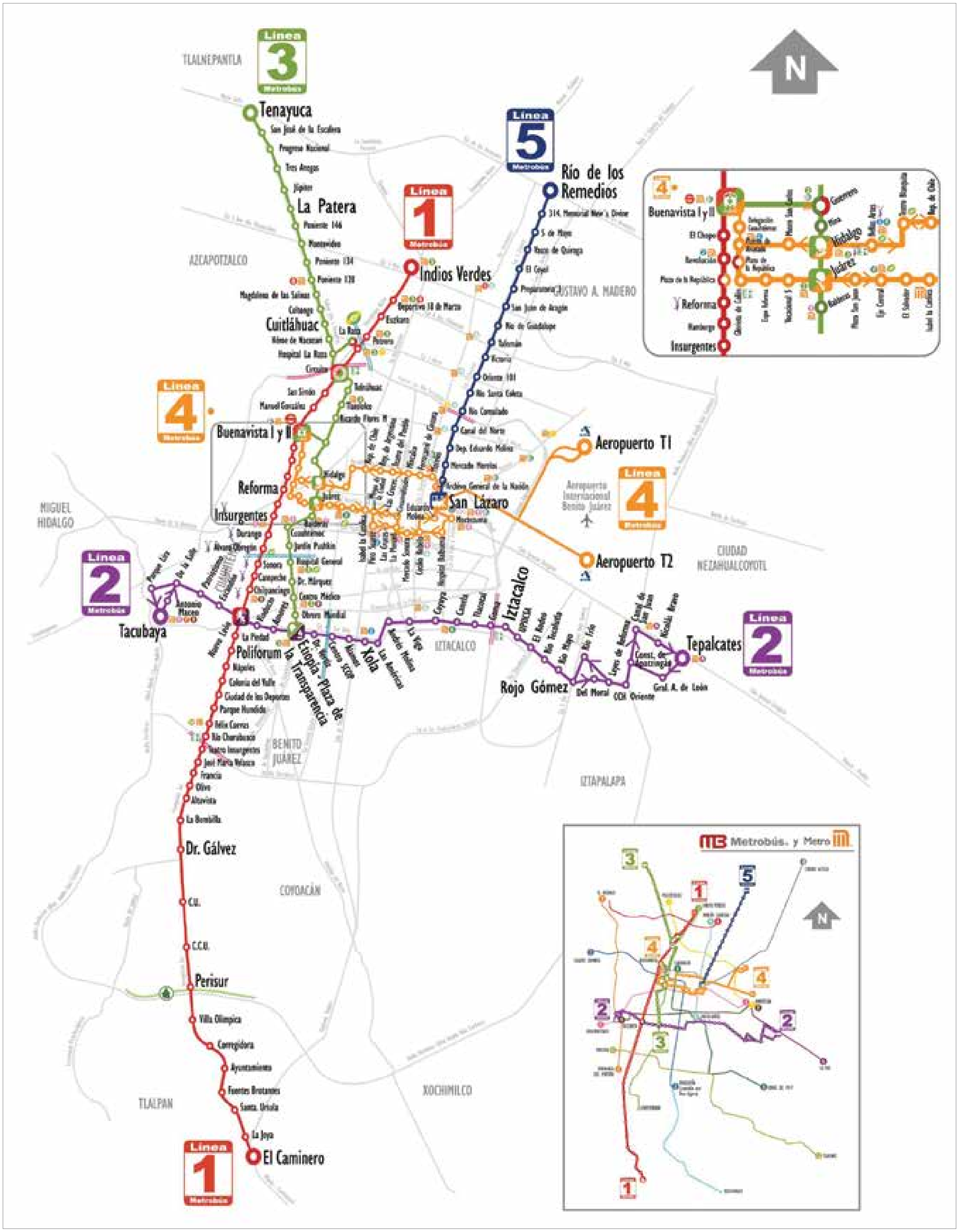
accessible mass transit system as a viable substitute. Part of the solution lay in creating an effective Bus Rapid Transit System.

Mexico City is served by the largest metro system in Latin America. While this busy system transports nearly 8 million people per day, it only covers half of the urban area, and has not been effective in tackling congestion and air pollution.

The Metrobús was inaugurated in 2005, replacing a total of 1,108 standard and microbuses (*peseros*) with 161 articulated buses running at an average speed of 19 km/hr, thus reducing travel time by 50 percent (Voukas 2012). At 93 km long, the Metrobús serves 850,000 passengers daily (Excelsior 2013) and has resulted in the reduction of 690 tons of nitrogen oxide, 2.8 tons of fine particulate matter, 144 tons of hydrocarbons and 80,000 tons of CO2 annually (CTS-México 2009). Over the years, it has improved mobility on its routes by 50 percent, reduced accidents by 30 percent and shifted an estimated 6 percent of travelers from private vehicles to public transport (CTS-México 2009).

The BRT has had three phased expansions so far. In December 2008, Line 1 expanded to fully cover the *Avenida Insurgentes* route, increasing the length of Line 1 to 30km. This 43-station line serves approximately 420,000 passengers per day. The Metrobús has reduced travel time on this route from 2 hours to 55 minutes. This expansion also created Line 2 *Eje 4 Sur* running west to east. In February 2011, service on Line 3 commenced and as of 2012 this line serves 130,000 passengers daily, reducing travel time by 40 percent. Construction of Line 4 further serving the west-east corridor was inaugurated in April 2012. As of June 2013, two more lines have been announced—Line 5, covering the northeast and Line 6, connecting the northwest of the city with the airport east of the city. Given its early success, Mexico City Mayor Ebard also launched *Insurgentes Sur*—a 9.5km extension of the Metrobús with full handicappedaccess. Similar facilities are being planned across the other lines.

Figure 13 System Map of Mexico City's Metrobus



7.3 METROBÚS LINE 3 COST-BENEFIT ANALYSIS

This analysis, which examines the costs and benefits of Metrobús Line 3, estimates the present value of costs as $2.087 billion pesos ($158 million 2012 USD) discounted at a 12 percent rate. The present value of benefits of Metrobús Line 3 is $2.496 billion pesos ($190 million 2012 USD) (Table 15). For the period 2009 to 2028 the project has an internal rate of return that is greater than the discount rate of 12 percent and a benefit-cost ratio greater than one. These parameters indicate the project is a worthwhile public investment on an aggregate level.

7.3.1 METROBÚS COSTS

As Table 16 shows, infrastructure is by far the largest cost of the project. At 1.613 billion pesos it makes up 77 percent of the total costs, and includes resurfacing of the road, including reinforcement of the segregated bus lane, and building the stations. This cost was mainly paid for with public funds. The second largest cost (16 percent of the total) is bus fleet acquisition, which required private operators to buy all new articulated buses to operate the BRT line and replace the old, traditional “pesero” buses. The new buses were paid for with private money and with the proceeds of scrapping their old buses.

Table 15 Metrobús Line 3 Cost-Benefit Analysis Summary Indicators

	MXN Million (2012)	USD Million (2012)
Present Value 2009-2028 Costs	$2,087	$158
Present Value 2009-2028 Benefits	$2,556	$194
2009 – 2028 Benefit/Cost ratio	**1.22**	
2009 – 2028 Internal Rate of Return	**14.4%**	

Table 16 Metrobús Line 3 Costs (Present Value, 12% Discount Rate)

Present Value of Costs 12% discount rate	MXN Million (2012)	USD Million (2012)
Infrastructure construction	$1613.6	$122.5
Infrastructure maintenance	$195.9	$14.9
Bus fleet acquisition	$337.9	$25.7
Bus renovation plus salvage value	-$60.8	-$4.6
TOTAL COSTS	**$2086.6**	**$158.4**

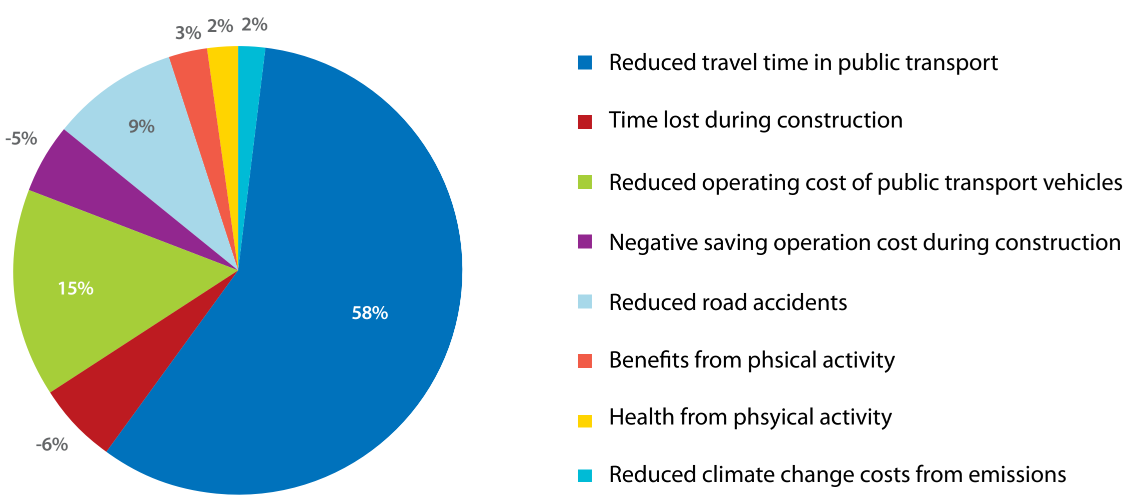
7.3.2 METROBÚS BENEFITS

Travel time savings for transit users are by themselves larger than the infrastructure costs (See Table 17). They amount to 1.86 billion pesos and make up 58 percent of the total benefits from the project (Figure 14). Metrobús operates at higher speeds than traditional public transport or private vehicles in Mexico City. Reduced vehicle operation costs are 15 percent of the benefits of the project, followed closely by the reduction in accidents (9 percent of total benefits). These are the result of the way Metrobús operates: segregated lanes, use of a smaller number of larger and newer buses, and optimized service scheduling, among other features. Separating bus traffic from mixed traffic has significant impacts on

Table 17 Metrobús Line 3 Benefits (Present Value, 12% Discount Rate)

Present Value of Benefits 12% discount rate	MXN Million (2012)	USD Million (2012)
Reduced Travel Time in Public Transport	$1864.5	$141.6
Time Lost during construction	-$178.7	-$13.6
Reduced Operating Cost of Public Transport Vehicles	$497.1	$37.7
Negative saving operation cost during construction	-$149.4	-$11.3
Reduced Road Accidents	$304.0	$23.1
Benefits from Physical Activity	$91.5	$6.9
Health Benefits from Reduced Emissions	$59.7	$4.5
Reduced climate change costs from emissions	$67.2	$5.1
TOTAL BENEFITS	**$2555.8**	**$194.1**

Figure 14 Distribution of Mexico City's Metrobús Present Benefits



commercial speeds and trip reliability, leading to lower travel times as well as lower emissions and fuel use. It also reduces interactions with other vehicles, resulting in improved road safety. Road safety benefits also arise as a result of the formalization of private operators, who now have trained and formally hired staff driving their buses.

7.3.3 METROBÚS DISTRIBUTIONAL ANALYSIS

The distributional analysis builds upon the Metrobús cost-benefit analysis, allocating users by their income as indicated in a user survey. People between the income brackets of $1,500 to $15,000 pesos comprise the majority of the BRT ridership (Table 18).

Table 18 Income Levels of Metrobús Users

Household Annual Income (MXN 2012)	Percentage of Metrobús Passengers
Less than $1500	2%
$1,501 -$4,500	20%
$4,501 - $7,500	33%
$7,501 - $15,000	32%
$15,001 - $30,000	11%
>$30,000	1%

Source: EMBARQ Mexico

The largest benefits of Metrobús Line 3 accrue to the second quintile, those earning 4,501-7,500 pesos per month (Figure 15 and Table 19). This is consistent with the fact that 33 percent of Metrobús users come from that income quintile and is also consistent with the location of the line, which crosses areas inhabited by the middle class. Improved quality of service when compared to the traditional minibuses also helped attract users from the middle class, some of whom previously used their car. Better integration with the rest of the public transport system might encourage patronage from lower- and higher-income users, which is limited somewhat by the areas covered by the line. Positive benefits also accrue to the lowest and the third quintiles as well. However, the largest losses accrue to the upper quintile, as was the case with Bogota's TransMilenio. This is due to the fact that this group pays most of the taxes which support the system's implementation costs; it also reflects the fact that the main users of the system do not come from this quintile and thus this quintile does not benefit as much from the travel time savings and other user benefits.

Figure 15 Metrobús Line 3 Net Present Discounted Benefits by Income Quintile

Distribution of Net Benefits (Discounted at 12%)

Table 19 Metrobús Line 3 Benefit-Cost Ratio by Income Quintile

Cost Benefit Ratio by Quintile (monthly income, 2012 MXN)					
Total	$0 - $4,500	$4,501 - $7,500	$7,501 - $15,000	$15,001 - $30,000	> $30,000
1.22	1.41	2.35	1.36	0.72	0.52


Library Gardens Eastbound

CHAPTER 8

CASE STUDY: JOHANNESBURG, SOUTH AFRICA'S REA VAYA PHASE 1A

8.1 KEY FINDINGS: REA VAYA PHASE 1A

EMBARQ's analysis of the costs and benefits of the Rea Vaya BRT reveal the following key findings:

- Rea Vaya Phase 1A has a benefit-cost ratio of 1.19 and net present benefits of R1.171 billion ($143 million 2012 USD).
- The bus operation and maintenance contract and the capital costs together constitute 96 percent of the total project costs.
- The high cost of the bus operating contract reflects, in part, the cost of formalizing and empowering the minibus taxi industry.
- On average, BRT users save 13 minutes per trip, and travel time savings represent 37 percent of the total project benefits.
- Avoided road fatalities contribute 28 percent of the present value of the Phase 1A benefits.
- Phase 1A has been a progressive project: the upper income quintile bears the majority of the costs while the project benefits accrue to lower quintiles, predominately the 4th highest income quintile.
- The city's poorest residents are underrepresented in BRT users and therefore are not significant beneficiaries of the project. They recieve 4 percent of the project benefits, while only contributing to 2 percent of the costs.

Rea Vaya Case Study

SCOPE OF ANALYSIS

Phase 1A

LINE LENGTH

25.5 km

DAILY RIDERSHIP

40,000

PLANNING/CONSTRUCTION BEGAN

2007

OPERATIONS BEGAN

2009

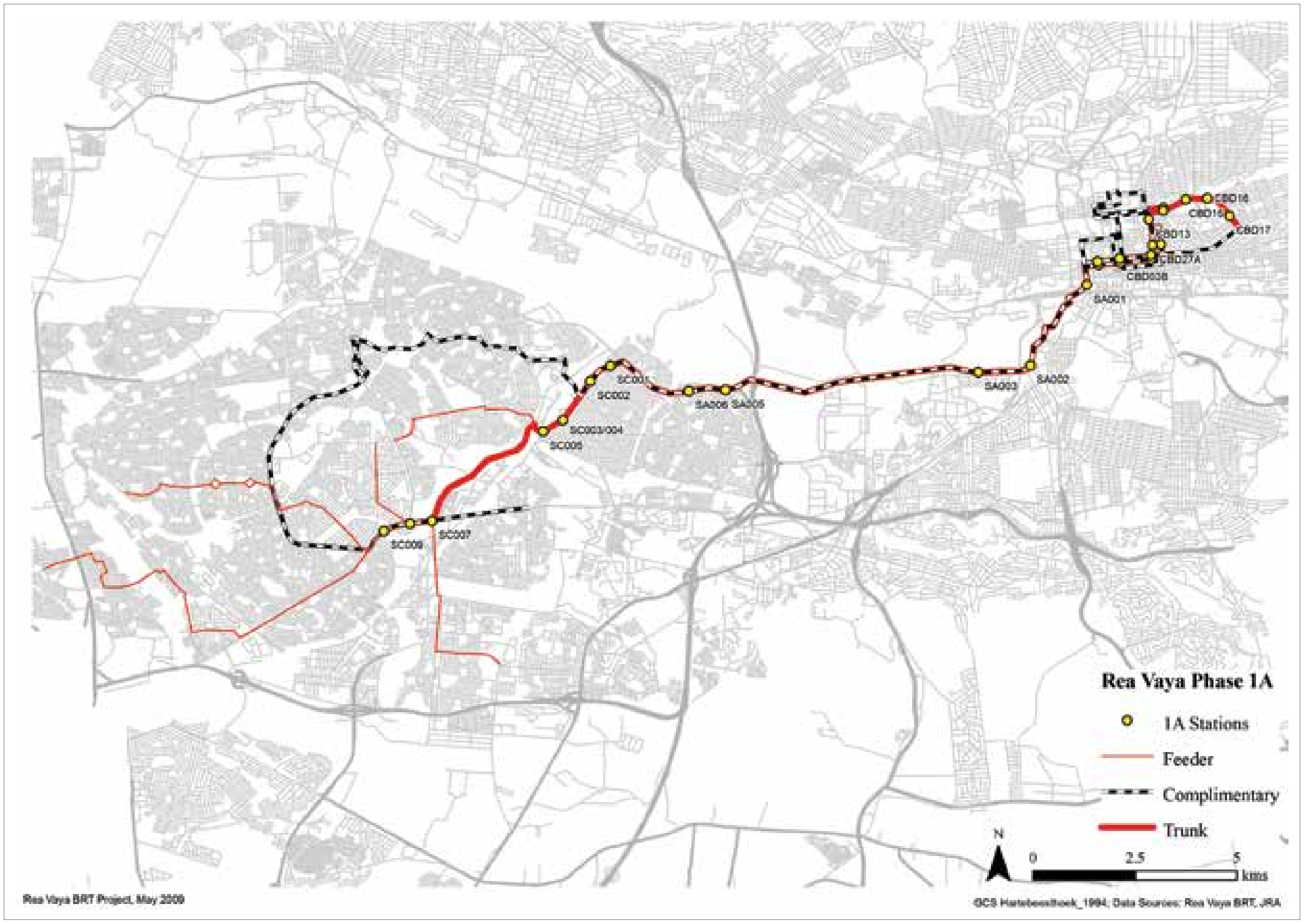
8.2 JOHANNESBURG AND REA VAYA BACKGROUND

Johannesburg, South Africa's largest city, is home to nearly 4.4 million people (CoJ 2013b). It is a relatively low-density city in which the spatial legacy of apartheid still dominates the built environment. The city's poorest residents tend to live in townships like Soweto, about 16 km southwest of the central business district and further removed from the wealthier northern suburbs. Thirty-eight percent of South African commuters rely on public transport, and a majority of those (70 percent) depend on minibus taxis (CoJ 2013)—small 16-person vans that mostly operate informally.

Under South Africa's Apartheid system, the poorest residents lived in townships on the outskirts of the city. Township residents depended on public transport to get to employment opportunities in the city. However, government-operated public transport services were expensive and inconvenient. It was illegal for an African to obtain a permit to operate a taxi, so for several decades taxis provided transport services illegally. The Transportation Deregulation Act of 1988 legalized operation of a 16-person taxi, creating and regulating a limited number of operating permits. The taxi industry subsequently became one of very few employment opportunities for black people under Apartheid, resulting in extreme competition for the limited permits (Venter 2013). In the "taxi wars" of the 1990s, associations of taxi owners fought for control of routes, resulting in hundreds of deaths among owners, drivers and commuters (Barrett 2003).

Today, South Africa's taxi industry employs about 185,000 people, of which 95 percent are black and only 2 percent women (Budlender 2003). These include drivers, but also queue marshals, taxi washers and administrative staff. Very few taxi drivers are self-employed and most work under informal employment arrangements for the taxi owner. Drivers are often paid a wage, a portion of the taxi fares or some combination of both. In 2002, a taxi driver in Johannesburg was likely to earn between R160-500 per week (Budlender 2003). Drivers who are paid a portion of the fare revenue have an incentive to compete aggressively for passengers, often racing or jockeying with other taxis to collect passengers along the corridor. Drivers are typically responsible for vehicle repairs and so have a disincentive to

Figure 16 Rea Vaya Phase 1A Route Map (Source: Rea Vaya 2009)



maintain the roadworthiness of vehicles. Taxi industry employees do not receive employment benefits.

Taxis meet travel demand that is otherwise unmet by the city's other public transport services; however, taxis provide a relatively low quality of service for commuters. Taxis carry 70 percent of Johannesburg's public transit trips and operate at high frequency along the city's main commuting corridors during peak hours. For commuters traveling particular routes, taxis essentially provide on-demand service.

In several ways, the quality of service provided by taxis is poor. Extreme competition has driven down the quality of vehicle maintenance and driving, resulting in a drop in road safety (Venter 2013). With the exception of a few very new taxi ranks, stations or shelters for passengers are of low quality or non-existent. From Soweto, a commuter would take a taxi to a taxi rank in downtown Johannesburg. A transfer and new fare would be necessary to travel out to the northern suburbs. Transfer times can be unpredictable as drivers will typically wait to depart a taxi rank with a full vehicle. Finally, taxi routes are not inteligible to the uninformed. There are no published taxi route maps and a series of hand signals allow passengers to indicate their desired route/destination to approaching taxis.

In 2007, the City of Johannesburg approved a transport plan that set a target of having 85 percent of residents within 1 kilometer of a BRT trunk corridor or feeder route (CoJ 2013b). Selecting bus rapid transit as the structural element of the city's public transit network, the city approved the first BRT corridor, which would not only provide a critical transit link between Soweto and downtown, but also serve the city's two 2010 FIFA World Cup venues. The World Cup was an opportunity to accelerate planning and construction of Phase 1A of the new BRT system, Rea Vaya, starting in 2007. Rea Vaya played an important role in spectator transport for the World Cup and has subsequently become an increasingly popular choice for commuters.

A key aim of Rea Vaya, certainly with Phase 1A, was inclusion of the taxi industry in the new BRT (Seftel and Rikhotso 2013). The city intended that taxi owners displaced by the BRT would become shareholders in a new formal bus operating company, and that former taxi drivers would become Rea Vaya BRT bus drivers. In exchange for participating in the BRT as operators, existing taxi operators would withdraw their taxis and routes (McCaul and Ntuli 2011).

Trial Phase 1A operations began in August 2009 under an interim bus operator while contract negotiations between the city and affected taxi owners continued for over a year. Eventually, in September 2010, a negotiated bus operating contract was signed between the City of Johannesburg and more than 300 representatives of taxi owners (McCaul and Ntuli 2011). The 12-year negotiated contract was based on a fee per bus kilometer that is calculated based on operating input costs (fixed and variable costs such as fuel, uniforms), bus procurement costs (repaying loans) and a profit margin (Seftel and Rikhotso 2013). In February 2011, Piotrans, the new bus operating company, took over Rea Vaya operations. Piotrans is 100 percent owned by former members of the taxi industry.

8.3 REA VAYA COST-BENEFIT ANALYSIS

The cost-benefit analysis of Johannesburg's Rea Vaya BRT system includes costs and impacts for Phase 1A, which began initial operations in August 2009

The current analysis estimates the present value of Phase 1A costs between 2007 and 2026 as 6.15 billion 2012 South African Rand ($749 million 2012 USD) (Table 20). The present value of the benefits of Rea Vaya Phase 1A accruing to BRT users and others over the 20-year horizon is 7.3 billion 2013 South African Rand ($892 million 2012 USD). Based on the current analysis, the project has a benefit-cost ratio of 1.19 and an internal rate of return of 12 percent. Based on the parameters included in this study, the benefits to society of the construction and operation of Phase 1A of Johannesburg's Rea Vaya BRT system exceed the costs and the project is viewed favorably as a public investment.

Table 20 Rea Vaya Phase 1A Costs & Benefits

	ZAR (2012)	USD (2012)
Present Value 2007 -2026 Costs (millions)	R6,149	$749
Present Value 2007 -2026 Benefits (millions)	R7,320	$892
2007 – 2026 Benefit-Cost ratio	**1.19**	
Internal Rate of Return	**12%**	

8.3.1 REA VAYA PHASE 1A COSTS

Over a 20-year time horizon, the bus operation and maintenance contract and the project's capital costs constitute 96 percent of the total project costs (Table 21, Figure 17). The present value of the 12-year bus operating contract with Piotrans, the company comprised of former taxi owners, is estimated as 2 billion Rand ($248 million 2012 USD), one third of the total project cost. The contract includes a fee per bus-kilometer calculated based on actual costs of bus fuel and tires; employee wages, salaries and benefits; bus operating licenses; fleet insurance; bus loan repayment costs and profit (McCaul and Ntuli 2011). This typically exceeds the fare revenue collected and so requires a government subsidy (CoJ 2013a).

Negotiated bus operating contracts are often more expensive, but in Johannesburg's case, the contract enabled the city to advance an important priority: formalizing the minibus taxi industry. A profit margin was included to ensure the affected bus operators were not 'worse off' under the new BRT scheme, but the final rate of 28 percent was significantly higher than both the City's initial offer and the 10 percent return expected on a commercial venture in South Africa (Seftel and Rikhotso 2013). The higher cost reflected the taxi industry's strong negotiating position and the city's vested interest in empowerment and transformation of the taxi industry (Seftel and Rikhotso 2013). The high cost of the negotiated bus operating contract, together with the added costs of negotiation, preparation and mediation, reflect the social cost of reforming an informal transport industry.

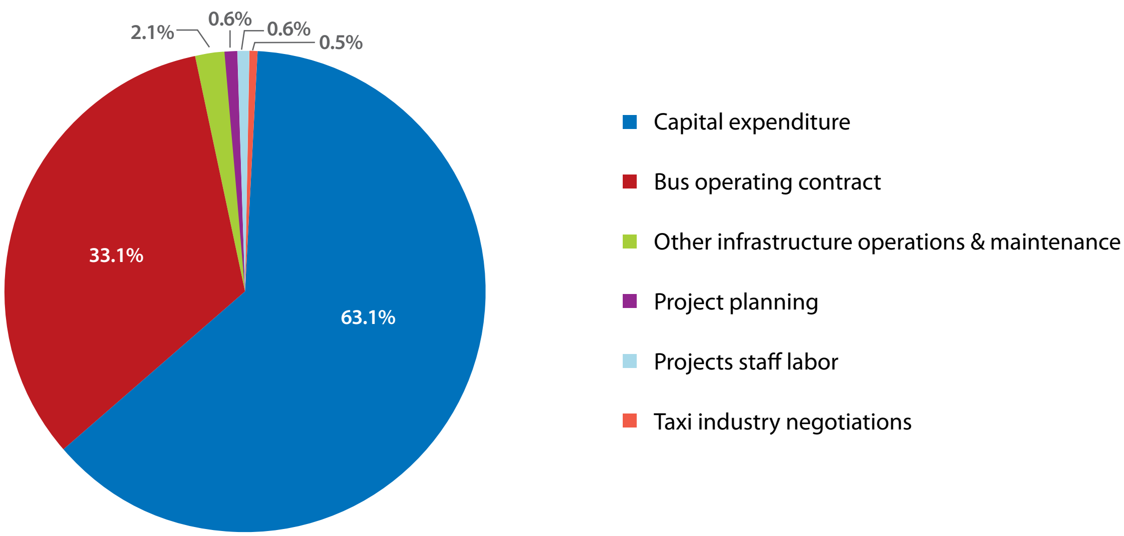
The capital costs, including those for infrastructure (stations, busways, depots), initial bus procurement and technology (automatic fare collection, intelligent transport systems), make up nearly 63 percent of the project costs. In some cases the infrastructure costs include necessary upgrades to urban infrastructure (i.e., utilities, sidewalks), completed during the construction of BRT lanes and stations.

The present value of the remaining project costs — operations and maintenance of stations and depots, project planning, and negotiations with the taxi industry – are insignificant, reflecting less than 4 percent of the total project costs.

Table 21 Rea Vaya Phase 1A Costs (Present Value, 12% Discount Rate)

Costs	2007-2026 (million ZAR 2012)	2007-2026 (million USD 2012)
Capital expenditure	R3,881	$473
Bus Operating Contract	R2,033	$248
Other Infrastructure O&M	R127	$15
Project Planning	R39	$5
Project Staff Labor	R39	$5
Taxi Industry Negotiations	R30	$4
Total Costs	**R6,149**	**$749**

Figure 17 Distribution of Johannesburg's Rea Vaya Costs



8.3.2 REA VAYA PHASE 1A BENEFITS

Over the period 2007 – 2026, the present value of Rea Vaya's benefits total 7.3 billion Rand ($892 million 2012 USD) (Table 22). The most significant benefit is travel time savings, which represents 38 percent of total benefits, or roughly 2.7 billion Rand ($331 million) (Figure 18). Benefits from avoided road fatalities contribute an additional 28 percent of the total benefits, or 2.0 billion Rand ($249 million). Reduced mortality as a result of BRT users' increased walking saves 1.2 billion Rand ($141

Table 22 Rea Vaya Phase 1A Benefits (Present Value, 12% Discount Rate)

Benefits	2007-2026 Benefits	2007-2026 Benefits
Travel time savings	R2,719	$331
Road Fatalities avoided	R2,046	$249
Increased physical activity	R1,161	$141
Vehicle operating cost reductions	R1,399	$170
Travel time lost during construction	R-313	$(38)
Road accidents avoided	R159	$19
CO2e emissions avoided	R149	$18
Total Benefits	**R7,320**	**$892**

million). Similarly, reductions in vehicle operating costs for BRT users' private vehicles and the 585 minibus taxis scrapped under the project also save 1.4 billion Rand over the 20-year time horizon. Travel time lost during construction, benefits from reductions in road accidents (injury and property damage-only accidents) and CO_2e emissions reductions are relatively negligible.

The travel time savings for BRT users are achieved in several ways. Fifty-three percent of the corridor includes segregated, exclusive BRT lanes, which help to minimize delays caused by congestion in the mixed traffic lanes and keep the average speed of the BRT relatively high, at 30 km/hr (McCaul 2012). The most likely beneficiaries of this improved travel time are the 83 percent of users shifting to Rea Vaya from taxi, private car or bus (see Figure 19). Finally, prepaid, level boarding through multiple bus doors at Rea Vaya stations helps to reduce delays in boarding and alighting passengers. These factors combine to save each BRT passenger an average of 13 minutes per trip (Venter and Vaz 2011).

Figure 18 Distribution of Johannesburg's Rea Vaya Present Benefits

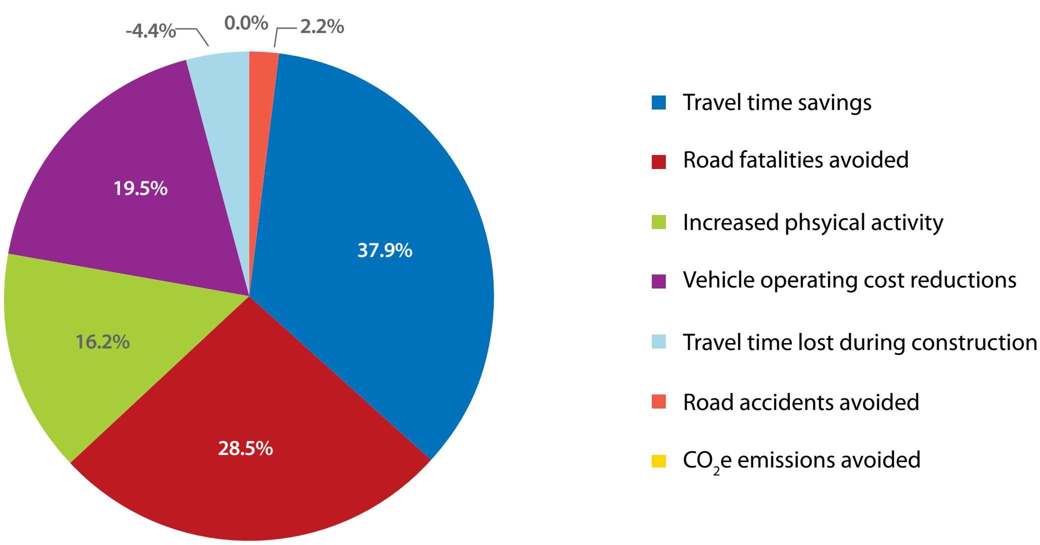
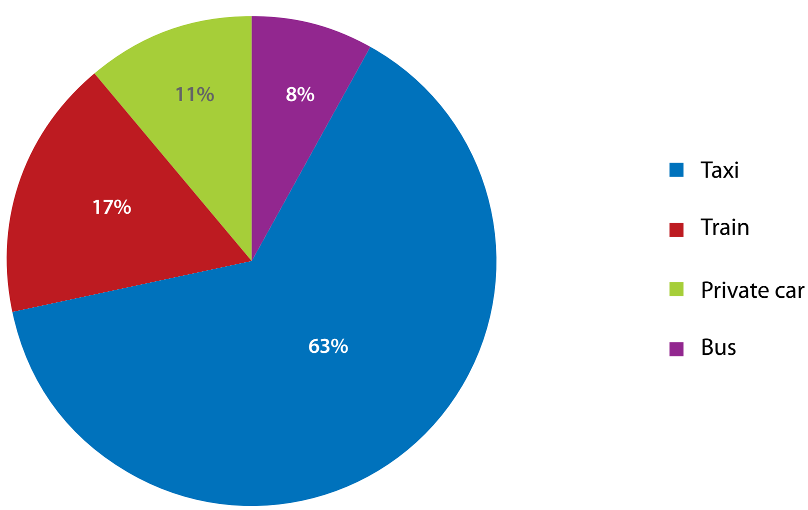


Figure 19 Rea Vaya Phase 1A Mode Shift



Source: McCaul 2012

For part of the Phase 1A corridor along the Soweto Highway the exclusive, segregated bus lanes replace a priority lane for minibus taxis. Thus, even though 585 taxis were removed from the roads when Phase 1A service commenced, taxis who continue to use the Soweto Highway may experience longer travel times. Where the Rea Vaya bus lanes replaced a mixed traffic lane and reduced capacity for other modes on the corridor, there may also be increased travel times. During two years of construction, any vehicles along the corridor were susceptible to delays.

Avoided road fatalities contribute nearly 28 percent of the present value of the Phase 1A benefits, at a value of 2.046 billion Rand ($249 million). EMBARQ estimates one road fatality is avoided annually for every kilometer of high-quality BRT because of improved pedestrian crossings and infrastructure, smoother traffic operations and reduced vehicle kilometers. For Rea Vaya Phase 1A, this translates to 26 fatalities avoided each year.

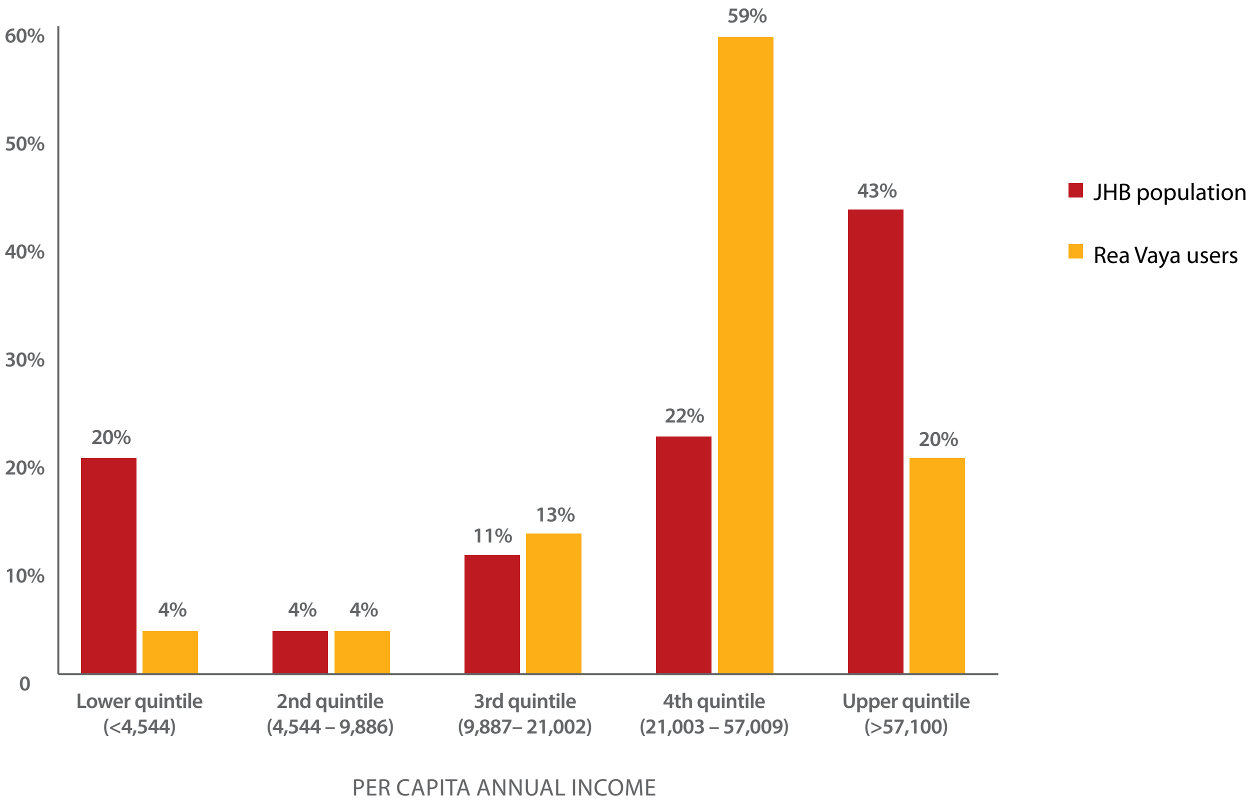
A reduction in road accidents (injuries and property-damage only) is assumed based on improved infrastructure and rationalized traffic flow. The shift of passengers from more polluting modes to Rea Vaya's high-capacity Euro IV low-sulfur diesel buses, and removal of minibus taxis from the roads contributes to the CO2e emissions reductions. Johannesburg has certified the emissions reductions for Rea Vaya Phase 1A and 1B with the Voluntary Carbon Standard and expects to save nearly 400,000 metric tons of CO2e for the two phases over a 10-year period (SQS 2011). Likewise, the 11 percent of Rea Vaya Phase 1A passengers who shifted to the BRT from private cars will see a reduction in vehicle operating and maintenance costs as will the owners of the 585 scrapped taxis. Vehicle operating and maintenance cost reductions total 1.3 billion Rand over the 20-year horizon.

8.4 REA VAYA DISTRIBUTIONAL ANALYSIS

From an initial assessment of Johannesburg's Rea Vaya BRT system, Venter and Vaz caution against claims that BRT is automatically an effective means to achieving poverty reduction goals. Lcal characteristics of the BRT project, such as availability of other transport modes, user fares, and location and configuration of routes, ultimately determine the impact on a city's poorest residents (Venter and Vaz 2011). A user survey of 150 households in the Orlando neighborhood of Soweto township served by the Rea Vaya trunk route revealed that the BRT is disproportionately used by middle-income users. Venter and Vaz conclude that, since the Rea Vaya fare is higher than the commuter train, which is also accessible in Orlando, rail remains the preferred mode for the poorest residents and the direct benefits of the BRT system accrue to middle-income residents.

As Figure 20 shows, Rea Vaya Phase 1A users are disproportionately represented in the fourth income

Figure 20 Income Distribution for Rea Vaya Users Compared to Johannesburg by Quintile



Source: Adapted from Venter and Vaz 2011; StatsSA 2013

quintile (R21,033 – 57,009 per year), whereas 43 percent of the citywide population is in the top quintile and 20 percent in the lower.

Rea Vaya is a progressive public project; the upper quintile bears the majority of the costs while the benefits accrue to the lower quintiles. The upper quintile supports the majority of the Rea Vaya costs, since several of the lowest quintiles are not required to pay national income tax and may receive some exemptions from local property taxes as well. Since only 20 percent of Rea Vaya passengers fall in this upper quintile, they are not realizing many of the user benefits. The net benefits (benefits minus costs) for the upper quintile are negative and the benefit-cost ratio is less than one (Figure 21 and Table 23).

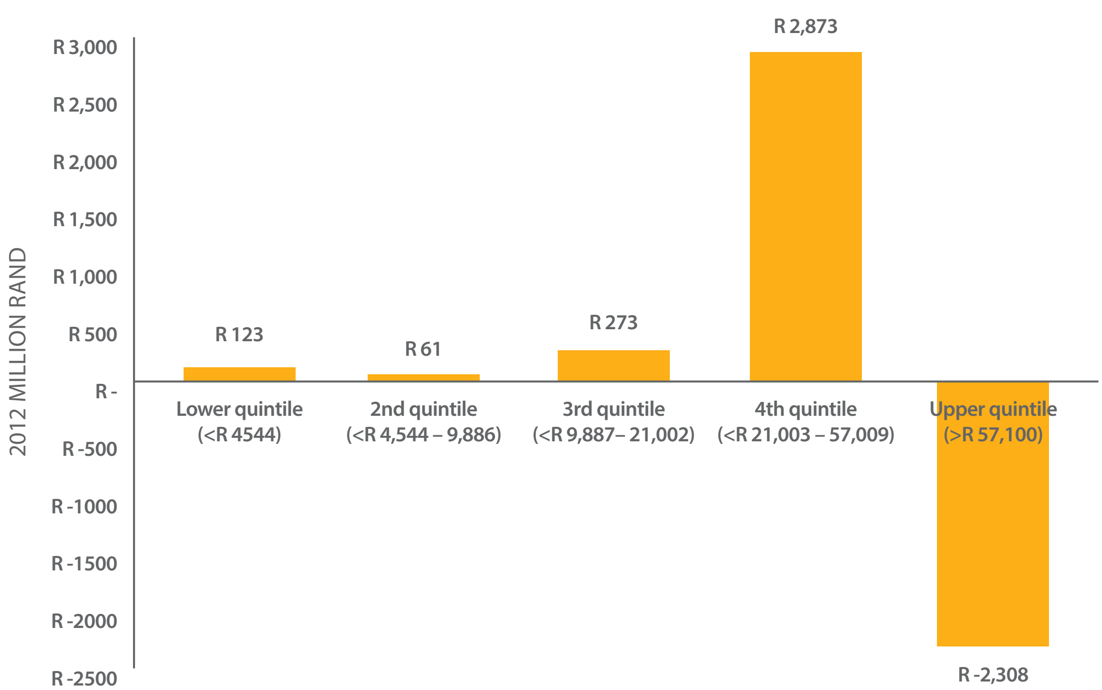
The poorest Johannesburg residents are underrepresented among Rea Vaya users[8] and therefore not the largest beneficiaries of the project. Nevertheless, their benefit-cost ratio is the second largest at 2.14 since they share in 4 percent of the project benefits while only contributing 2 percent of the costs. The lower quintile's net benefits over the 20-year horizon total 153 million Rand. It should be noted that changes in property values have not been included in the CBA. Rising housing prices as a result of the BRT system could negatively affect lower-income renters.

Members of the fourth quintile are the largest beneficiaries of the project and have a benefit-cost ratio of 3. Since the majority of Rea Vaya users fall within this quintile, they benefit proportionally from the project's significant travel time savings. Nearly 60 percent of the project benefits accrue to this quintile, while they contribute to 23 percent of the project costs. The fourth quintile's net benefits over twenty years total more than 2.9 billion Rand.

Table 23 Rea Vaya Benefit-Cost Ratio by per Capita Annual Income Quintile

	Lower quintile (<4,544)	2nd quintile (4,544 – 9,886)	3rd quintile (9,887 – 21,002)	4th quintile (21,003 – 57,009)	Upper quintile (>57,100)
Share of total costs	**2%**	**4%**	**11%**	**23%**	**60%**
Share of total benefits	4%	4%	13%	59%	19%
Net benefits (million Rand)	R153	R67	R289	R2,906	R-2,244
Benefit / Cost ratio	2.14	1.28	1.43	3.02	0.39

Figure 22 Rea Vaya net Present Discounted Benefits by Income Quintile



CHAPTER 9

CASE STUDY: ISTANBUL, TURKEY'S METROBÜS

9.1 KEY FINDINGS: METROBÜS

EMBARQ's analysis of the costs and benefits of Istanbul's Metrobüs BRT system reveals the following key findings:

- Total net present benefits of Metrobüs over 20 years are TL 11.4 billion ($6.4 billion USD); benefits exceed costs by a ratio of 2.8-to-1.
- The largest proportion (64 percent) of benefits comes from travel time reductions, followed by vehicle operating cost reductions (23 percent) and increased traffic safety (9 percent).
- Metrobüs costs are driven primarily by operating and maintenance costs.
- The largest proportion of users of the BRT system are in the lower- and middle-income groups, though benefits exceeded costs in all income groups.

9.2 ISTANBUL AND METROBÜS BACKGROUND

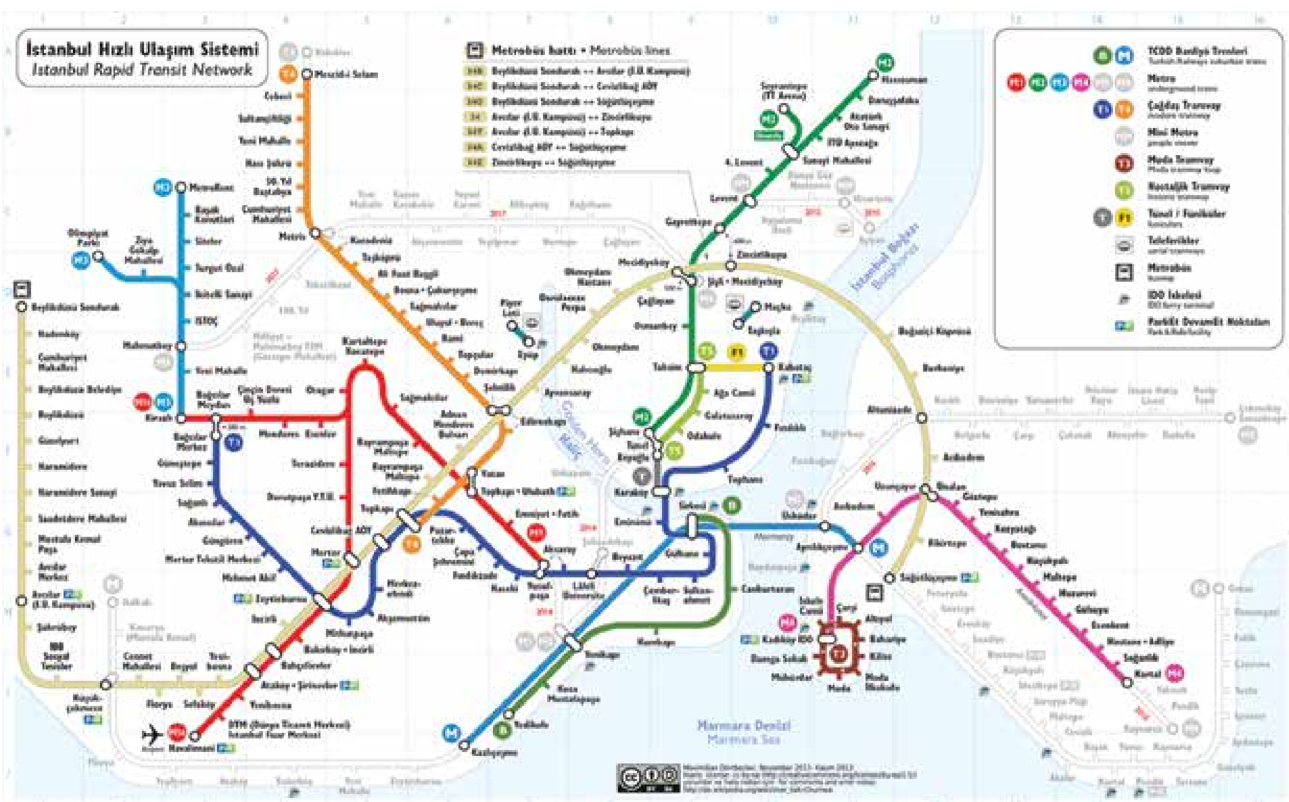
Istanbul, a city of nearly 14 million inhabitants sprawling across over 5,000 sq. km, is one of the largest cities in the world and serves as a major commerce hub for Europe and the Middle East. Based on archaeological findings, some experts put Istanbul's earliest settlements at 6,500 BCE, making it also one of the oldest cities in the world.

Istanbul is divided into two sections by the Bosporus sea channel, which connects the Black Sea and the Marmara Sea while forming the natural boundary between Europe and Asia. While this distinguishes Istanbul as a transcontinental city, it also complicates transportation and creates a choke point for road traffic. The Asian side is predominantly residential, while the European side is home to most of the city's businesses and workplaces (Yazici *et. al.* 2013). As a result, commuting across the Bosporus channel is a daily necessity for many of the city's inhabitants.

Two highway bridges as well as water transportation connect the European and Asian sides. In addition, a 13.6-km underground rail tunnel—the Marmaray project—that will link railways on both sides of the Bosporus is under construction and set to be completed by the end of October 2013. The full 76-km commuter rail project is expected to be completed by 2018. Historically, transportation in Istanbul has been heavily reliant on road-based options (92.3 percent) compared to rail (5.5 percent) and water (2.2 percent) (Yazici *et. al.* 2013 and Gunay 2007).[9] Car ownership in Istanbul, while lower than most European cities, is growing at a rate faster than population growth. In 1980, there were just 43 cars per 1,000 inhabitants; by 2006, that figure had trebled to 134 (Gercek & Bulay 2007). With increased car ownership and a natural daily bottleneck over the Bosporus, both bridges are heavily congested for much of the day.

Istanbul has a comprehensive public transportation system including commuter rail, metro, light rail, and a network of city buses and minibuses. Around 53 percent of inhabitants use one or more forms of public transportation daily (Gunay 2007). Istanbul's minibuses and large-capacity taxis, dolmus ("full" in Turkish), provide point-to-point service under regulation of the Istanbul Municipality (Yazici *et. al.* 2013). The city's historic significance has made the construction of Istanbul's metro system complicated, as new artifacts and archaeological sites are often discovered during excavation and delay construction. As a result, the city's above-ground public transport options are more developed than its metro.

Figure 22 Istanbul Public Transport Schematic. (Metrobüs is the light yellow line running west-east.)



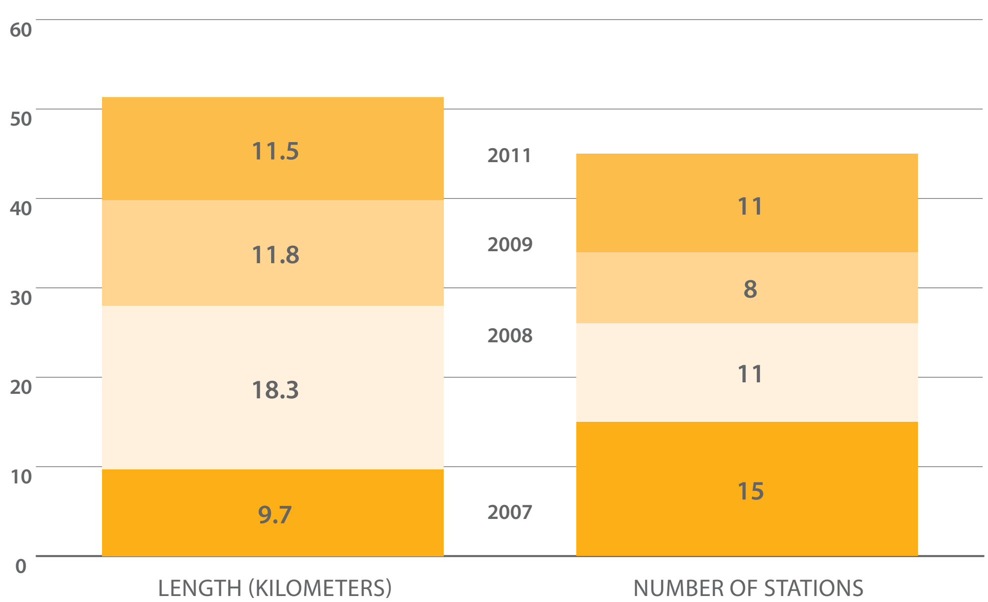
Source: Maximilian Dörrbecker, creative commons.

Istanbul's Metrobüs system was designed to provide low cost, rapid service to the city's inhabitants traveling east to west and vice versa. It is the first bus rapid transit system in Turkey and has the distinction of being the first transcontinental BRT in the world. By appropriating space in the median of Istanbul's freeway, D100, for the construction of a counter-flow, dedicated lane in both directions, Metrobüs was designed to operate at near highway speeds. As a result, Metrobüs provides substantial travel time savings benefits to its users compared to alternative modes of transport.

Metrobüs infrastructure was built by the Istanbul Municipality and is operated publically by the Istanbul Electricity, Tramway and Tunnel General Management (IETT). Alpkokin and Ergun (2012) estimate Metrobüs operating costs to be USD 3.56 per vehicle-km. While slightly higher than the operating costs for conventional buses (USD 3.13/vehicle-km), Metrobüs operating costs are more than offset by its revenue of USD 4.75 per km (Alpkokin and Ergun 2012).

Construction of the first phase of Metrobüs began in late 2005 and Metrobüs began serving the most densely populated section of Istanbul with its first 18.3-km section in September 2007 (Alpkokin and Ergun 2012). In 2008, after 77 days of construction, Metrobüs expanded 11.8 km east from Topkapi to Zincirlikuyu, adding 11 stations to the 15 built in the first phase. Phase II also initiated service to the business district, which was met with increased public acceptance and ridership (Yazici *et. al.* 2013). In 2009, Metrobüs expanded across the Bosporus Bridge and connected the Asian side of the channel with the European side as part of its phase III expansion. Phase IV of Metrobüs further extended the system west by 9.7 km and completed the 51.3-km BRT line. An additional phase is being considered, though there are currently no details available.

Figure 23 Metrobüs Construction Phases.



Source: Maximilian Dörrbecker, creative commons. IETT, 2011 from Yazici et. al.. (2013)
Note: Phase 4 is currently in operation.

Metrobüs Case Study

SCOPE OF ANALYSIS

4 phases

All 4 phases of Metrobüs currently in operation

SYSTEM LENGTH

51.3 km

DAILY RIDERSHIP

600,000

(2012)

PLANNING/CONSTRUCTION BEGAN

Late 2005

(Phase 1)

OPERATIONS BEGAN

Sept. 2007

(Phase 1)

The total project cost (including construction and equipment) for the Metrobüs line is estimated to be USD 466 million, or about USD 9 million per kilometer (Yazici *et. al.* 2013). This includes tunnels to access the Bosporus Bridge, as well as non-grade intersections and special facilities for returning buses in Zincirlikuyu, Topkapi and Avcilar. Phase I-III added the BRT lanes in the median of D100 without reducing general lane capacity. The most recently completed section (Phase IV) required road expansion and was also implemented without reducing the capacity of D100.

While Metrobüs operates on dedicated lanes throughout the rest of the system, planners opted to not add additional lanes on the Bosporus Bridge, nor restrict access to existing lanes, which would have been necessary to maintain a dedicated right-of-way for Metrobüs. Instead, Metrobüs merges with bridge traffic for transit over the Bosporus and resumes dedicated right-of-way service after crossing. While this approach does place Metrobüs in general traffic lanes, it allows Metrobüs to skip the queue and enter onto the bridge more quickly than general traffic (Yazici *et. al.* 2013).

The system serves an estimated 600,000 passenger trips every day, with a maximum load of 30,000 trips per hour per direction (Alpkokin and Ergun 2012; Yazici *et. al.* 2013). Metrobüs is able to achieve this level of service by running at a very high frequency during peak hours (up to one bus every 30 seconds) and operating 350 high-occupancy articulated and bi-articulated buses with capacity ranges from 140-200 passengers. With no signalized stops or intersections, Metrobüs is able to operate at an average speed of 40 km/hr; Alpkokin & Ergun (2012) report maximum sectional speeds of up to 78 km/h based on GPS observations. Operational speeds were reduced to 35 km/hr in 2013 due to safety considerations.

Survey data collected through IETT annual rider assessments indicates that most passengers are commuters, taking Metrobüs every day (29.1 percent) or every weekday (25.3 percent). The average age is between 35 and 44 years old, and most take Metrobüs to and from work (38.2 percent) or school (16.1 percent) (Yazici *et. al.* 2013).

Overwhelmingly, the main reasons stated for using Metrobüs have to do with travel time saved. In the 2010 IETT survey, “fast” and “no traffic congestion” were by far the most popular responses, combining to account for 70.8 percent of all users surveyed (Yazici *et. al.* 2013). This is not surprising given that IETT estimates that the average Metrobüs user saved 52 minutes in travel time every day (Yazici *et. al.* 2013). A plurality of users (34.8 percent) accessed Metrobüs by walking, followed by dolmus/minibus (25.5 percent) and IETT bus (22.0 percent). Similarly, 40.3 percent of Metrobüs users transferred from Metrobüs by walking. This is consistent with the profile of a commuter who uses Metrobüs as their primary transportation to and from work or school.

The implementation of Metrobüs has had a positive impact on public transit options in Istanbul as well. IETT has removed from operation 113 IETT buses, 76 private buses, and 1,296 minibuses, and redirected riders to Metrobüs (Yazici *et. al.* 2013). This ridership shift has yielded significant environmental benefits, as Metrobüs is more efficient than transport alternatives. In addition, Alpkokin and Erugn (2012) report operating costs for Metrobüs are more than covered by fare revenue, despite the fact that the average fare for commuters (including transfers) has decreased more than 50 percent compared to travel without Metrobüs (Yazici *et. al.* 2013). Overall, the addition of Metrobüs to Istanbul's public transit system has improved the operating situation for IETT and reduced the financial burden on public transit users.

9.3 METROBÜS COST-BENEFIT ANALYSIS

The cost-benefit analysis of the Metrobüs system examines the costs and benefits associated with the system's four completed phases (51.3 km) over a time horizon of 20 years (2007-2026). Implementation and operating costs, as well as benefits, are scaled up to reflect the growth of the system over its first four years of operation.

The cost-benefit analysis over the assumed 20-year time horizon reveals that the benefits of Metrobüs outweigh costs associated with the project, as reflected in the 2.8 benefit-cost ratio and the internal rate of return (IRR) or 65.8 percent. The present value of Metrobüs benefits amount to TL 17.8 billion (USD 9.95 billion), while the present value of costs is estimated to be around TL 6.3 billion (USD 3.5 billion) (Table 24). This indicates that based on the parameters included in this study, the benefits to society of the construction and operation of Istanbul's Metrobüs exceed the costs and the project is favorably reviewed as a public investment.

Table 24 Istanbul Metrobüs Cost-Benefit Ratio

Net Present Value 2007 – 2026	Turkish Lira (2012)	USD (2012)
Costs (millions)	TL 6,323	USD 3,541
Benefits (millions)	TL 17,765	USD 9,948
2007-2026 Benefit/Cost ratio	**2.81**	
Internal Rate of Return	**65.8%**	

9.3.1 METROBÜS COSTS

The primary costs associated with bus rapid transit projects are implementation costs (including planning, construction, and equipment costs) and operating costs. In the case of Metrobüs, no external financing was utilized and fare revenue exceeds operating costs (Table 25), meaning that public subsidy is not needed to sustain the operation of Istanbul's BRT (Alpkokin and Ergun 2012). A 12 percent discount rate is assumed.

This analysis uses a construction and equipment cost estimate of USD 9.08 million per km, based on available secondary sources (Yazici *et. al.* 2013, and Hidalgo and Bulay 2008), and assumes station rehabilitation costs, additional bus procurement costs, and bus maintenance costs based on assumptions from primary data and secondary sources (see Appendix E for additional information). As Istanbul's Metrobüs is operated by IETT and not on a separate service contract, its operating costs are aggregated with conventional bus transit operations. For this reason, EMBARQ's analysis utilizes Alpkokin and Ergun (2012)'s estimate of USD3.56 per vehicle-km and other operational data from Yazici *et. al.* (2013) to estimate annual operating costs.

While the Istanbul case relies more on secondary sources than the other case studies, the final estimate of discounted total costs (including capital, operating, and maintenance costs over 20 years) associated with Metrobüs is in line with the other case studies considered. In fact, the discounted total cost per km for Metrobüs is on the high end at USD 69.03 per km. While there are many factors that contribute to economic cost that may differ across cases, the comparison across case studies suggests that the cost side of the Istanbul cost-benefit analysis is consistent with the other case studies and, if anything, may bias towards over-reporting costs (Table 26). The high benefit-cost ratio, therefore, occurs because of high benefits as opposed to low costs.

Table 25 Present Value of Costs, Istanbul Metrobüs (12% discount rate)

Present Value of Costs	Millions TL (2012)	Millions USD (2012)
Capital Expenditure (including reinvestment in capital infrastructure and bus procurement)	TL 1,324	$ 741
Operating & Maintenance Costs	TL 4,999	$ 2,800
Total Costs	**TL 6,323**	**$ 3,541**

Table 26 Discounted Cost per km Across Case Studies

City	Length (km)	Discounted Total Cost in USD (millions)	Discounted Cost per km	Benefit-Cost Ratio
Bogota	84	$ 2,359	$ 28.08	1.6
Mexico City	17	$ 158	$ 9.32	1.2
Johannesburg	25.5	$ 749	$ 29.37	1.2
Istanbul	51.3	$ 3,541	$ 69.03	2.8

9.3.2 METROBÜS BENEFITS

Over the 2007-2026 horizon, the present value of Istanbul's Metrobüs benefits aggregate to 2012 TL 17.8 billion (USD 9.95 billion). The benefits associated with Metrobüs are dominated by travel time reductions for Metrobüs users, which account for 64 percent of total discounted benefits or TL 11.4 billion (USD6.4 billion) (Table 27 and Figure 24). Benefits from reduced vehicle operating cost contribute an additional TL 3.8 billion (USD 2.2 billion), followed by TL 1.6 billion (USD 881.2 million) in road safety benefits, TL 700 million (USD 392 million) in avoided premature deaths due to physical activity, and TL 272 million (USD 152 million) in benefits from CO2 emissions avoided.

Benefits from travel time savings for Metrobüs accumulate to TL 11.4 billion (USD6.4 billion) over the 20 year time horizon of analysis. The substantial travel time savings benefit is the product of the combination of high ridership and high average travel time savings on the route. Metrobüs ridership is relatively high at 600,000 daily passenger trips, driven by demand and large capacity articulated buses running with very short headways. In Istanbul, average travel time savings per trip is 26 minutes (Yazici *et. al.* 2013), double the 13 minutes saved per trip on Rea Vaya in Johannesburg. Metrobüs achieves this high travel time savings because it is a highway-speed BRT with dedicated travel lanes.

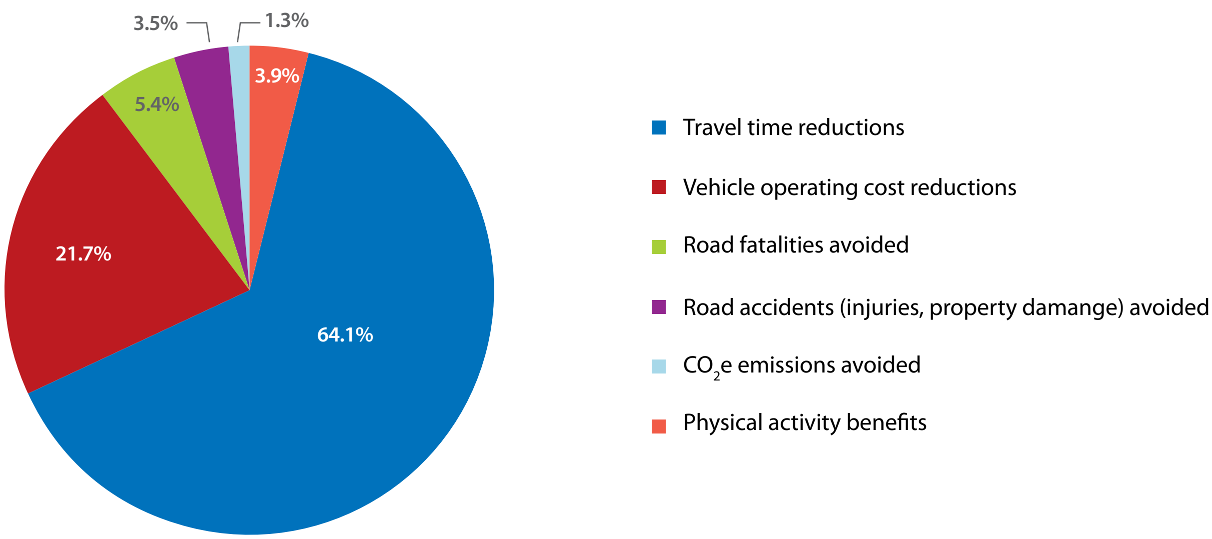
While Metrobüs costs are largely supported by the **upper socio-economic group,**

Metrobüs net benefits (benefits minus costs) are spread across all groups but the largest net benefits accrue to the second lowest income group. In all income groups, the benefit-cost ratio exceeds 1.0.

Table 27 Present value of Benefits, Istanbul's Metrobüs (12% discount rate)

Benefits	2007-2026 (Million 2012 TL)	2007-2026 (Million 2012 USD)
Users' Travel Time Reductions	TL 11,372	$ 6,369
BRT Users' Vehicle Operating Cost Reductions	TL 3,847	$ 2,154
Road Fatalities Avoided	TL 949	$ 531
Road Accidents (injuries, property damage) Avoided	TL 625	$ 350
Physical Activity Benefits	TL 700	$ 392
CO_2eq Emissions Avoided	TL 272	$ 152
Total Benefits	**TL 17,765**	**$ 9,948**

Figure 24 Distribution of Istanbul's Metrobüs Present Benefits.



The sizable benefits from BRT users' vehicle operating cost reductions are also driven by high daily ridership. The proportion (9%) of Metrobüs trips that shifted from car transportation is consistent with the other cases; however, the high ridership translates into large savings from avoided vehicle operation costs; higher than average petrol prices and an average trip distance of 15 km also contribute to Metrobüs benefits in this category.

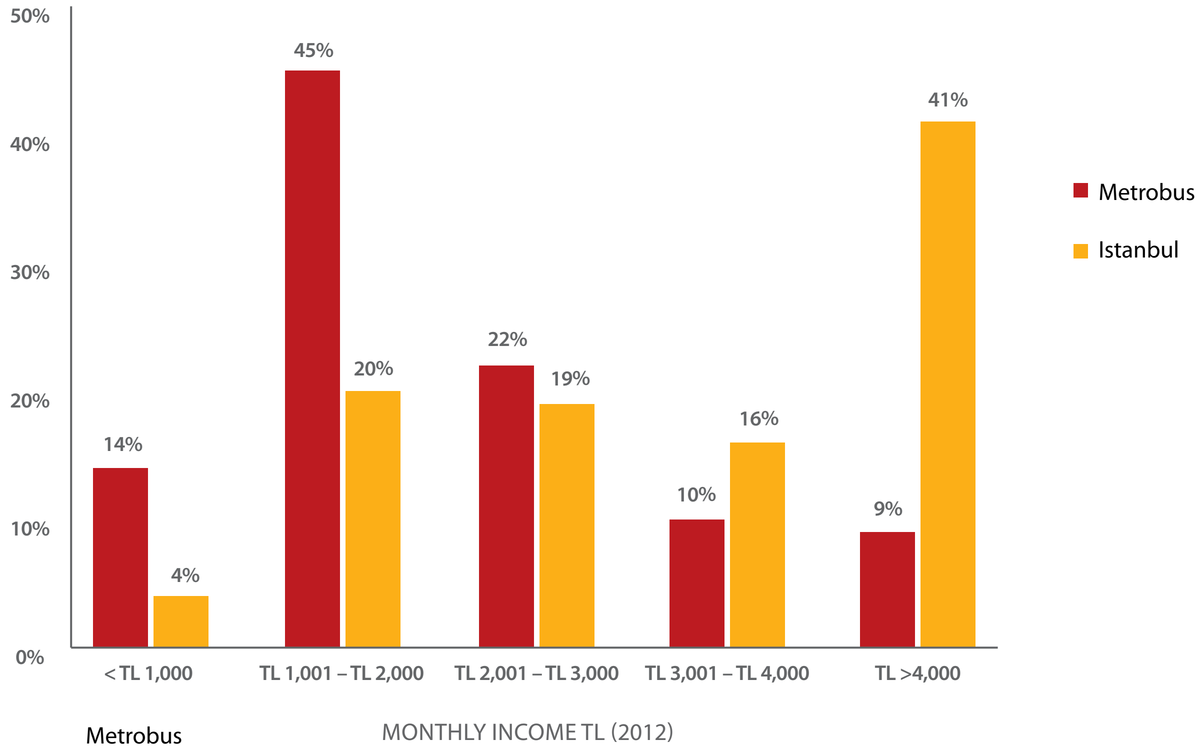
Given that Metrobüs runs on safer, dedicated lanes, and that most Metrobüs users would have used public transit or personal vehicles operating in general traffic lanes if the BRT had not been built, this report concludes that there are traffic safety benefits from the implementation of Metrobüs. The analysis estimates that TL 1.6 billion (USD 881.2 million) is saved over 20 years from reductions in traffic fatalities and injuries. While road safety data on Metrobüs's D100 corridor is not yet available, this report estimates that 30 road fatalities and 87 traffic-related injuries are avoided every year based on incident per km trends in EMBARQ's traffic safety studies. The economic assessment of health and road safety benefits follows the methodology laid out in section 3.3.2.

The introduction of Metrobüs has also had a positive impact through increased physical activity of TL 700 million (USD 392 million). According to IETT survey data, before the advent of Metrobüs, 1.8 percent of commuters walked to their transport mode. After the implementation of Metrobüs, 34.8% of Metrobüs users reported walking as their mode of transport to Metrobüs and 39.3 percent of users reported walking as their mode of transport from Metrobüs. Over one fifth of walkers reported walking more than 10 minutes to andfrom Metrobüs. Using the WHO HEAT model, we estimate around 25 premature deaths are avoided every year from increased physical activity due to the implementation of Metrobüs.

9.4 METROBÜS DISTRIBUTIONAL BENEFITS

Metrobüs user income distribution is negatively skewed, indicating that Metrobüs users include a disproportionate number of riders from the lower socioeconomic groups of Istanbul (Figure 25). Most striking, a plurality (45 percent) of Metrobüs users earn between TL 1000-2000 per month, while 41 percent of Istanbul residents take in a monthly income of more than TL 4,000. Similarly, 14 percent

Figure 25 Income Distribution for Metrobüs Compared to Istanbul by Socioeconomic Group (IETT, 2011 ridership survey, TurkStat Income and Living Conditions Survey 2011)



Metrobus

Source: IETT, 2011 ridership survey, TurkStat Income and Living Conditions Survey 2011).

Istanbul

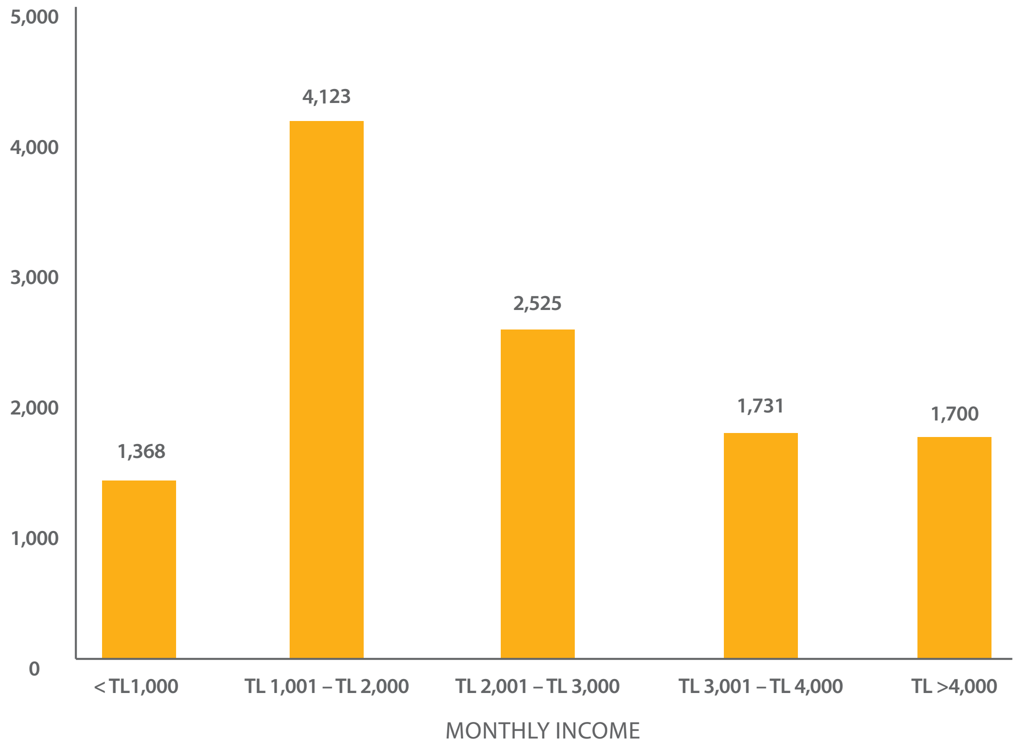
of Metrobüs users earn less than TL 1,000 compared to only four percent of the public.

While Metrobüs costs are largely supported by the upper socioeconomic group, Metrobüs net benefits (benefits minus costs) are spread across all groups, benefiting the TL 1,000-2,000 income group the most nominally (Figure 26). Interestingly, the benefit-cost ratio by socioeconomic distribution group is greatest for the highest income group while the largest net benefits accrue to the TL 1,001-TL 2,000 income group. In Istanbul, higher income groups bear a higher proportion of costs because of a higher income tax rate, but they also partake in a greater share of benefits because they are more likely to own automobiles and therefore take advantage of the reduced vehicle operating costs. In this case, the benefits outweigh the costs. The TL 1,001-2,000 income group still received the most net benefits because of the way ridership is distributed across income groups. In all income groups, the benefit-cost ratio exceeds 1.0 (Table 28).

Table 28 Metrobüs Benefit-Cost Ratio by Socioeconomic Group

Total	TL < 1,000	TL 1,001-2,000	TL 2,001-3,000	TL 3,001-4,000	TL >4,000
2.80	2.80	2.65	2.82	2.99	2.38

Figure 26 Net Present Discounted Benefits by Socioeconomic Group.



CHAPTER 10

BRT GROWTH IN LATIN AMERICA

The future of BRT looks bright. Trends at the local, national and international levels suggest continued growth of BRT worldwide. Cities continue to choose to implement BRT as part of their public transport networks. National governments are financing urban transport policies and programs that prioritize mass transit including BRT. And international donor commitments prioritize sustainable transport solutions to address urgent urban development challenges.

Based on data collected by EMBARQ, continued growth of BRT systems – new systems and expansions to existing ones – is expected. An estimated 143 cities are currently constructing 1,000 kilometers of new or expanded BRT corridors and planning 1,600 more kilometers (EMBARQ Brasil 2013).

Several national transit investment programs facilitate funding for mass transit including BRT, and some explicitly earmark funds for BRT. Under PROTRAM, Mexico's national mass transit funding program, there are 35 BRTs approved or in final planning across Mexico. Brazil's development acceleration program (PAC) has earmarked USD 7.7 billion for BRT systems in 32 cities, doubling the kilometers of BRT in Latin America by the 2016 Olympic Games. India's second national urban renewal program is expected to earmark USD 12 billion for implementation of urban rail and bus systems over the next ten years. China's 12th 5-year Plan sets a goal of adding BRT systems in 12 new cities by 2017.

In the summer of 2012, the world's largest multilateral development banks committed

Trends at the local, national and international levels suggest continued **growth of BRT worldwide.**

Cities continue to choose to implement BRT as part of their public transport networks. National governments are financing urban transport policies and programs that prioritize mass transit including BRT. And international donor commitments prioritize sustainable transport solutions to address urgent urban development challenges.

to invest more than USD 175 billion over 10 years to support sustainable transport in developing countries (WRI, 2012). This financial commitment by the Latin American Development Bank, Asian Development Bank, Andean Development Corporation, European Bank for Reconstruction and Development, European Investment Bank, Inter-American Development Bank, Islamic Development Bank, and the World Bank helped elevate urban transport to the forefront of the sustainable development discussion at the 2012 UN Sustainable Development Conference in Rio de Janeiro (Rio+20). Importantly, this USD 175 billion is not new funding for transport, but rather a commitment to shift the banks' existing urban transport portfolios away from investments like freeways and flyovers to more sustainable mass transit like BRT (WRI 2012).

The following sections provide some insights on the current BRT development in Latin America, China, India and Southern Africa. They show that there are commitments and policies in place to suggest sustained growth of BRT in coming years.

10.1 BRT Growth in Latin America

10.1.1 REGIONAL PROGRESS

Latin America continues to lead the world in the number of cities with BRT or high-quality bus corridors (54 cities), combined length of routes (1389 kilometers, or 34 percent of the world total) and number of daily passengers (18 million, or 62 percent of the global passenger load) (BRTdata.org 2013). The region has a long history of bus corridors and BRT, which developed gradually, but has increased rapidly in recent years. In the 1970´s, bus corridors were implemented in Curitiba, Brazil, and Lima, Peru, and later upgraded to full BRT (Curitiba in 1992 and Lima in 2011). BRT expansion proceeded slowly in subsequent decades; there were only 11 cities with BRT before 1990, mainly in Brazil, and only 20 cities before 2000. Since 2000, however, the expansion of Latin American BRT systems has proceeded rapidly, with 34 cities in 11 countries implementing BRTs. It is now an integral part of urban mobility systems in of all the region's largest cities (Mexico City, Sao Paulo, Buenos Aires, Rio de Janeiro, Lima, Bogota, Santiago, Belo Horizonte and Guadalajara), and increasingly in medium and smaller cities.

The largest BRT operations are found in Sao Paulo (129 km, 3.1 million passengers per day), Bogota (120 km, 1.9 million passengers per day) and Rio de Janeiro (67 km, 1.7 million passengers per day). One of the fastest expansions occurred in Mexico City, with 95 km completed in a seven-year time span.

Regional similarities have developed, particularly when it comes to bus operations. Most Latin American cities operate BRT and bus corridors using private providers, with the notable exceptions of Quito (two out of three corridors), Medellín (one corridor integrated with Metro) and Mexico City (Trolleybus and Metrobús corridors). In the prevailing public-private partnership models, basic infrastructure (bus corridors, stations) is built by government, while bus operations and fare collection are contracted, through concessions, with private parties. The business models for the privately operated systems are varied, with net-cost (area or route contracts) prevailing. Gross-cost (payment based on bus kilometers operated) were common in Brazil some years ago and have been used in recent Mexican systems, notably Mexico City's Metrobús. There is a new trend across the region for mixed systems combining elements of revenue per kilometer and per passenger (e.g., Colombian systems, and new bus operation contracts in Brazil).

BRT and bus corridors have facilitated an important regional urban transit transformation. On the one hand, BRT systems have improved speed, safety and environmental performance of public transport services, enhancing quality of service for the users. On the other hand, concession contracts have ushered in the evolution of unorganized and informal bus service providers to consolidated formal companies. These companies have expanded beyond the borders of their own countries; for example, it is possible to find Colombian bus operators in Panamá, Perú and Chile. The Colombian operator Fanalca was even involved in management of bus operations for the first year of Johannesburg's Rea Vaya Phase 1A (McCaul and Ntuli 2011).

10.1.2 COMMON CHALLENGES

Despite the widespread success of BRT in Latin America, systems across the region face several common challenges. Latin American cities will need to prioritize finding solutions to these challenges to ensure the continued and widespread success of BRT:

- **Declining quality of service:** several systems face very high occupancy and low reliability, especially in the peak hours;
- **Excluding poorest residents:** high fares are excluding the lowest-income population;

- **Limited integration:** integration (physical, fare, service) with other transport services is lacking;
- **Competition from metros:** metro expansion is advancing in many cities.

One of the challenges of BRT systems is to continue improving even years after being implemented. User surveys in Bogota show that in 2001, right after operations started, TransMilenio obtained a 4.8/5.0 score. Ten years later the score is now 3.0/5.0, with the main concern being overcrowding in buses (Camara de Comercio de Bogota 2010).

As the TransMilenio and Metrobús cases studies showed, the poorest residents are not yet well represented among BRT users. There have been great productivity gains introduced through BRT; for example the number of passengers per vehicle-km increased from 1.0 to 5.0 in Bogota and 2.0 to 10.0 in Mexico City. However, the costs of fully formal systems have also introduced a burden on the user fare. As a result there is an increasing need for operational subsidies, so quality can be kept at a high level and the lowest income population can still afford the service. There is a growing trend for the introduction of subsidies after their elimination in the 1980s. For instance, Transantiago in Chile receives more than US$500 million per year to cover the costs of students and keep the overall fare below USD 1 per trip. Bogota recently introduced a permanent subsidy and is working to establish targeted subsidies for the low-income population using smart cards. Mexico City´s Metrobús operates at a deficit that is covered by government subsidies to the public operator and management agency.

More progress is needed to move from corridor-based solutions towards integrated public transport networks. There has been a long tradition of integrated solutions in Brazil, but these remain rare in the rest of the region. Early movements towards integrated systems outside of Brazil include:

- In 2007 Santiago transformed the whole urban public transport network, with serious implementation issues. The system has stabilized since, and today provides a fairly good quality of service, but runs a large operational deficit.
- Bogota is now working towards an integrated system. Contracts have been awarded and 20 percent of the new fleet is in operation. Complete integration is expected by mid-2014, by which time all of the traditional one-man-one-bus system will be replaced and the overall city fleet reduced from 16,000 to 12,000 vehicles.
- Lima and Mexico City are also attempting citywide integration. Lima is releasing contracts for five structural corridors integrated with the Metropolitano BRT corridor and covering 50 percent of the city's daily transit trips. Mexico City announced plans to overhaul citywide bus operations, replacing and reducing 22,000 individual operation concessions.

At the same time, the region is witnessing a re-birth of metro construction, which competes with BRT and other efficient and affordable public transport modes for funding and political support. Along with the metro expansions in Mexico City, Santiago, Medellin, Caracas, Santo Domingo, Rio de Janeiro and Sao Paulo, cities like Panama and Quito are advancing construction of their first metro lines, while Fortaleza and Bogota are advancing designs. Investment in these expansions and new lines exceeds USD 25 billion.

10.1.3 CONTINUED MOMENTUM

According to data collected by EMBARQ, 15 percent of the new and expanded systems in development globally will be in Latin America. In the coming years, EMBARQ expects important expansions in cities where BRT has already been introduced. The largest expansion is anticipated in Rio de Janeiro, which plans to complete an additional 150 km before 2016, in preparation for the 2014 FIFA World Cup and 2016 Summer Olympics. Mexico City is also projecting that it will add 105 km to the Metrobús system in the next 5 years. Santiago has a plan to upgrade 100 km of bus priority lanes into full BRT, and Bogota is expected to add 40 km before 2016.

An important factor in the continued momentum of BRT growth in some Latin American countries is the support of national government transport investment programs. Under Brazil's urban development acceleration plan (PAC), USD 7.7 billion has been earmarked for investment in new or expanded BRT in 32 cities, supporting the preparation for the World Cup and Olympic Games. Through Mexico's national mass transit investment program, PROTRAM, an estimated USD 3.5 billion (50 percent grants from the national government and 50 percent loans by Banobras the state-owned development bank in Mexico) is available for investment in mass transit. Through the program, nearly 30 BRT systems have been approved or are in final planning; 5 of them are in construction or trial operations (Puebla, Acapulco, Estado Mexico, Chihuahua and Monterrey).

In summary, Latin America has witnessed a rapid expansion of BRT in recent years, which will continue with the help of national transit investment programs. The continued success of BRT across the region depends on cities attending to several common

7.7 billion

BRT investment under Brazil's urban development acceleration plan (PAC).

40 km

expected to be added to Bogota's Transmilenio by 2016

3.5 billion

available through Mexico's national mass transit investment program, PROTRAM.

challenges, including quality, equity and integration, and competition from large investments in urban rail.

10.2 BRT Growth in China

Despite its relatively recent arrival in China, BRT has gained popularity since the inauguration of the country's first corridor, Beijing's Line 1, in 2004 and is currently expanding rapidly in Chinese cities. Currently 17 cities have bus rapid transit or high-quality bus corridors transporting 2.3 million passengers each day. Guangzhou's BRT remains among the world's highest throughput systems, moving an impressive 850,000 passengers per day.

While BRT has been successful in several first tier cities[10], the most recently inaugurated Chinese BRT systems are in second tier cities with populations less than five million including Urumqi (2011), Yinchuan (2012), Lianyungang (2012) and Lanzhou (2013). Here, the BRT systems form the backbone of the urban public transport networks. Three of these new systems (Urumqi, Yinchuan and Lanzhou) are the first in less-developed western China.

As with other urban infrastructure, BRT systems in China are typically constructed very quickly. It took the city of Lianyungang only eight months to construct and open its 34 km first corridor, while Urumqi built up a four-corridor, 40 km BRT system in merely three years (Baidubaike 2013; Urumuqi Government 2013). This rapid implementation would enable Chinese cities to scale up BRT systems quite quickly.

Recent national policies may help build momentum towards Chinese cities implementing more BRT in the coming years. The State Council recently recommended BRT as a key component of surface public transport systems in China, and a policy directive of the Ministry of Transport establishes a national goal of 5000 kilometers of BRT implemented by 2020 (China MoT 2013).

10.3 BRT Growth in India

Ahmedabad's Janmarg – India's first full BRT system — introduced a new transit paradigm to India when it began operation on October 15, 2009. It started with 12.5 km of segregated lanes, expanded slowly, and recently reached 63 km of its planned 88 km in Phase 1. In order to minimize disruption and build support, the designers worked with a "connect busy places, avoid busy roads" motto to ensure that private traffic wouldn't suffer (Swami 2010). In addition, rather than only thinking about corridor development, a systemic solution was sought. Key elements of the system include exclusive busways, median-located stations, pre-ticketing, extensive use of technology for

bus and passenger information and efficiency, dual side access buses, and bus priority at intersections. There are nine public-private partnerships providing services to ensure the smooth operation of the system. This includes construction and maintenance of bus stations, bus operations, control room management including ticketing, sky walks, parking, hardware elements (such as turnstiles, sliding doors), advertisements, landscaping, and housekeeping.

Monthly customer surveys report high levels of satisfaction. On a range of 0-10, Janmarg receives an average rating of 9.4 over the 42 months of available data, ranging from 8.3-9.5 (CEPT 2010-2013). Users express satisfaction with speed, comfort, and overall service, while the top concerns consistently include safe pedestrian crossing and fair prices.

In the four years since the inauguration of Ahmedabad's Janmarg, six other Indian cities have followed suit and implemented BRT. In 2012, the city of **Rajkot** launched the first 10.7-km corridor of their BRT system, and **Visakhapatnam**, located in eastern India, opened an 18-km corridor, with 173 city buses permitted to use some portion of the BRT lanes, carrying a total of 109,000 passengers per day (Bachu 2013). In mid-April 2013, Atal Indore City Transport Services Limited (AICTSL) launched trial operations for **Indore's** new iBus BRT system which had been in planning for seven years. The 11.8-km corridor includes 21 median stations, is plied by 14 custom buses, and is expected to carry 25,000 daily passenger trips.

Most recently, a 24-km corridor was launched in **Bhopal** in 2013. The system is expected to eventually carry 70,000 passengers per day and include 20 high-quality air conditioned buses. Bhopal's MyBus system is an important innovation in India BRTs. While the BRTs in Ahmedabad, Indore and Rajkot are closed trunk and feeder systems (only BRT services are permitted to use the segregated bus lanes, and passengers transfer from smaller feeder buses to the main BRT corridor buses), Bhopal's system operates like a hybrid open system with direct service (the BRT corridor has dedicated service while other buses are also permitted to access the corridor; this reduces the need for passengers to transfer) (Wright and Hook 2007, 213-221). Bhopal's success will be important for demonstrating the feasibility of open systems in Indian cities.

Additional BRTs are in development across India. The next BRT is expected to launch at the end of 2013 in the city of **Surat**, where Phase 1 will include 10 km of the 30-km system. **Pune** is currently upgrading a segregated bus corridor to a full-fledged BRT corridor and planning for full BRT systems is also advancing in **Bangalore, Hubli-Darward, Naya Raipur**, and **Mumbai**.

These new developments are quite remarkable given that until as recently as 2010 many people, including experts, saw BRT as a system suitable for Latin America but not for a country like India (Michell 2013). Even after Ahmedabad's success with Janmarg, many critics said such systems would not flourish outside the state of Gujarat. Indore and Bhopal's recent successes confirm that BRT can be successfully adapted to a variety of Indian urban contexts. This will be critical for scaling up BRT across other Indian states.

With support and funding from the central government, BRT will be implemented in more cities across India. The Government of India is currently preparing the terms of the second national urban renewal program, the Jawaharlal Nehru National Urban Renewal Mission (JnNURM). Under the first implementation of JnNURM, urban transport projects worth USD 4 billion have been commissioned since 2006, including approximately USD 840 million for bus rapid transit. Most public transport funds are destined for roads, which then fill up with the new private vehicles. Hidalgo *et. al.* (2011) report research by the Center for Science and the Environment (CSE) and the Indian Institute for Human Settlements (IIHS) that documents that 70 percent of the JnNURM investment has funded roads and flyovers, while only 15 percent has been allocated to mass transit. Private vehicle ownership has expanded greatly in line with increased incomes and insufficient public transport.

The next phase of JnNURM is expected to include USD 12 billion for implementation of rail and bus systems between 2013 and2023. The Government of India can accelerate the growth of BRT in India by earmarking funding for systems under the second JnNURM, and by providing the necessary resources for cities to complete high-quality project analysis, planning and implementation (Hidalgo *et. al.* 2012).

10.4 BRT Growth in Southern Africa

10.4.1 REGIONAL PROGRESS

BRT is not yet common in urban transport networks in African cities. Africa currently features only three cities with operational BRT: Johannesburg and Cape Town in South Africa, and Lagos, Nigeria. These systems total 62 km (1.5 percent of world total) and carry a combined 280,000 daily passengers (0.8 percent of world total). Each of these cities is also planning or constructing extensions to their BRT systems. Johannesburg launched the 18-km Phase 1B in October 2013 and is advancing plans for the northern Phase 1C extension. Cape Town continues to roll out new routes for their MyCiti BRT system (MyCiti 2013). A second phase of the Lagos BRT, adding 13.5 km to the existing corridor, is planned (C40 2013).

Several new systems are in planning and under construction across the continent. South African cities of Rustenburg and Nelson Mandela Bay, the metropolitan municipalities of eThekwini (includes Durban) and the City of Tshwane (includes Pretoria) are planning or constructing new systems. EThekwini Municipality is investing R10 billion (approximately 1 million 2013 USD) to complete the first 60 km of a 190-km BRT system by 2018 (Mdlalose 2013).

10.4.2 COMMON CHALLENGES

While each city presents a unique urban context, there are some common challenges facing BRT projects across African cities that can impede implementation or limit political or public support (Seftel and Rikhotso 2013; McCaul 2009; Venter 2013; UN-HABITAT 2010a):

- Relatively low/sprawling urban population densities;
- lack of local institutional capacity for project planning and implementation;
- inadequate funding;
- strong opposition from incumbent operators, especially in the informal economy;
- lack of affordability for poorest residents;
- the challenge of using BRT projects as a mechanism for broader transport sector reform.

In cities with relatively low urban density and dispersed built environments, travel demand is often not concentrated along corridors. The common closed, trunk-and-feeder BRT system structure is not well suited to this context, and alternative BRT configurations or transport solutions may be required.

Lack of capacity in public agencies for transport planning, design, operations and policy can significantly challenge BRT project development. Seftel and Rikhotso (2013) indicate that limited capacity contributed to the slow roll-out of 12 or 13 BRT systems leading up to the 2010 FIFA World Cup.

As the cases showed, capital costs are often a significant percentage of the overall BRT project costs. Municipal funding or national government investment is needed for capital expenditure, while ongoing operations and maintenance costs must be budgeted for as well. This may be particularly challenging for cities with limited property tax income or national income tax.

As was revealed in the Rea Vaya case, and mirrored in the others, while often progressive in nature, BRT systems do not by default benefit the poorest residents. To increase the benefits accruing to the poorest residents, it is important for BRT systems to have user fares that are affordable to (or subsidized for) this group, and stations conveniently accessible to neighborhoods where the lowest income strata live and work. This is an issue that new or expanded BRTs across Africa will need to address.

Many African cities, including those currently planning or implementing BRT, have significant informal transport sectors – whether dominated by minibus taxis, matatus, daladalas, boda bodas, or tro-tros. The interests of these informal operators, and the extent to whether they are incorporated into the new BRT system, needs to be addressed in each city. Johannesburg's protracted negotiations with the taxi industry led to strikes, violence and, unfortunately, deaths (McCaul 2012; Seftel and Rikhotso 2013). Johannesburg's experience will surely offer valuable lessons for other South African cities looking to implement BRT.

Given the extent of the informal transport industry in many African cities, implementing a BRT system can be used as a mechanism to reform and formalize the sector. This can enable the city to meet key transformation and empowerment objectives, but negotiations with the informal sector can be time-consuming and costly (Seftel and Rikhotso 2013). These tradeoffs need to be balanced and taken into account during BRT planning and financing discussions.

BRT is not yet common in urban transport networks in African cities. Africa currently features only three cities with operational BRT: **Johannesburg** and Cape Town in **South Africa**, and Lagos, **Nigeria**.

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10.4.3 FUTURE OPPORTUNITIES

African cities will face rapid urbanization in coming years. In 2009, Africa's population exceeded one billion, of which nearly 40 percent lived in urban areas. By 2030 more than half of the population will live in urban areas, and by 2040 this urban population is projected to grow to one billion by 2040 (UN-HABITAT 2010b). To keep pace with the mobility demands of this rising urban population, urban transport services will need to expand and dramatically improve in coverage, quality and efficiency, replacing, at least partially, the widespread informal services. If several commonplace challenges are addressed, BRT could become an integral part of Africa's urban public transport systems.

Additional funding and policy support for mass transit generally and BRT specifically will help build momentum for BRT across the continent. The South African national government has agreed to fund an operational subsidy for all BRT cities, through a special Public Transport Network Operational grant (Seftel and Rikhotso 2013). This ought to help ensure that user fares can accommodate the poorest residents better in the future.

Kenya's government recently committed USD 113 million matching funds to a BRT and other urban transport reforms in Nairobi, which will also receive USD 300 million in World Bank financing (World Bank 2012). A Global Environment Fund (GEF) project supports BRT planning in Addis Ababa, Ethiopia, Kampala, Uganda and Nairobi, Kenya and there are projects in development in Accra, Ghana and Dar es Salaam, Tanzania (Dzikus 2012).

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

11.1 CASE STUDY SYNTHESIS

The four BRTs presented in the case studies represent a variety of projects with a range of infrastructure and service designs, implemented and operated in different urban and political contexts. All of the projects have positive net present benefits, with positive NPV and benefits exceeding costs. The internal rates of return indicate each of the investments was at least as socially profitable as the opportunity cost of public funds (Table 29).

The four cases suggest several general conclusions about BRT costs and benefits:

- **Travel time savings** dominate the BRT benefits as a result of segregated bus lanes and other design features which minimize waiting and in-vehicle times.
- Shifting from informal/unregulated service with smaller vehicles operating in mixed traffic, to newer, larger buses operating at higher speeds results in significant **reductions in vehicle** operating costs with BRT (Bogota, Mexico City and Istanbul).
- **Capital costs** and **bus operating costs** were the most significant portion of project costs in the cities.

- BRT projects can be a mechanism for broader **urban infrastructure or transport reform**. They can be used to facilitate formalization of an informal public transport industry (Bogota, Mexico City, Johannesburg) and simultaneously improve complementary urban services (Johannesburg). This can come at an extra cost incurred by the BRT implementing agency, or at the same time as the BRT implementation, but which has a broader purpose than the BRT itself.

For the most part, the largest proportion of users from the case study BRT systems is in the lower- and middle-income groups (Table 30). The lowest- and the highest-income groups are not well represented among BRT passengers; this influences how the project benefits are distributed across segments of society. As the majority of the BRT costs in the cases are paid with public revenue derived from taxes, the project costs typically accrue to the highest-income strata. Since the dominant benefit is travel time savings, the majority of benefits tend to accrue to the strata most represented by BRT users – typically lower- and middle-income. While the BRT projects tend to be progressive and beneficial to lower income strata, the lowest-income residents are not benefitting the most from the projects.

Exclusive bus lanes, and the provision of public transport itself, are pro-poor policies. Allocating two lanes of roads to buses reserves space for vehicles with higher capacity, and people of all income levels, rather than prioritize personal motorized vehicles that carry far fewer people and are used by higher-income citizens. This is difficult to quantify, although travel time savings presented in the case studies above are used as a proxy. Another method of presenting this improvement is looking at how many people are moved on BRT (all income levels) versus in mixed traffic (with many private motorized vehicles, thus excluding the poorest). Using Ahmedabad's Janmarg as an example, 150 people are moved in one BRT lane in each direction, taking up 84 square meters, compared to mixed traffic that moves only 45 people using 3 lanes, or 486 square meters (Swamy 2013).

11.2 Recommendations

Lessons from the TransMilenio, Metrobús, Rea Vaya and Metrobüs cases inform generalized recommendations for how policy, infrastructure and operations design, and project financing can maximize the net social benefits of BRT projects.

11.2.1 TRANSPORT POLICY RECOMMENDATIONS

National and municipal urban transport policies dictate the type and quality of urban transport infrastructure cities implement. These policies can be structured in such a way to encourage transparent

Table 29 Summary of Case Study Cost-Benefit Analyses

BRT System	Scope of Case Study	Net Present Benefits (2012 million USD)	Benefit-Cost Ratio	Social IRR
TransMilenio, Bogota	Phase 1 & 2	$1,400	1.6	23%
Metrobús, Mexico City	Line 3	$36	1.2	14%
Rea Vaya, Johannesburg	Phase 1A	$143	1.2	12%
Metrobüs, Istanbul	Phases 1-4	$6,407	2.8	66%

Table 30 Summary of Distribution of Net Present Benefits for Four Cases

Distribution of Net Benefits by Income Strata (2012 million USD)					
BRT System	1 (Lowest)	2	3	4	5 & 6 (Highest)
TransMilenio, Bogota	$ 92	$ 642	$ 603	$ 238	$ (176)
Metrobús, Mexico City	$ 11.4	$ 37.9	$$ 12.2	$ (9.5)	$ (16.4)
Rea Vaya, Johannesburg	$ 18.6	$ 8.2	$ 35.2	$ 353.9	$ (273.3)
Metrobüs, Istanbul	$ 765.9	$ 2,308.5	$ 1,414.0	$ 969.0	$ 952.1

Legend: Gain least/Lose | Gain most

and objective assessment of the merits of a particular investment based on the societal impacts. Urban transport policies should consider:

- National and local investment decisions should be predicated on objective and transparent evaluation of alternatives, including an assessment of social costs and benefits (such as a Cost Benefit Analysis) to determine whether proposed projects represent a good use of limited resources.
- Where possible, project evaluation should consider the distributive impacts – which segments of society benefit and which lose.
- National transit investment schemes such as Mexico's PROTRAM, Brazil's PAC and India's JnNURM, can help catalyze widespread adoption of BRT as an urban transport solution.

11.2.2 PROJECT PLANNING AND IMPLEMENTATION RECOMMENDATIONS

The physical design, service plans and institutional arrangements dictate many of the benefits and costs analyzed in the case studies. Decisions made during the project planning phases affect which segments of society gain and lose the most as a result of the project. The four cases suggest key recommendations for cities planning BRTs:

- BRT systems should be designed to best accommodate the local travel demand and urban context. Choices about expanding capacity with station by-pass lanes, larger stations, or bi-articulated buses, should be driven by corridor demand and available funding.
- Travel time savings are often the most significant social benefits resulting from BRT systems. Design of routes, services and infrastructure should aim to minimize passenger waiting, transfer and in-vehicle transit times to maximize the travel time savings and to deliver a system that is attractive to users. Exclusive, segregated BRT lanes are a key design element.
- User fares should be defined based on technical methods and the actual cost of operations to reduce the need for operational subsides and political interference (Hidalgo and Carrigan 2010).
- Engagement with existing bus operators early in the project planning phase can build buy-in and ensure inclusion. Be aware that negotiated operator contracts are often more costly than competitive contracts.

- To attract more users from the lowest income quintiles, cities should consider accessibility of the BRT service to poor residents and the price of user fares compared to other modes. Targeted subsidies for particular income strata may be warranted.
- The implementation and operation of BRT systems provide an opportunity to strengthen the capacity of institutions at the local level and to improve urban transport regulation.
- BRT systems should be part of fully integrated transportation networks.

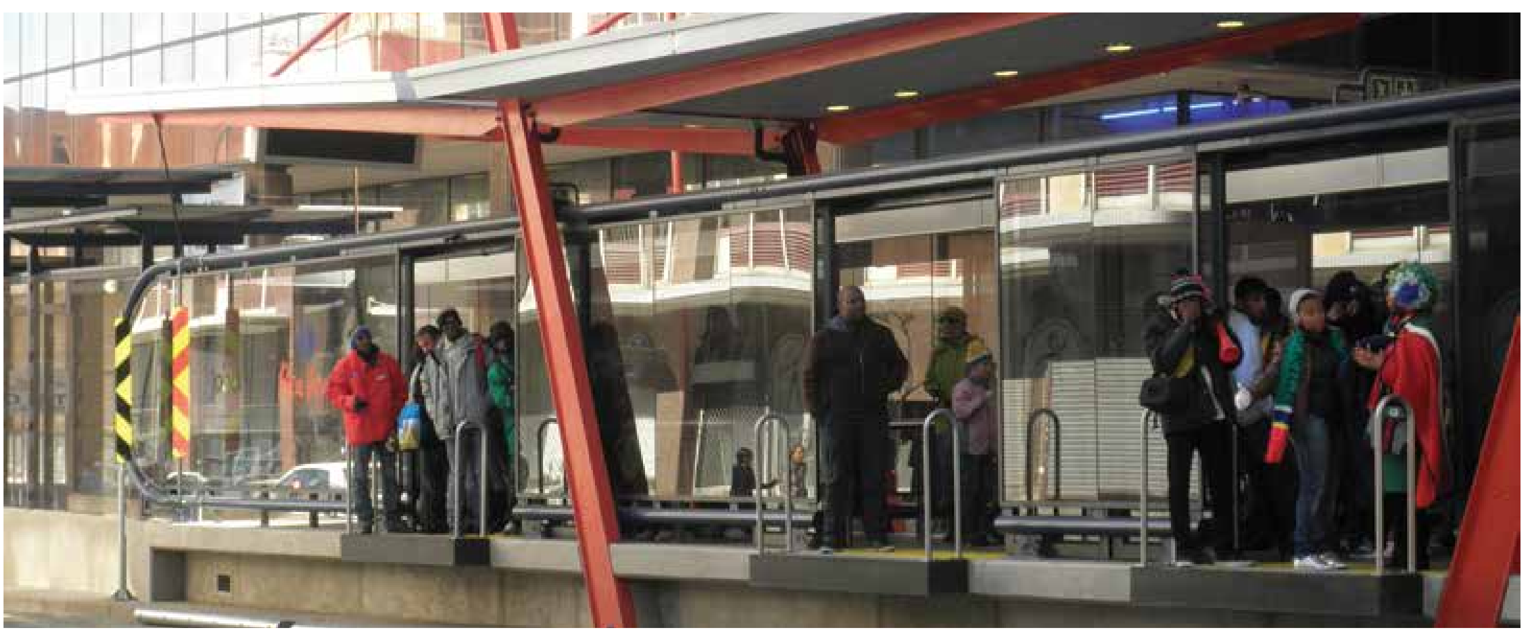
11.2.3 PROJECT FINANCE RECOMMENDATIONS

Financial institutions are relevant and critical stakeholders in BRT projects. Banks provide the necessary finance for project implementation, which is often infeasible with equity alone. With the exception of Istanbul, the four projects reviewed in this report all supplemented public funding with private financing.

The four case studies included here demonstrate positive social benefits of BRT, and banks that have been involved in BRT have identified positive commercial and financial results from the projects. Banks assess BRT investments considering the financial returns for the operator, as well as the social and environmental impacts. Doing so requires those who arrange BRT financing to have an informed understanding of the complexities of both the bus and BRT industries, as well as the scope of impacts of urban transport reform.

Specific recommendations for facilitating finance of BRT systems include:

- Loans are typically required and should be adapted to the specific conditions of each BRT project. This may include analyzing the concession contract to permit advancing lines of credit to previously informal operators.
- Financial institutions should be brought into the project planning process early, and can support cities and other project stakeholders in the project planning and preparation.
- Trust funds are a good mechanism for facilitating debt repayment by earmarking funds but conditions need to be assessed carefully so as not to negatively affect the bus operations. They can also ensure transparency of financial transactions.
- Special teams for bus and BRT finance that understand the industry (manufacturers, operators, government) can be very effective, as they have typically followed a large number of projects through all their phases (planning, implementation, adjustment, maturity).
- On-going dialogue with development institutions and non-governmental organizations is also advisable.



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Endnotes

1. The relative popularity of BRT in Latin America, and especially Brazil, is a result of ingenuity. Cities in this region grew very fast in the 1970s and 1980s as a result of urban industrialization and, in some cases, armed conflict in rural areas. But resources to improve mobility in cities were, and still are, very scarce. As a result, local planners, with some support from international organizations like the World Bank and the Inter-American Development Bank, developed local solutions that prioritized bus travel, recognizing the large capital investments required for rail.

2. This comparison only addresses medium- and high-capacity transit modes and excludes lower-capacity conventional buses, which may still constitute the majority of public transport in a city.

3. Tailpipe emissions depend on the specific bus technology and fuel selection. However, the newest models of urban transit buses can meet Euro IV or Euro V emissions standards (Cooper *et. al.* 2012).

4. The HEAT model and its associated methodology can be accessed online at http://www.heatwalkingcycling.org/index.php.

5. When considering the land value impacts as part of the overall economic impacts of a transit system, one should avoid adding up travel time savings and land value impacts, as this might amount to double counting, since they both account in different ways for the value of travel time reductions. However, while travel time savings represent a benefit to transit users, land value increases represent a benefit to the city through the increased tax revenue that can be expected as a result. This is particularly relevant when considering potential value capture mechanisms, such as tax increment financing (TIF), for funding a new transit system.

6. A limitation with respect to interpreting results across studies is the lack of a clear definition in the literature as to what constitutes "close to transit" versus "away from transit." Some studies simply choose a cutoff distance and report the difference in property values within versus outside a given radius, which can vary from 30 meters (Perk and Catala 2009) to 150 meters (Rodriguez and Mojica 2009) or more. Other studies use different model specifications and report the change in property value by unit of distance to the station (e.g. Perdomo 2011). The different studies also use different currencies from different years, which poses a challenge in comparing results across different studies.

7. For example, PROTRAM, the Programa de Apoyo Federal al Transport Masivo, Mexico's Program for Federal Support to Mass Transit (SHCP *et.al* 2009; ADB 2013).

8. Venter and Vaz (2011) suggest that the lowest-income residents in Soweto's Orlando neighborhood may prefer to use the less-expensive commuter rail network than the BRT.

9. While it is reasonable to assume an increase in rail use with the completion of the Marmaray project, it is not likely that this will significantly affect BRT use, as commuter rail tends to be utilized by long distance commuters and the average Metrobüs BRT trip is 15 km (Yazici *et. al.* 2013).

10. In China, cities often are categorized as first-tier, second-tier and third-tier cities. There is no formal definition of the categories, but there is a common agreement that the first-tier cities refer to Beijing, Shanghai, Guangzhou and Shenzhen, which are more economically developed. An accepted threshold for a second-tier city is a population of at least 3 million and a minimum per capita GDP of US$2,000. Using that definition, there are some 60 second-tier cities.

11. Istanbul Metrobüs is operated publically by the Istanbul Electricity, Tramway and Tunnel General Management (IETT) without a bus operating contract.

12. The estimates in Table 32 are somewhat conservative and actual benefits from safety improvements might be higher. In estimating the value of a statistical life (VSL) for fatality reductions, we have relied on a conservative reference value for VSL. See Appendix A for more details.

13. Secretary of Transit and Transportation, Estudio de Tarifas de Transporte Público Colectivo [Study of Collective Transit Fares], Universidad de los Andes, August 2006. The estimated financial value is $1,406.37/km, with the economic value being $1,253.71/km. This figure is adjusted using the consumer price index: 5.69% for 2006 and 7.67% for 2007.

14. Atmospheric warming is a global phenomenon with multiple implications: higher sea levels, increase in extreme climatic events, changes in average weather patterns (temperature, precipitation, wind patterns, solar radiation), etc. A variety of impacts are produced: sinking of coastal regions, flooding, increased risk of landslides, drought, greater hurricane frequency, glacial melting at the poles and at high elevations, changes in ecosystems and agricultural productivity, etc.

15. The total amount of emissions reduction certificates verified for 2006 and 2008 was 197,718 CO2 eq (TransMilenio S.A.), with an estimated market value of 5,931 million 2008 pesos.

APPENDICES

13.1 Appendix A – EMBARQ's BRT Impact Evaluation Methodology

The cost-benefit analysis (CBA) methodology is used to estimate both public and private costs and benefits for society as a whole (Harberger and Jenkins 2002, Gramlich 1997, and Boardman *et. al.* 2006). Socioeconomic analysis attempts to analyze a project from the point of view of the society overall, examining the net effects on resources used to produce goods and services. In addition to the financial or market costs, it also considers externalities and indirect or intangible costs, such as public health and environmental impacts. This difference between "economic" costs and "financial"/"market" costs is frequently a source of confusion, but the economic CBA approach utilized in this study attempts to capture the broader economy-wide effects. Thus the social benefits and costs will be different than those seen in the market, but more accurately capture the costs and benefit to society as a whole.

The economic CBA method is similar to financial analysis of a project (projecting out flows and then discounting to a net present value for analysis), but with a wider set of inputs. Typically, the benefits and costs are estimated using impact evaluation studies, surveys, and other means. Each benefit and cost is quantified and valued based on research studies that estimate the monetary impact of a change in the benefit or cost. In order to compare benefits and costs over the time horizon of a project, benefits and costs are projected out until the project sunsets and then the monetary values are adjusted to a present value through discounting.

Unlike a financial CBA, transfers between sectors (taxes, subsidies, interest payments) are not included in an economic CBA as they net out when looking at the impacts to society in aggregate.

While including both public and private costs is important in all CBA, it is even more important given the combined public-private partnership provision of many of these services in the cases under study. The public costs include studies and project preparation costs, real estate purchase and resettlement, infrastructure construction and/or rehabilitation, infrastructure maintenance, implementation of control center, control center operation and costs of public project management agency. The private costs include bus fleet acquisition, bus fleet operation, and implementation of the fare collection system. These cost and benefit flows are projected out (typically 20 years), and then discounted to arrive at a net present value of project costs and benefits. The four cases presented here apply this approach.

13.1.1 KEY ASSUMPTIONS

As with most analysis, it is necessary to make a few assumptions to conduct a cost-benefit analysis. Below, we list the key assumptions that play an important role in the cost-benefit analysis, along with our reasoning. In each case, we aimed to balance consistency with local conditions while recognizing international standards and the need to be conservative in our estimates.

13.1.1.1 PROJECT TIME HORIZON

We assume a 20-year operating time horizon for each BRT case study as this is a common operating time horizon for a BRT project based on the existing literature. By using a consistent time horizon, we are able to ensure that each project is evaluated using similar cost and benefit assumptions.

A longer time horizon tends to increase net benefits because costs tend to be concentrated in the early years of a project due to capital and equipment costs. After an extended period of operation, however, buses will need to be replaced, stations rehabilitated, and roadway resurfaced. In the cases selected, useful lifetime of the fleet and infrastructure (busways, stations, equipment) tends to be less than 20 years. Using the 20-year time horizon for the CBA ensures that we capture the fleet and infrastructure renewal or replacement costs in future years. Similarly, bus operating concession contracts in Bogota and Mexico City (10 years), and Johannesburg (12 years) are less than the 20-year horizon, ensuring the full cost of current contracts are included in the CBA[11].

13.1.1.2 DISCOUNT RATE

The key advantage of cost-benefit analysis is its ability to compare costs and benefits in present day dollars. This allows policymakers to consider a project in its entirety and determine if the net benefits justify its implementation. In order to achieve this apples-to-apples comparison, both costs and benefits are estimated per annum over the course of the project time horizon (20-years, see Section 13.1.1.1) and then discounted to 2012 net present values. The discount rate is therefore an important assumption in this analysis. A higher discount rate will reduce the net present values of the costs and benefits, whereas a lower discount rate will inflate the net present value.

The CBA analysis presented in each case uses a 12 percent discount rate based on World Bank and Asian Development Bank guidance (Belli *et. al.* 1998 and Gollier 2011). In practice, the social discount rate utilized by individual governments varies considerably. For example, the Philippines uses a 15 percent rate while the U.K. Treasury uses 3.5 percent (Harrison 2010). As benefits and costs for the BRT projects considered here span 20 years, the cost-benefit analysis is sensitive to the discount

Table 31 Comparison of Financial and Economic Cost Benefit Analysis

Type of Cost and Benefit	Economic CBA	Financial CBA
Sales	Included	Included
Consumer surplus	Included	Excluded
Benefits of reduced pollution	Included	Excluded
Operating cost	Included	Included
Investment cost	Included	Included
Taxes	Excluded	Included
Subsidies	Excluded	Included
Transaction cost	Included	Excluded
Regulatory cost	Included	Excluded
Increase in working capital	Included	Included
Net Benefit before Financing = Investment Point of View		
Loans	Excluded	Included
Equity	Excluded	Included
Debt service payments	Excluded	Included
Income taxes	Excluded	Included

rate used. The higher the discount rate used, the smaller the value of benefits and costs from future years. While some suggest that 12 percent is high for a social discount rate (Lopez 2008), we utilize this rate because it is a conservative estimate given that costs tend to be higher in the near term compared to benefits. There is also a tendency for national governments in developing countries to align domestic assessments with assessments made by multilateral development banks. In many of the cases, 12 percent is the discount rate used in domestic analysis as well. In the Johannesburg case, while the government of South Africa recommends an 8 percent discount rate, we have harmonized the analysis with the other cases and utilized the 12% discount rate in the Rea Vaya cost-benefit analysis.

Each of the cases included a sensitivity analysis to test the stability of the results with an 8 percent instead of a 12 percent discount rate. As expected, the net present value increased 63-219 percent.

13.1.1.3 SOCIAL COST OF CARBON

The social cost of carbon is an estimate of the monetized value of damages caused by an increase in greenhouse gas emissions; it reflects the benefit of reducing greenhouse gas emissions now to avoid the cost of those damages in the future (Greenspan Bell and Callan 2011). A benefit of a BRT project that reduces greenhouse gas emissions is avoiding the future cost of those damages. There is significant uncertainty and disagreement surrounding the social cost of carbon. The US government recommends $21 per ton of CO2 (2007 USD) as the central value, but considers a range of $5-$65 (2007 USD), whereas the UK government considers a range of $41-$124 per ton of CO2 with a central value of $83 (Greenspan Bell and Callan 2011). A review of academic literature reveals a very wide range of values from less than $0/ton to over $400/ton, with a mean value of about $30/ton (2000 USD) (Stern 2007). We used this value of $30/ton since it was the mean of many studies and a middle value between US and UK government recommendations.

Likewise, the choice of a discount rate for the social cost of carbon is equally important and controversial. The carbon discount rate reflects the cost current generations will impose on themselves to benefit future generations with greenhouse gas emissions reductions, so the higher the discount rate, the less significant future costs of carbon become (Greenspan Bell and Callan 2011). The 2007 Stern Review used a carbon discount rate of 1.4 percent; a commonly used rate is 3 percent, and the US government utilizes rates of 2.5 to 5 percent. The higher rates shift more of the burden of addressing emissions and climate change to future generations, presumably because of an underlying assumption that future generations will be wealthier than today (Greenspan Bell and Callan 2011). Choice of a lower discount rate indicates a preference not to delay climate change mitigation decisions and their costs to future generations (Greenspan Bell and Callan 2011). Believing that climate change mitigation, including decisions to invest in sustainable low-carbon transportation, should not be delayed, EMBARQ chose the low value of 1.4 percent utilized in the Stern Review.

Each of the four cases tested the sensitivity of the results to lower social cost of carbon and higher carbon discount rate. A social cost of carbon of $0/ton, reduced the case studies' net present values by as much as 50 percent, but still resulted in positive benefit-cost ratios. Likewise, a carbon discount rate of 5 percent reduced the net present values by as much as 44 percent, but also had minimal impact on the benefit-cost ratios, since the cost of carbon reductions is a small percentage of each case's total project benefits.

13.1.2 ESTIMATING ROAD SAFETY IMPACTS

Evaluating road safety impacts of BRT systems involves estimating the change in traffic accidents and casualties that can be attributed to a new BRT project. The challenge in estimating safety impacts lies mainly in the general randomness of crash data. Crashes generally tend to be over-dispersed (i.e., the variance is considerably larger than the mean) and crash counts at a given location can vary widely over time in the absence of any intervention. From the perspective of evaluating impacts of interventions, this poses the problem of how to deal with regression to the mean (RTM) effects, which could significantly bias the estimates. RTM refers to situations in which a location that experiences a particularly high or low crash volume in one year will usually tend to experience a crash volume closer to the mean the following year (Barnett, van der Pols and Dobson 2004). For this reason, the preferred technique for evaluating the safety impacts of interventions such as BRT is the Empirical Bayes (EB) method. Hauer *et. al.* (2001) provide an overview of the EB method and its application to road safety, while Goh *et. al.* (2013) apply EB to the case of a BRT system in Melbourne. The basic premise of the EB method is that there are more clues to the safety record of a particular entity than the actual crash records. EB creates a weighted average of the actual crash counts and estimated crash counts for a given entity, based on a safety performance function (or SPF) calibrated with data from similar and nearby streets, and most commonly using a negative binomial model. This approach is illustrated in equation 1:

$$E_{y_0}(m \mid N_{y_0}) = \exp\left(a + \sum_{i=1} ß_i \times x_i\right) \times w + N_{y_0} \times (1 - w) \qquad (1)$$

Where $E_{Y_0}(m \mid N_{Y_0})$ = expected number of crashes on entity m (e.g., an intersection, street segment, etc.) in year Y_0 given that N crashes have been observed on the same entity in year Y_0

N_{Y_0} = actual crash counts on entity m in year Y_0

X_i = variables used to predict crash frequency.

$a_i ß_i$ = model parameters, estimated using either a Poisson or a negative binomial (Poisson-Gamma) distribution, depending on the over-dispersion of the crash data

w = weight to be assigned to the average between actual and estimated crashes; the weight is a function of the crash counts estimated by the SPF and the variance in the crash data used to develop the SPF; Hauer *et. al.* (2001) and Barbosa *et. al.* (2013) provide different possible formulations for the weight.

The EB method provides very robust estimates of safety impacts and it was EMBARQ's preferred method for estimating the impact of BRT projects. However, it is also relatively data intensive, particularly for developing world cities, and we were therefore unable to use it for all the BRTs in our database. Whenever the application of the EB method was not feasible, we relied instead on using only crash counts.

EMBARQ's BRT impact estimates are not based on a before-and-after analysis, but rather on the comparison between a "baseline" scenario (assuming the BRT had not been implemented) and the actual conditions on the ground after BRT implementation. In the case of road safety impacts, the baseline scenario is created by taking the reported crash data before the start of BRT construction and projecting it to the first year of BRT operation by applying trends in crashes observed at the city level. This was an important step in isolating the change in crashes that could be attributed to the BRT versus the existing citywide trends (e.g., Bogota was experiencing a sharp citywide decrease in crashes at the time that the TransMilenio BRT was implemented, while Mexico City witnessed an increase in crashes during the implementation of Metrobus Line 3). More details on the detailed safety impact calculations can be found in Duduta *et. al.* (2012) and Duduta, Lindau, and Adriazola-Steil (2013).

Finally, most developing world countries tend to under-report traffic injuries and fatalities. Hijar *et. al.*.

(2011) have studied this under-reporting in detail for the case of Mexico and attribute it to two main causes: differences in the definition of injuries and fatalities, and miscoding of fatality data in national databases. The World Health Organization (WHO) has developed adjustment factors to standardize the data across the different countries (WHO 2013) and we apply these factors in our analysis.

13.1.2.1 ESTIMATING THE ECONOMIC BENEFITS FROM ROAD SAFETY IMPROVEMENTS

The main challenge in estimating the economic benefits from safety improvements associated with BRT is that there is no "correct" methodology for assigning a monetary value to crashes (Diez Roux and Bhalla 2012). There is a range of possible methodologies available in the literature, some of which consider only the loss of life or quality of life (e.g., Esperato *et. al.* 2012), while others include all other costs but exclude loss of life or quality of life estimates (e.g., Blincoe *et. al.* 2002). Moreover, there is often a disparity even among studies using a similar indicator – such as the value of a statistical life, or VSL – since there are different possible methodologies for estimating it.

The main constraint for developing robust estimates of the cost of crashes in the developing world is the

Table 32 Economic Benefits of Selected BRT Sstems From Safety Improvements, Per Year, Per Kilometer of BRT

		Fatal crashes	Injury crashes	Property damage crashes	Total (per km)
Guadalajara (Mexico)	2012 USD	138,302	131,316	57,358	326,977
	2012 MXN	1,821,301	1,729,304	755,351	4,305,955
Mexico City (Mexico)	2012 USD	289,119	213,154	(5,171)	497,101
	2012 MXN	3,807,407	2,807,022	(68,101)	6,546,328
Ahmedabad (India)	2012 USD	170,131	6,891	273	177,295
	2012 INR	9,091,285	368,213	14,590	9,474,088
Bogota (Colombia)	2012 USD	513,241	237,007	n/a	750,248
	2012 COP (thousands)	922,242	425,879	n/a	1,348,121
Melbourne (Australia)	2012 USD	98,976	32,868	934	132,778
		95,591	31,744	902	128,237

lack of accurate local data. Injury costs, for instance, can vary significantly with the degree of injury severity. The United States uses a standardized injury scale, coding injuries from MAIS 0 (no injury) to MAIS 7 (fatal) and allowing researchers to estimate costs for each MAIS level. This type of precision is not currently available in the datasets we were able to obtain from the developing world. Most commonly, databases distinguish between fatalities and injuries with no further mention of severity level. In addition to the lack of precision and standardization in the data, there is often a lack of local estimates for the different components of the cost of crashes (i.e. medical expenses associated with an injury crash, property damage costs, etc.). For this reason, we were not able to develop comprehensive cost estimates, and we relied instead on capturing most of the cost of crashes by using several key concepts that are relatively well documented in the literature regarding the developing world.

The reductions in crashes after BRT implementation yield economic benefits by reducing different types of costs associated with traffic accidents, including fatal crashes, injury crashes, and property damage only (PDO) crashes. Table 32 shows the annual economic benefits from improvements in traffic safety estimated for four different BRTs in Mexico, Colombia, India, and Australia. All of these BRTs' safety improvements have resulted in significant positive economic benefits[12]. The largest benefits accrue from the reductions in fatal crashes, both because fatal accidents are reduced at a higher rate than other types of crashes and because the cost of a fatal crash is considerably higher than that of an injury or PDO crash. In the case of Mexico City's Metrobus, for instance, despite the slight negative economic impact due to the increase in PDO crashes, there is a net overall benefit of USD 497,000 per year per kilometer of BRT, due to the significant reductions in injuries and fatalities. This suggests that for the 95-kilometer citywide Metrobus BRT system, annual economic benefits from safety improvements are in the range of USD 45,000,000 to 50,000,000.

13.1.2.2 VALUE OF STATISTICAL LIFE

In order to estimate public health benefits from road safety improvements and environmental benefits, it is necessary to apply a monetary value to human life. In the case of a traffic fatality avoided, the benefit of the BRT system is the value of the life saved requiring a figure for the value of a human life. As is common in the public health research community, EMBARQ's CBA methodology utilizes an estimate of the value of a statistical life (VSL) in the calculation of traffic safety and public health benefits.

Value of statistical life calculations are inherently controversial as they attribute a monetary figure to a human life. They tend to be even more controversial when comparing VSL values across countries as they are often misinterpreted as implying a human life is worth less in a developing country compared to a developed one. The inclusion of "statistical" in the term is not an accident. The VSL is the value that the statistically average person places on a marginal improvement in safety extrapolated to the value of a human life. It is not meant to be a statement of the value of a given life. It is also necessary to adjust VSL values to fit the local context in order to compare benefits and costs. If one were to estimate the value of a statistical life in Turkey, for example, where average income is around 1/5th of that in the United States, using a VSL figure based on a survey of Americans without adjustment would vastly overstate the public health benefits to Turkish society compared to the costs. To address this, we employ a benefits transfer approach that adjusts the estimate of an American statistical life to each country considered based on the gross national income of the country compared to the United States. As a result, the same methodology and input source can be used for each case study for consistency. (A detailed explanation of this approach can be found in the appendix.)

A VSL estimate can be derived using a number of techniques and VSL estimates vary considerably. For the purpose of the cost-benefit analysis in this report, the most conservative assumptions are made to ensure that if there is a bias in estimating benefits, it is towards underreporting. We use a low estimate of U.S. VSL (2009 USD 3.58 million) as the basis of our conversion to other country contexts. We also assume that the VSL figure includes all economic elements of a life lost (e.g., lost wages, medical costs, impact on family and friends, etc.) and do not add additional benefits to a fatality avoided. This ensures that we do not overestimate the benefits of a BRT project.

Empirical VSL estimates are usually available predominantly for developed countries. Therefore, most of the literature on VSL for emerging economies focuses on methodologies for transferring estimates of VSL from the developed to the developing world (Cropper and Sahin 2009). Furthermore, there is a wide range of VSLs from different studies in the developed world. In this study, we use a reference value the VSL for road injuries for the United States reported by Esperato et. al. (2012) of USD 3.81 million. VSL for each country in our sample is calculated based on the reference VSL in the US of USD 3,810,000, using the formula suggested by Esperato et. al.. 2012, shown in equation 2:

Where VSL_j = value of a statistical life in country j

GNI_j = the gross national income per capita in country j and in the United States, respectively

η = the income elasticity of VSL; we use a range of values from 1.0 to 1.5, as recommended by Cropper and Sahin (2009) and Esperato et. al.. (2012)

The VSL estimates for each country are shown in Table 33.

$$VSL_j = 3{,}810{,}000 \times \eta \times \frac{GNI_j}{GNI_{us}} \quad (2)$$

Table 33 Estimates by Country

Country	Value of a Statistical Life (VSL), Per Country (2012 USD, from eq. 2)	
	Lower estimate (η=1)	Higher estimate (η=1.5)
Mexico	675,172	1,012,758
Colombia	417,351	626,027
Turkey	872,470	1,308,705
India	95,265	142,897

We did not develop our own estimate for VSL in Australia. In fact, we excluded Australia from our detailed calculations of the value of economic benefits. This is due to the fact that unlike the other countries in our sample, there is considerable research available in Australia for developing local estimates of the cost of crashes. The Australian Bureau of Infrastructure, Transport, and Regional Economics (BITRE) has developed detailed cost estimates for crashes at different levels of severity (BITRE 2009). It seemed more appropriate to value the economic benefits of safety improvements from BRT in Australia using the more widely cited and used local estimates rather than re-estimating them using our methodology for data-poor contexts. This will allow for comparisons between the safety benefits of BRT in Melbourne and other comparable projects within the same region. It will not allow for comparisons of benefits across different BRTs in our database, since the estimates are developed using different methodologies (i.e. the BITRE estimates are considered to be quite conservative). This is consistent with our decision to avoid comparisons across countries, and only use the estimates for cost-benefit analyses within each BRT system.

The accuracy of our estimates of injury costs is severely limited by the poor quality crash data available in the cities included in this study. The most important limitation is the lack of a clear and standardized definition of injury severity levels. Since costs vary significantly with injury severity, a lot of detailed information is lost when the citywide databases distinguish only between “fatality”, “injury”, and “no injury,” as is the case for most of the data in our sample. Due to this limitation, the economic benefits presented in this section should be regarded as rough, order-of-magnitude estimates.

The United States uses a standardized scale of injury severity known as the Abbreviated Injury Scale, which distinguishes between seven categories of injury severity. The classification of injury severity varies widely across the countries we study here, as do reporting standards for injuries. In the absence of accurate data on injury severity by country and how the definitions would translate to the abbreviated injury scale, we have used the median injury severity, MAIS3, as the default value for all injuries in our database. All our injury-related cost estimates are based on the MAIS3 category.

There were no local data available for developing estimates of the cost of injury crashes and that of property damage only crashes. Therefore, we developed estimates using the costs in the United States as a reference and using the assumption that ratio of these costs in the different countries to the costs in the US will be the same ratio as that of gross national income. This relationship, which is similar to the one used for estimating VSL is illustrated in equation 3:

$$C_j = C^n_{US} = \times \frac{GNI_j}{GNI_{us}} \qquad (3)$$

Where C^n_j, C_{us} = the cost of component n (e.g. medical expenses) in country j and in the United States, respectively

GNI_j, GNI_{us} = the gross national income per capita in country j and in the United States, respectively

This approach likely underestimates the actual costs of PDO crashes, since the actual elasticity of PDO costs to income is likely to be less than 1. Indeed, vehicles and other property will likely cost less in a developing world country than in the US, but it is unlikely that that the difference will be the same as that of the income between the two countries. However, in the absence of any estimates on this relationship, assuming an elasticity of 1 seems the most cautious approach, which will yield a conservative estimate of the cost of PDO crashes.

Table 34 Cost of Injury Crashes by Country

Country	Cost of a Traffic Injury	
	2012 USD	2012 local currency
Mexico	31,876	419,775 (MXN)
Colombia	19,648	35,305,491 (COP)
Turkey	52,948	94,551 (TL)
India	4,484	239,611 (INR)

Table 35 Estimated Cost of a Property Damage Only (PDO) Crash

Country	Cost of a Traffic Injury	
	2012 USD	2012 local currency
Mexico	689	9080 (MXN)
Colombia	426	765,860 (COP)
Turkey	790	1,411 (TL)
India	97	5198 (INR)

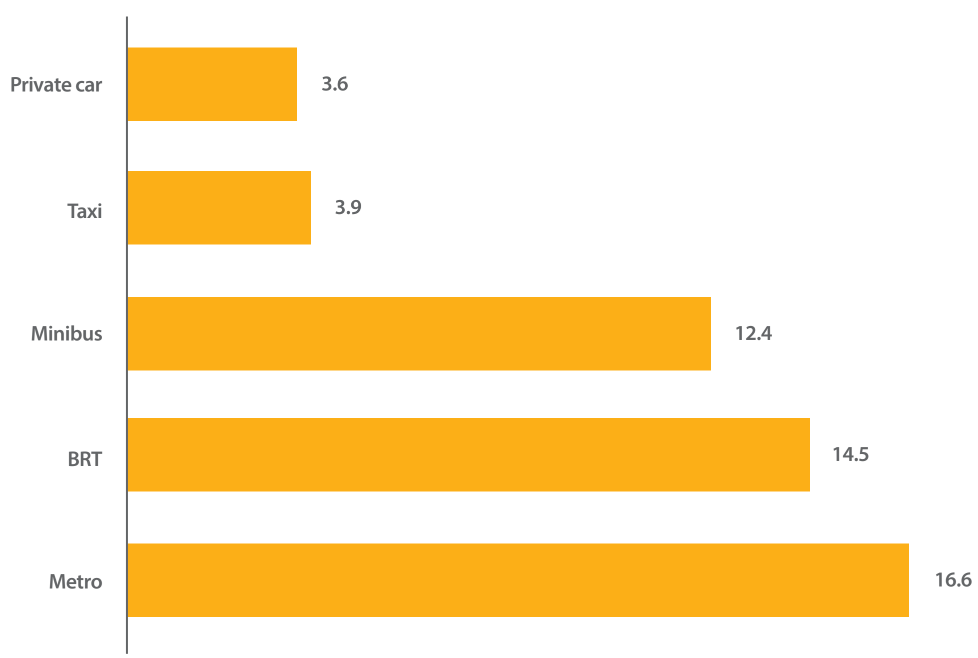
13.1.3 ESTIMATING PHYSICAL ACTIVITY IMPACTS

Estimating the change in physical activity levels for BRT passengers that is attributable to the BRT is subject to some uncertainty, since we do not currently have data on walking levels for BRT passengers before and after BRT implementation. Instead, we have before and after data on mode of transport, and a cross-sectional dataset of walking minutes per trip by mode from a household survey. The second component involves estimating the health benefits from increased walking and assigning an economic value to the number of premature deaths avoided. This is done using the World Health Organization's Health and Economic Assessment Tool (HEAT) model and by applying VSL estimates consistent with estimates used for the road safety component.

Using data on mode shift together with the walking time associated with each transport mode, it is possible to develop estimates on the overall change in walking time per trip for BRT passengers after the implementation of the BRT. We again mention here the caveat that the data on walking time by mode is cross-sectional, and therefore we cannot prove that BRT contributed to increases in walking; rather, we can point out that the evidence suggests an increase in walking, but one that would need to be confirmed with before and after data for more robust results.

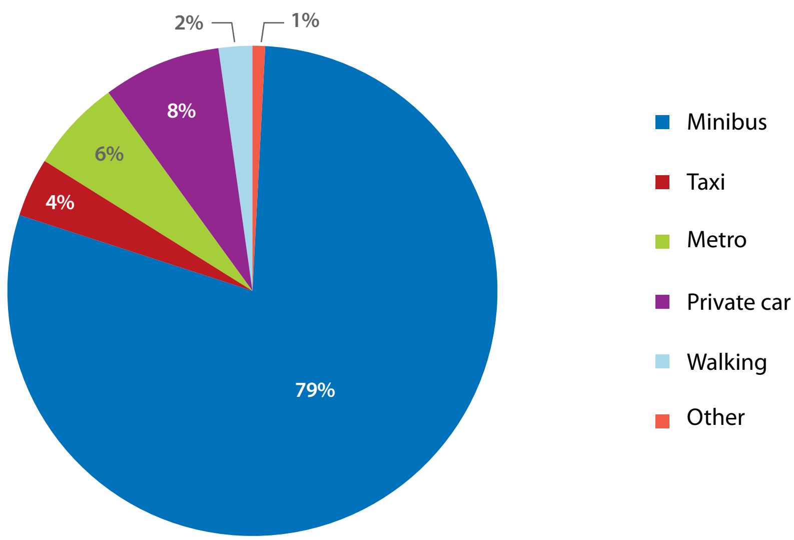
There is a strong correlation between a person's mode of transport (e.g., personal car, taxi, bus, Metro) and their level of physical activity (Mexico City Household Travel survey 2007). This has to do with the characteristics of each travel mode. A trip in a personal car should be expected to have the lowest level of physical activity of all transport modes, since cars provide point to point transportation with minimum amounts of walking involved. A taxi trip might involve slightly more walking, especially if the passenger must walk on the street to hail a cab. Transit modes in general should involve a higher amount of physical activity, since passengers must walk to and from stations. The amount of walking should be closely correlated with the average distance between stations, meaning that Metro passengers should walk, on average, more than BRT passengers, who in turn should walk more than bus or minibus passengers. Naturally, pedestrians and cyclists should have the highest levels of physical activity. These hypotheses are confirmed by data from Mexico City's 2007 household travel survey. Survey respondents reported minutes of walking at the end of each trip, which can be compared against their mode of transport. As Figure 27 shows, BRT is one of the motorized transport modes with the highest amount of physical activity involved, second only to the Metro.

Figure 27 Average Minutes of Walking Per Day for Transportation for Mexico City Residents, by Transport Mode Used



Source: Mexico City 2007 household travel survey

Figure 28 Main Mode of Transport Previously Used by BRT Passengers in Mexico City Before the BRT Became Available



Source: 2006 and 2007 Metrobus passenger surveys, EMBARQ Mexico

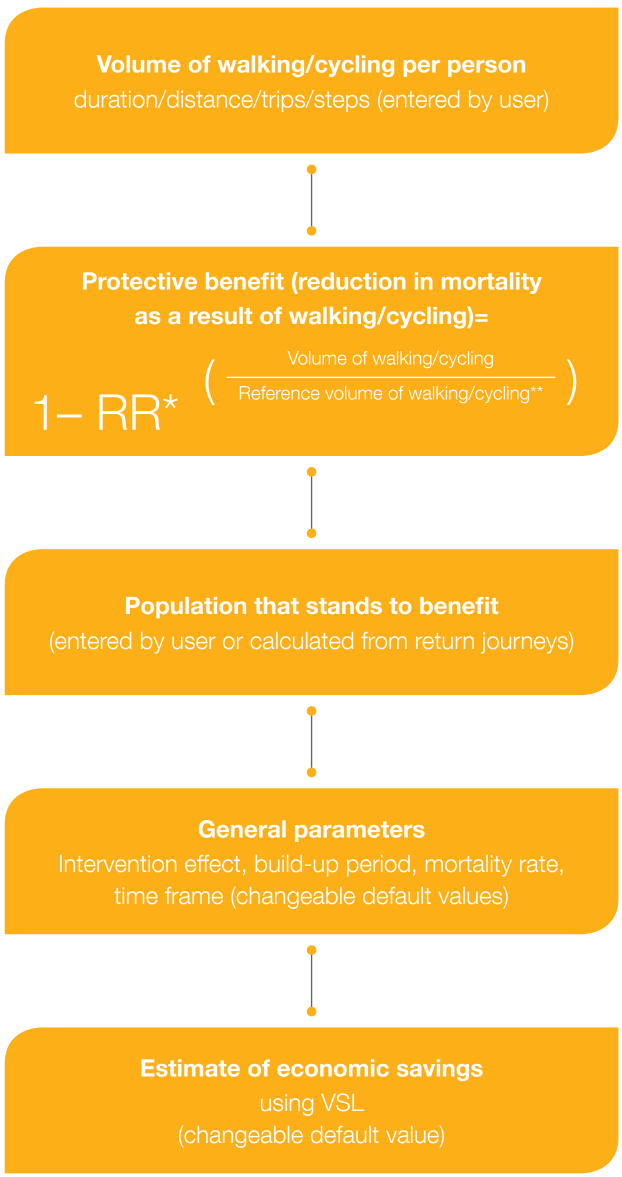
The survey results show that the majority of BRT passengers in Mexico City had previously used minibuses. Known in Mexico City as "colectivos," these are privately operated minibuses operating under concession from the city government and assigned to specific routes. They are the predominant mode of transport in Mexico City, accounting for over 45 percent of trips in 2007, according to the Mexico City household travel survey. In addition, a small percentage of passengers had switched from other modes, including private cars and Metro. In Beijing, the largest shift to the BRT occurred from regular city buses, with some passengers also switching from Metro and private vehicles.

In Mexico City the greatest health benefits accrued to those switching from private cars (the most sedentary mode according to the survey) to the BRT. We estimate that of all the people riding the Metrobus BRT in Mexico City on a given day, around 50,000 had previously relied on a private car for the same trip. We estimate that that after switching to the BRT, these people walk an additional 11 minutes every day. According to the results of the HEAT tool, this increase in walking has resulted in avoiding 21.3 premature deaths per year in this population. Conversely, the estimated 9,400 people who now ride the Metrobus BRT instead of walking have lost about 3 minutes of physical activity per day, which resulted in an additional 0.97 premature deaths per year. Overall, however, the majority of the shift to BRT occurs from more sedentary modes, and overall, the Metrobus system is estimated to help avoid 65.7 premature deaths per year from the increase in physical activity.

We can then use the data on changes in walking levels to run WHO's HEAT model and evaluate changes in health outcomes for BRT passengers and their associated economic value. We used data on daily passengers for each BRT to convert the percentage mode shift to absolute numbers. It is important here to mention the distinction between daily passenger trips (the most common metric for reporting BRT ridership) and individual passengers using the BRT, often multiple times in a day (the more relevant metric for health assessments). Only the former is reported by BRT agencies, and in order to convert passenger trips to passengers, we used data from local household surveys on the average number of daily trips taken by BRT passengers.

We provide here a brief overview of the methodology behind the HEAT tool, which is described in more detail in Kahlmeier et. al. (2011). The basic functioning of the HEAT tool for estimating benefits from physical activity is illustrated in Figure 29.

Figure 29 The Basic Functioning of the HEAT Tool



*RR= releative risk of death in underlying studies (walking: 0.78 *(21)*; cycling: 0.72 *(23)*).

**= Volume pf cycling per person calculated based on 3 hours/week for an estimated 36 weeks/year at an estimated speed of 14 km/hour in Copenhagen. Volume of walking based on 29 minutes/day at 4.8 km/hour.

Source: Kahlmeier ***et. al.*** 2011

We applied the HEAT tool for each for each type of mode shift (i.e., from bus to BRT, from car to BRT, etc.) and estimated the health impact for each subgroup of our population.

13.1.3.1 ESTIMATING THE ECONOMIC BENEFITS FROM INCREASED PHYSICAL ACTIVITY

The HEAT tool assigns an economic value to the premature deaths avoided by applying the concept of value of a statistical life (VSL). The methodology used for developing VSL estimates is described in detail in section 0 (Estimating the economic benefits from safety improvements).

13.1.4 DISTRIBUTIONAL ANALYSIS METHODOLOGY

In order to estimate the distribution of costs and benefits across different income groups or socioeconomic strata, we first calculate the total project costs per year and the total project benefits per year using standard CBA methodologies. Next, we disaggregate the indicators used in the CBA (NPV, and benefit-cost ratio) to assess the costs and benefits across the distribution of income strata.

In this analysis, we follow the method of expanding the CBA with a series of indicators to analyze socioeconomic distribution of costs and benefits by

Table 36 Main Assumptions and Parameters for the TransMilenio Evaluation

Component	Value in 2012 COP	Value in 2012 USD	Units	Comments
Infrastructure investment	$25,987 $46,179	$14 $26	Millions per km	Phase I (1) Phase II (1)
Infrastructure rehabilitation	50% of initial investment	50% of initial investment		Year 11 (2)
Investment in buses	$589 $198	$0.328 $0.110	Millions per unit	Articulated (1) feeder (1)
Replacement of buses	100% of initial investment	100% of initial investment		Year 10 (2)
Operation of trunk buses	$2,293	$1	Pesos per km	Average, 2002–2008 (1)
Operation of feeder buses	$109.03	$0.061	Millions per bus/year	(1)
Value for travel time	$2,667.03	$1.48	Per trip hour	Based on income (2)
Losses during construction	50% time savings	50% time savings		(2)
Impacts on accidents and health	$2,126,320,464 $30,167,509 $3,340,099 $116,238,852 $39,691 $42,526	$1,183,327 $16,789 $1,859 $64,689 $22 $24	Death Injury Accident Chronic bronchitis Restricted activity/day lost day	Value of a statistical life; uninsured accidents; health equivalent in Mexico (2)

Source: (1) TransMilenio S.A., (2) Assumed value.   Supporting tables and explanations for the assessments are included in the Appendix.

quintiles for each year for a series of years out into the future and discount them, similar to standard CBA. We then allocate these discounted costs and/or benefits by income quintiles or a similar socioeconomic category to get a net present value of benefits minus costs as well as benefit-cost ratios by category. Typically this is done through a matrix that weights variables and allocates both costs and benefits across the socioeconomic groups utilized. Project costs are typically distributed based on which income strata contribute to public revenue (i.e. taxes) or private costs. Benefits are distributed based on which portion of the population the benefits accrue to – (i.e. BRT users, city population).

13.2 Appendix B – TransMilenio Case Study: Data, Assumptions, Analysis

This analysis of Phases I and II of Bogota's TransMilenio was conducted ex-post implementation, building on the ex-ante analysis included in the project finance documents. The data and information comes from TransMilenio S.A. and from secondary sources, with the original modeling underlying our analysis done by Steer Davies Gleave.

Table 37 Sources of Information and Assumptions Made in Calculating TransMilenio Cost Flows

	1998–2008	2009–2018
PUBLIC COSTS		
Studies and project preparation costs	TMSA	No additional costs considered
Real estate purchase and resettlement		
Infrastructure construction and/or rehabilitation	Total amount provided by TMSA distributed among 1999-2001 for Phase I and 2003-2006 for Phase II	Construction rehabilitation in year 11 equal to 50% of initial investment. Remaining value based on 11-year service life of rehabilitation
Infrastructure maintenance	Cumulative amount provided by TMSA distributed between 2002 and 2008 for Phase I and between 2007 and 2008 for Phase II	Maintenance value remains steady until 2018, not included in years where there is rehabilitation
Implementation of control center	TMSA	Reinvestment in year 10 of operation equal to 50% of initial cost. Remaining value based on service life of 10 years
Control center operation	TMSA	Increase proportional to growth in demand
Costs of the public project management agency	District Secretary of the Treasury Operational budget committed as of December of each year	Increase proportional to growth in demand

13.2.1 TRANSMILENIO COST-BENEFIT ANALYSIS MAIN ASSUMPTIONS

The assessment was made for the 20-year term 1998–2017 and uses a social discount rate of 12 percent, the rate used by the government of Colombia, as suggested by the National Planning Department.

13.2.2 TRANSMILENIO PROJECT COST ANALYSIS

The sources and assumptions used for the TransMilenio cost analysis are presented in Table 37.

Cost estimates include reported costs for 1998 through 2008 and forecasts for 2009–2018. The cost of infrastructure rehabilitation is most significant (50 percent of construction costs), followed by the replacement of vehicles and other equipment in year 10 of operation. Flows include salvage prices for infrastructure and equipment, calculated according to the remaining service life of the investments.

Public costs represent 61 percent of the project's total cost, of which construction and infrastructure rehabilitation are the most significant (47 percent). Private costs represent 39 percent, of which fleet operation (20 percent) and fleet acquisition (12 percent) are the most significant.

13.2.3 TRANSMILENIO PROJECT BENEFITS ANALYSIS

Benefits identified for mass transit system users and non-users:

	1998–2008	2009–2018
PRIVATE COSTS		
Bus fleet acquisition	TMSA	Replacement of fleet in year 10 and increase proportional to growth in demand Implicit price per bus from TMSA information. Remaining value based on service life of 10 years
Bus fleet operation		Increase in kilometers of route proportional to growth in demand Gradual reduction in PKI. Implicit price per kilometer (trunk) and per bus (feeder) from TMSA information.
	1998 – 2008	2009 – 2018
		Increase in kilometers of route proportional to growth in demand Gradual reduction in PKI. Implicit price per kilometer (trunk) and per bus (feeder) from TMSA information.
Implementation of collection system		Replacement in year 10 equal to 50% of initial cost. Remaining value based on service life of 10 years
Collection system operation		Increase proportional to growth in demand

Source: Prepared by EMBARQ

- Mass transit user travel time savings;
- Travel time losses during construction;
- Mass transit fleet operation savings;
- Savings due to accident reduction;
- Savings due to local pollution;
- Savings due to avoided greenhouse gas emissions.

Savings are calculated comparing the current situation under the project versus the hypothetical situation without the project. This evaluation does not take into account benefits to overall traffic due to reduced congestion in mixed lanes. We now turn to each of these benefits, in turn.

Transit user travel time savings: These are the result of changes in trip speeds and station access times. Travel times are calculated using transportation modeling, in which the origin-destination matrix (ODM) is assigned to the mass transit network. Modeling is performed for the peak hour. For the purposes of weighting travel time savings, a single economic value for travel time is suggested for all users in order to avoid creating bias. Empirically, it is noted that travel time value is related to income: the higher the income, the greater the subjective value of travel time. However, the distinction due to income level creates a preference for projects that benefit higher-income social sectors versus progressive projects that benefit middle- and low-income sectors. Thus we use the average value for travel time for the population be used, resulting from an approximation via labor compensation. This assessment assumed that total mass transit demand remains equal in the with-project and without-project scenarios.

Travel time losses during construction: Construction and/or rehabilitation projects create travel time losses. A 50 percent increase in travel times is assumed during construction, versus the no-project scenario for passengers in the project corridor.

Mass transit vehicle operation cost savings: The project assumes the retiring of colectivo vehicles. The elimination of vehicles generates a savings in operating costs. To do the calculation, a total travel distance of 61,295 km per year per vehicle was estimated (205 km per day, 299 days a year) with an operating cost per kilometer of $1,426.68. This value is produced by adjusting the economic cost per kilometer estimated by the Secretary of Transit and Transportation (2006) for the purpose of calculating *colectivo* fares.[13]

Savings due to reduced accidents: Improvements to road geometry and signalization, the separation of traffic flows, and the greater presence of traffic control personnel, along with new management mechanisms that eliminate competition for passengers on the roadway, all lead to a reduction in the number of accidents. The scenario without the project incorporates the trend toward reduced traffic fatalities independent of TransMilenio's implementation. The average annual reduction was 8.2 percent.

Supporting Data on Benefits

Travel time savings are estimated from a peak hour transport demand model that analyzes travel times with and without the project.

Savings during the off-peak period are assumed to be 50% of the savings in the peak period. By 2008 these savings reach 887,000 hours per year and by 2018 they reach 1,987,000 hours. The monetary value of time is estimated using the following equation:

$$CTV = \frac{RSM * SM * ESO * PTUA}{HET}$$

Where CTV = monetary value of time per passenger (COP/passenger-hour)

RSM = Average income as a factor of daily minimum wage

SM = Minimum wage (COP/day)

ESO = Work benefits factor (includes paid time-off, severance, payroll taxes)

PTUA = Portion of time used for non-work purposes

HET = Hours effectively worked per day

This results in a value of time of $2,667.03 per trip hour

Estimated operations savings due to the retirement of fleet vehicles between 2001 and 2008 were based on data from the secretary of Mobility. For 2009 through 2018, the additional TransMilenio fleet requirements were estimated according to organic growth in demand and *colectivo* bus-equivalents that will be retired from service.

Savings from reduced pollution and greenhouse gas emissions

Calculations of reductions in emissions of CO2eq, particulate matter, mono-nitrogen oxides and sulfur dioxide are based on expected levels of travel demand. Data for 2006 to 2012 are obtained directly from the Clean Development Mechanism project document prepared by Grutter Consulting. Data for 2001–2005 and 2013–2018 are estimated using the observed gradual downward trend over time. The reduction is the result of technological improvements to the overall transit fleet (buses, mini-buses, micro-buses, taxis, and private vehicles) and changes in fuel quality. The inferred values were multiplied by observed demand (2001–2008) and projected demand (2009–2018).

In this case, we used the analysis conducted for the Metrobús Project in Mexico City, prepared by the National Ecology Institute (INE 2008). An approximation is made using the calibration of regression equations that relate the level of contaminants emitted to health impacts.

The transformation factors, obtained via regression models, are shown in Table 6 below. The variation in cases of death is very small, meaning it is not possible to calibrate a model. A 1:4,803 ratio of deaths per bronchitis cases is used (average for observation period, with standard deviation of 0.55).

These health effects models were applied to emissions reductions estimated for TransMilenio Phases I and II. To create a conservative estimate and to consider variations in exposure conditions between Mexico City and Bogota, a 50 percent reduction factor was applied to the impacts. This was used to estimate deaths prevented, cases of bronchitis prevented, days of restricted activity avoided and work days avoided.

Table 6 Synthetic Models of Effects on Public Health Due to Emissions From Mexico City Metrobus – Coefficients with T Statistics

Dependent Variable	PM	NOx	SO2
Bronchitis Cases (R2: 0,999)	0.1299 (1,066)	0.01817 (35.28)	
Days of Restricted Activity (R2: 0.99997)	26,848 (9.733)	2.849 (3.341)	9.424 (2.913)
Work Days Lost (R2: 0.99997)	294.51 (11.0138)	8.06230 (108.40)	94.142 (3.002)

Source: EMBARQ estimates

To estimate economic effects, the value of a statistical life was set at 2.1 billion pesos, the value of bronchitis at 113 million, and values for days of restricted activity and lost workdays at 38,857 pesos/day and 41,633 pesos/day, respectively (amounts in 2012 pesos). These values are based on those used by INE in Mexico City.

The estimation of benefits due to reduced greenhouse gas emissions is the same methodology used for the other case studies and are discounted to present value at a rate of 1.4%.[14] The amounts received for these arrangements are small compared to estimated benefits.[15]

The value for benefits from prevented traffic accident fatalities is estimated based on values obtained in Chile (Bowland and Beghin 1998), Mexico (INE 2008), and from the World Bank (Project Appraisal Document 2004) and shown in Table 39.

Table 39 Economic Values of Traffic Accidents in Several Countries

Chile	519,000–675,000	$PPP 1992
Mexico	750,000	(2005)
Chile	793,495–1,032,002	(2008)
Mexico adjusted PPP	960,176	(2008)
Average, Chile and Mexico	936,462	(2008)
2008 exchange rate	1,923	COP/US$
Value of a statistical life	1,800,817,119	(2008)
Injured in traffic accident	13,286	(2008)
	25,549,379	(2008)
Simple collisions	1,329	(2008)
	2,828,787	(2008)

Source: Chile: Bowland and Beghin, 1998; MEXICO INE, 2008; Injuries and simple collisions: World Bank, 2004.

13.2.4 TRANSMILENIO SENSITIVITY ANALYSIS

To test the robustness of the analysis, a sensitivity analysis with changes in certain assumptions was undertaken. This analysis indicates that the project is robust: The net present value generally remains positive even in the face of significant changes in input values (Table 40). The greatest changes are seen in benefits from changes in the value of time or in travel time savings.

To further test the robustness of our analysis via another approach, we compare our analysis with that of others. The ex-post facto evaluation in this study has a benefit-cost ratio comparable to that of others as seen in Table 41. The ex post facto internal rate of return (IRR) is much lower than that originally calculated (mainly due to higher initial costs) and it is comparable to the results of the World Bank evaluations. The evaluations compiled in this table include those made for decision-making purposes (CONPES 2000 and World Bank Credit Transactions 2003, and 2004) and student exercises (Hidalgo and Illera 2001; Chaparro 2002; Echeverri, Ibáñez and Hillón 2004; and Ardila 2005).

The results of the evaluations are generally favorable: they have positive present values at a 12 percent annual discount rate, benefit-cost ratios greater than one, and internal rates of return greater than 12 percent. The evaluations are not directly comparable, because they all use differing physical scopes and disparate time horizons. In addition, the estimation assumptions for benefits are different (components incorporated, parameters such as the value of riders' time, valuation of accidents, and health impacts,

Table 40 Results of TransMilenio Sensitivity Analysis

	Net Present Value (COP million 2012)	Net Present Value (USD million 2012)	Change	B/C	IRR
Base scenario	2,515,526	1,400		1.59	23%
Salvage value equal to zero	2,429,157	1,352	-3.4%	1.56	23%
50% lower travel time value	951,744	530	-62.2%	1.22	17%
Losses during construction equal to 100% of time savings in first year	2,416,422	1,345	-3.9%	1.57	23%
Transit time savings 50% lower	1,263,558	703	-49.8%	1.30	18%
Value of a statistical life 50% lower	2,223,870	1,238	-11.6%	1.52	21%
Health and accident benefits equal to zero	1,585,628	882	-32.6%	1.37	19%
CO2 emissions reduction benefit equal to zero	2,401,727	1,337	-4.5%	1.57	24%
CO2 discount rate adjusted to 5%	2,351,476	1,309	-6.5%	1.55	22%

etc.). Among the seven available evaluations, only one has indicators of negative profitability (Echeverri, Ibáñez, and Hillón 2005). Ardila (2005) has criticized that analysis, noting methodological errors and faulty information sources.

13.2.5 TRANSMILENIO DISTRIBUTIONAL ANALYSIS ASSUMPTIONS

The distributions shown in Table 42 are the basis upon which our matrix is developed to allocate the costs and benefits across socioeconomic categories. In this case, the six Colombian socioeconomic categories are used, with weights assigned to each cost or benefit variable. This report utilized available data from Colombia where available, and where unavailable, used data available from similar countries. The matrices used are found below, and show costs being absorbed by the upper income groups who typically bear more of the burden of taxes, with benefits spread more broadly across income strata, except for those dealing with ownership of vehicles or firms running vehicles. Data from a user survey from 2008-2009 and a broader mobility survey from 2011 were used to understand the socio-economic characteristics of TransMilenio users.

Table 41 Compilation of Socioeconomic Evaluations of the TransMilenio System

Evaluation	NPV (12%) US$ Millions (year)	Benefit/ Cost Ratio	Internal Rate of Return	Scope/ Horizon
CONPES Document 3093 TransMilenio (2000)	1,495 (1998)	2.45	61.1%	24 trunk, 384 km 32 years Ex Ante
Hidalgo and Illera, Universidad de los Andes (2001)	632.36 (2001)	5.42	67.4%	42 km – Phase I 10 years Ex Post Facto
Chaparro, CEPAL (2002)	944.73 (2001)	2.84	60.3%	42 km – Phase I 10 years Ex Post Facto
Bogota Urban Services Project, World Bank (2003)	122.30 (2002)	1.37	24.7%	10.3 km – Avenida Suba 10 years Ex Ante
Integrated Mass Transit Systems, World Bank (2004)	163.74 (2003)	1.45	21.4%	19.3 km – NQS 10 years Ex Ante
Echeverri, Ibañez, Illón, Universidad de los Andes (2004)	-51.04 (2002)	-2.17	Not available	42 km – Phase I 15 years Ex Post Facto
Ardila, Universidad de los Andes (2005)	4,754 (2002)	2.40	Not available	42 km – Phase I 15 years Ex Post Facto

Table 42 Distribution of TransMilenio Costs and Benefits Across Income Strata

COSTS - Distribution Variables	Income Stratum				
	1	2	3	4	5 and 6
Infrastructure	0.05	0.10	0.15	0.20	0.50
Maintenance	0.05	0.10	0.15	0.20	0.50
Bus costs	0.05	0.10	0.15	0.20	0.50
Operating costs	0.20	0.20	0.20	0.20	0.20

BENEFITS - Distribution Variables	Income Stratum				
	1	2	3	4	5 and 6
Time travel savings	0.07	0.40	0.39	0.12	0.02
COV cost savings	0.03	0.05	0.12	0.30	0.50
Neg time savings - Public transit	0.07	0.40	0.39	0.12	0.02
Neg time savings - Private vehicles	0.06	0.11	0.14	0.20	0.49
Reduced emissions-health	0.25	0.25	0.20	0.15	0.15
Benefits from physical activity	0.07	0.40	0.39	0.12	0.02
Reduced emissions-greenhouse gases	0.20	0.20	0.20	0.20	0.20
Fewer accidents	0.30	0.30	0.20	0.10	0.10

13.3 Appendix C - Metrobús Line 3 Case Study: Data, Assumptions, Analysis

13.3.1 Metrobús Main Assumptions

Table 43 Mexico City BRT Metrobús Line 3 Evaluation Main Assumptions

Project scope	Metrobús Line 3
Time horizon	2009 – 2028
Useful life of infrastructure (buses, busways, stations)	15 years
Project Construction Time	1 year
Daily Demand	123.293 passengers/day
Annual Rate of Demand Growth	5%
Passengers' Value of Time	19.29 MXN/hour

13.3.2 Metrobús Cost Assumptions

Table 44 Sources of Information and Assumptions Used in Calculating Metrobús Costs

Operational & Maintenance Costs	
Bus Operating Costs	Operating cost per vehicle-km is 15.39 pesos and the operation of the older microbuses and older buses was $8.89/km and $13.28/km. It assumes that each one of the 54 articulated bus runs 239 km and that it works 293 days/year. Source: Metrobus.
Infrastructure maintenance	Assumes 30,000 MXN/km maintenance every year, 100,000 MXN/km maintenance every four years, 350,000 MXN/km every 8 years and full reconstruction of 15 million MXN/km R184 million annual contract cost.
Station and fare-collection maintenance	Include 25.3 million MXN/year for maintenance (Source: Metrobus)
Operational & Maintenance Costs	
Project planning and communication	Information provided by Metrobus. Approximately 13 million MXN
Infrastructure construction	Information provided by Metrobus. Approximately 1.415 million MXN
Information and fare collection system	121.4 MXN million. Source: Metrobus
BRT bus procurement	54 articulated buses bought for a total of 324.5 million MXN (Source: Metrobus)

13.3.3 METROBÚS BENEFIT ASSUMPTIONS

The forecast number of microbus and traditional bus trips are all allocated to the new Metrobús line, with its costs and benefits, so that Metrobús completely substitutes existing microbus and traditional bus trips and expenses.

Travel time savings from shorter travel times (despite longer waiting and station access times) represent one benefit captured and quantified. Lower operating costs, lower climate change costs, and improved health from lower pollution and fewer accidents are other benefits captured and quantified. Benefits from lower greenhouse gas emissions are monetized using the same methodology for the other case studies, and discounted to present value at a rate of 1.4 percent. Costs include infrastructure costs, acquisition of new bus fleets, and maintenance. The flows associated with both costs and benefits are projected over twenty years and then discounted back to yield a net present value.

13.3.3.1 METROBÚS PUBLIC HEALTH IMPACTS ANALYSIS AND ASSUMPTIONS

Analysis of the health benefits of Metrobús Line 3 assumed similar health benefits as INE reported for Line 1. An economic value was assigned to these health benefits, consistent with the methodology used in Section 4.3 Public Health Impacts (see Table 45).

The majority of BRT passengers in Mexico City's Metrobus system had switched from minibuses (79%), followed by private cars and taxis (12%), and Metro (7%). Any benefits in terms of air quality would be realized when trips on more polluting modes are replaced with trips on less polluting modes, either because a person chooses, for example, BRT instead of the private car, thus eliminating a trip on a more polluting vehicle, or because a specific mode is eliminated from the corridor altogether (e.g. minibuses). The majority of monetized health benefits are associated with reductions in fine particulate

Table 45 Health and Economic Impacts of Metrobús Line 1 Resulting From Improvements in Local Air Quality

Type of negative health outcome	Number avoided per year*	Economic value (2012 USD)**	
		Total	Per km
Premature deaths	2.54	2,148,275	71,600
Cases of chronic bronchitis	12.18	566,601	18,886
Work loss days	6,118	182,118	6,070
Total benefits		**2,896,994**	**96,566**

**Source:* computed from INE (2006)

** For premature deaths, this is estimated using VSL, calculated following the methodology outlined in section 0. For chronic bronchitis, we use the economic value per case reported in INE (2006) and we adjust to 2012 US dollars. For work loss days, we develop our own estimate using income data for Mexico matter ($PM_{2.5}$) and therefore the estimates in the INE study focus on the health benefits of reducing ambient $PM_{2.5}$ concentrations. The study assumed that changes in airborne $PM_{2.5}$ concentration are a function of changes in emissions of four pollutants: primary $PM_{2.5}$, nitrogen oxides (NO_X), hydrocarbons (HC), and sulfur dioxide (SO_2).

Using emission factors and estimated changes in mode share and traffic volumes, INE developed scenarios of emissions, comparing the Metrobus BRT scenario over 10 years in the future with a baseline scenario. The changes in total corridor level emissions by type of pollutant for the Metrobus scenario, as compared with the baseline scenario, are shown in Figure 30. The results clearly show that under the Metrobus scenario, emissions for all types of local pollutants were lower than in the baseline scenario. The health benefits associated with the reductions in emissions were estimated using concentration response functions from previous epidemiological studies linking ambient concentrations of PM2.5 to mortality or morbidity.

An approximation is made using the calibration of regression equations that relate the level of contaminants emitted to health impacts. The transformation factors, obtained via regression models, are shown in Table 46 below. The variation in cases of death is very small, meaning it is not possible to calibrate a model. A 1:4,803 ratio of deaths per bronchitis cases is used (average for observation period, with standard deviation of 0.55).

To estimate economic effects, the value of bronchitis was set at 640,290 pesos, and values for days of restricted activity and lost workdays at 219 pesos/day and 234 pesos/day, respectively (amounts in MXN 2012). These values are based on those used by INE in Mexico City.

13.3.4 METROBÚS SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to test the stability of the positive results in cost/benefit ratio and IRR. The results are relatively stable, and the benefit-cost ratio always remains larger than 1 even if the health and road safety benefits are set to zero or if greenhouse gas emissions reductions are not included.

Table 46 Synthetic Models of Effects on Public Health Due to Emissions From Mexico City Metrobus – Coefficients with T Statistics

Evaluation	NPV (12%) US$ Millions (year)	Benefit/ Cost Ratio	Internal Rate of Return
Bronchitis Cases (R2: 0,999)	0.1299 (1,066)	0.01817 (35.28)	
Days of Restricted Activity (R2: 0.99997)	26,848 (9.733)	2.849 (3.341)	9.424 (2.913)
Work Days Lost (R2: 0.99997)	294.51 (11.0138)	8.06230 (108.40)	94.142 (3.002)

Source: EMBARQ estimates

Figure 30 Difference in PM2.5 and SO2 Emissions (Metric Tons) on the Line 3 Corridor Between the Baseline Scenario and the Metrobús Scenario

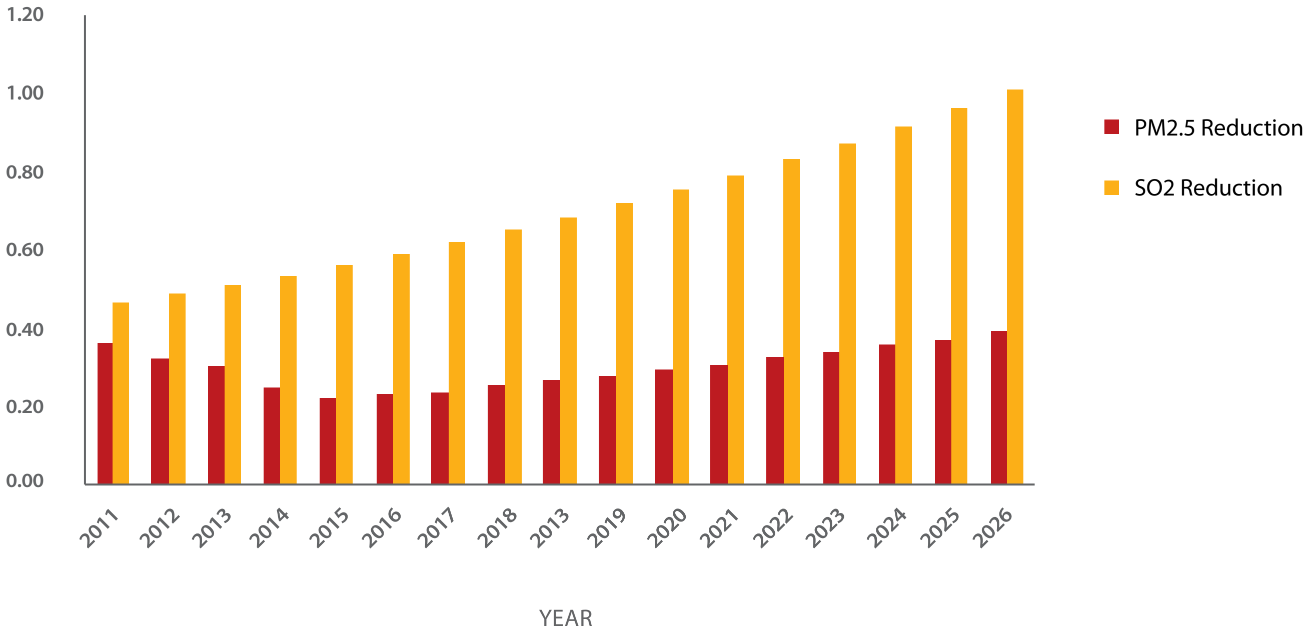


Table 47 Metrobús Sensitivity Analysis

	Net Present Value (MXN million 2012)	Net Present Value (USD million 2012)	Change	B/C	IRR
Base scenario	469.2	35.6		1.22	14%
Salvage value equal to zero	450.5	34.2	-4.0%	1.21	14%
50% lower travel time value	-373.6	-28.4	-179.6%	0.82	9%
Value of a statistical life 50% lower	410.4	31.2	-12.5%	1.20	14%
Health and accident benefits equal to zero	14.0	1.1	-97.0%	1.01	12%
CO_2eq emissions reduction equal to zero	402.1	30.5	-14.3%	1.19	14%
CO_2eq discount rate adjusted to 5%	448.6	34.1	-4.4%	1.19	14%
Social discount rate of 8%	1497.8	113.7	219.2%	1.72	14%

The model is highly sensitive to the discount rate. When a rate of 8 percent is used, it results in a net present value three times higher than the base scenario. It is also unstable when the value of travel time is reduce by half, yielding a benefit/cost ratio lower than 1 and a -180% change in the net present value. Travel time savings represent by far the majority of the project's benefits, so it is not surprising that the model is so sensitive to this value.

13.3.5 METROBÚS DISTRIBUTIONAL ANALYSIS ASSUMPTIONS

The distributions shown in are the basis upon which a matrix is developed to allocate the costs and benefits across socioeconomic categories. In this case, income quintiles are used, with weights assigned to each cost or benefit variable. Assignment of cost is based on the average tax burden for each income quintile, whereas benefits are assigned depending on what income quintile receives the benefits (i.e: Metrobus users receive the benefits in travel time reductions). This report utilized available data from Mexico either from official sources or from previous studies done by EMBARQ Mexico. The matrices used are found below, and show costs being absorbed by the upper income groups who typically bear more of the burden of taxes, with benefits spread more broadly across income strata, except for those dealing with ownership of vehicles or firms running vehicles.

Table 48 Distribution of Metrobús Costs and Benefits Across Income Strata

COSTS - Distribution Variables	Income Stratum				
	1	2	3	4	5
Infrastructure	0.05	0.10	0.15	0.20	0.50
Maintenance	0.05	0.10	0.15	0.20	0.50
Bus costs	0.05	0.10	0.15	0.20	0.50
Operating costs	0.05	0.10	0.15	0.20	0.50

BENEFITS - Distribution Variables	Income Stratum				
	1	2	3	4	5
Time travel savings	0.23	0.35	0.26	0.13	0.04
COV cost savings	0.00	0.36	0.19	0.11	0.35
Neg time savings - Public transit	0.23	0.35	0.26	0.13	0.04
Neg time savings - Private vehicles	0.06	0.11	0.14	0.20	0.49
Benefits from physical activity	0.23	0.35	0.26	0.13	0.04
Reduced emissions-climate change	0.20	0.20	0.20	0.20	0.20
Reduced emissions-health	0.25	0.25	0.20	0.15	0.15
Fewer accidents	0.30	0.30	0.20	0.10	0.10

13.4 Appendix D – Rea Vaya Phase 1A Case Study: Data, Assumptions, Analysis

13.4.1 Rea Vaya Analysis Main Assumptions

The analysis of Johannesburg's Rea Vaya BRT includes costs and benefits for Phase 1A which began initial operations in August 2009. Formal service under a bus operating contract with Piotrans, the company made up of former taxi owners, began February 2011. The analysis excludes specific costs and benefits associated with the 2010 FIFA World Cup event service, such as special event park and ride service to the stadiums. Since the regular BRT service was cancelled during the two-week World Cup, any user benefits and secondary benefits were not realized during that period. The cost-benefit analysis makes the simplifying assumption that the BRT service was not interrupted during the World Cup.

Like the other cases, the Johannesburg analysis considers a 20-year horizon, in this case from 2007-2026 inclusive. Specific assumptions relevant to Johannesburg include a 12-year useful life of infrastructure, and 5 percent annual inflation rate from 2014-2026 (compared to an average inflation rate of 6.6 percent between 2007 and2013).

13.4.2 REA VAYA COST ANALYSIS AND ASSUMPTIONS

Sources and assumptions used for the Rea Vaya cost calculations are presented in Table 50. Costs considered include planning, infrastructure construction and development, operations and maintenance. These costs were incurred by the City of Johannesburg (CoJ), national government, external funders (i.e. GEF, KfW), the private bus operating company and other contractors.

Table 49 Johannesburg BRT Impact Evaluation Main Assumptions

Project scope	Rea Vaya Phase 1A; excluding 2010 FIFA World Cup event-specific service
Time horizon	2007 – 2026
Useful life of infrastructure (buses, busways, stations)	12 years
2014-2026 estimated annual inflation rate	5%

Table 50 Sources of Information and Assumptions Used in Calculating Rea Vaya Costs

Planning Costs	
Staff and consultants	Grant award news (R20million KfW, USD$250k Clinton Foundation); National government contributed R5m and City of Johannesburg R4.3m; (CoJ 2010, 2011, 2012)
Probity firm	Costs reported in CoJ annual reports & financial statements (CoJ 2010, 2011, 2012)
Taxi Industry Negotiations: Taxi Steering Committee technical advisor, negotiation mediator, legal counsel and human/ material resources for taxi industry	Estimated from City's annual reports, financial statements (CoJ 2010, 2011, 2012). Costs declined after September 2010 signing of bus operation contract
Operational & Maintenance Costs	
Bus Operating Contract – Temporary operating company (Clidet)	2009-2011 cost estimated based on November 2009 monthly cost of service of R2.696 million and 12% annual monthly cost increase (CoJ 2013a). Temporary bus company ended when bus operating contract signed with Piotrans.
12-year Bus Operating Contract with Piotrans	R184 million annual contract cost (McCaul and Ntuli 2011). 28% profit margin (Seftel and Rikhotso 2013). Bus procurement costs total $43m (2009 USD), 3.2% over 11.5 years (Smith 2012). Contract cost assumed to increase with inflation in future years. For contract renewal in 2023, assumed 10% vehicle salvage rate; assumed city would negotiate lower profit margin of 10% as was done for Phase 1B (Seftel and Rikhotso 2013) and there would be less favorable vehicle procurement loan rates.
Station maintenance contract	Costs sourced from CoJ annual reports ((CoJ) 2010, 2011, 2012). Assumes annual contract cost increases with inflation.
Automatic fare-collection system operations & maintenance cost	
Voluntary Carbon Standard verification	2011 annual contract cost (CoJ 2012); assumes increases annually with inflation
Labor Costs	Assumes 2 full-time managers, 1 administrative staff as new positions created for project. Estimated salary and benefits cost based on staff labor + benefits in Johannesburg Development Authority (JDA) annual financial report (JDA 2010). Assumes annual increase with inflation
Capital Costs	
Busway construction	R83.7million per kilometer (JDA 2010, 2011, 2012)
Station construction	Approximately R14.6 million per station (JDA 2010, 2011, 2012)
Depot construction	R30.7 million for lease/construction of temporary depot; R150m for construction of permanent depot (JDA 2010, 2011, 2012)
Advance Traffic Management Control Center	Estimated R10 million cost
AFC	R210 million for equipment, installation and testing costs (CoJ 2010, 2011, 2012)
Taxi storage & scrapping	585 taxis scrapped or sold; national government paid owner R54k/taxi (McCaul and Ntuli 2011)
BRT bus procurement	Export credit agency bus fleet financing R43 million (2009) for 11.5yrs at 3.2% interest rate (Smith 2012). Annual payments made in 2009 and 2010 before Piotrans bus operating contract signed. After 2011, loan repayment included in bus operating contract fee.

13.4.2.1 PLANNING COST ESTIMATES

Planning costs include staff and consultants who completed early project modeling, design and planning. A probity advisor was brought in to oversee the project and reduce opportunities for corruption and abuse of authority.

The cost of engaging and negotiating with the affected taxi industry is included in the planning costs. Since the start of the project, the city committed to incorporating the taxi industry in the new BRT project as the new BRT operators, thus electing not to have a competitive bidding process for the bus operating contract (McCaul and Ntuli 2011). This negotiated contract process often takes longer and can result in higher costs for cities (Seftel and Rikhotso 2013), but ensures the objectives of inclusion and empowerment are met. In Johannesburg's case, significant time was spent defining which taxi owners were "affected by" the BRT and therefore would be included in the bus operating contract negotiations. A professional moderator was provided to guide the negotiations between the city and affected taxi owners, and the city provided legal counsel, human and technical resources for the taxi associations to ensure they could participate in the negotiations in an informed way. The cost of the taxi negotiations includes the city's costs but excludes costs to the individual taxi owners themselves, in terms of time or lost income, as this information was not available. City of Johannesburg annual reports for 2007-2012 provide the public cost details. The taxi negotiation costs are estimated at less than 1% of the present value of the project costs, but were critical to the success of the project, and the source of much delay.

Funding for these planning activities was provided by overseas development assistance as well as the National government (Allen 2011).

13.4.2.2 REA VAYA CAPITAL COST ESTIMATES

Capital costs considered include infrastructure (busways, stations, depots) construction, an advanced traffic control center, technology (automatic fare collection and passenger information systems) and bus procurement.

Construction of the 25.5 kilometer Phase 1A BRT corridor included road works, upgrading or replacing utilities, segregated lanes along much of the corridor and load-bearing concrete sections at stations and intersections. Phase 1A includes 30 glass and steel stations with automatic bus boarding doors, automatic fare collection, passenger information signage and station staff facilities. An existing bus depot was leased from a current citywide bus operator and converted to a temporary BRT depot while a new state of the art dedicated Rea Vaya deport was constructed. The Johannesburg Development Agency (JDA), the city's infrastructure development entity, oversaw the Phase 1A infrastructure construction. JDA's annual reports between 2007-2012 provided the detailed costs.

With the help of a private bank, Johannesburg arranged a favorable line of credit for the 41 articulated and 102 standard Rea Vaya buses through a Brazilian Export Credit Agency (BNDES) (McCaul 2009). The R43 million (2009 ZAR) loan had a 3.2 percent interest rate, lower than the prevailing national rates, and a repayment term of 11.5 years (Smith 2012). Once a formal bus operating company was formed and contracted, the bus procurement loan costs were included in the contracted fee per kilometer (McCaul and Ntuli 2011). For this analysis, it was assumed that the city was obligated to make two annual loan payments in 2009 and 2010 totaling R70 million. After 2010, the bus operating contract cost included the bus loan costs.

Finally, it was agreed that among the "affected taxi owners", 585 taxis would be removed from operation along the new BRT routes. These taxis would be sold or scrapped, and under an existing taxi recapitalization scheme the government would pay the owner R54,000 for each scrapped taxi. After relinquishing the taxi route permit for the scrapped vehicle, the "affected" taxi owner could purchase a share in Piotrans, the new taxi operator investment company (with whom the city would sign the BRT operating contract), for an R54,000 equity contribution (McCaul and Ntuli 2011). Since the taxi recapitalization would have occurred regardless of the Rea Vaya project, these costs are excluded from the cost-benefit analysis.

13.4.2.3 REA VAYA BUS OPERATING CONTRACT COST ESTIMATE

The 12-year bus operating contract between the city and Piotrans, the new taxi operator investment company, stipulates Johannesburg would set the number of bus kilometers the BRT service should operate and pay Piotrans an annually adjusted fee per kilometer based on actual input costs. The fee covers fuel, Piotrans staff wages and salaries according to the agreed upon company organogram, tires and spare parts, vehicle licenses, fleet insurance, bus loan payments and a 28 percent profit margin (McCaul, Ntuli, 2011; Seftel and Rikhotso 2013).

In 2011 the annual bus operating cost was R184million (McCaul and Ntuli 2011). Assuming an annual bus procurement loan payment of R35 million and a 28 percent profit margin, the cost of inputs (fuel, parts, uniforms etc) is estimated. It is assumed that the input costs increase annually with inflation.

For the bus operating contract renewal in 2023, it is assumed that the city will negotiate a lower profit margin as they have done for the Rea Vaya Phase 1B contract. Also, higher cost of buses and less favorable loan interest rates are assumed for the renewal.

13.4.2.4 REA VAYA OPERATIONAL & MAINTENANCE COST ESTIMATE

In addition to the bus operating contract cost, operational and maintenance costs for Phase 1A include station maintenance, automatic fare collection (AFC) system maintenance, voluntary carbon credit verification and the city's project staff labor. Actual annual costs for station maintenance (i.e. maintaining the sliding bus boarding doors) and AFC service and maintenance contracts are available in the City's annual financial reports. For future years, it was assumed these contracts would continue and their costs would increase with inflation.

Johannesburg contracts an agency to verify the carbon emissions reductions achieved by Rea Vaya as part of their Voluntary Carbon Standard carbon credit program. The annual cost of this contract is available in the city's annual report and was assumed to continue over the 10-year crediting period, increasing with inflation.

Finally, labor costs included in this analysis include only those marginal increases in labor resulting from the BRT project. Many of the city's Department of Transportation staff would have been employed by the city without a BRT project. Only the cost of staff whose positions would not have existed without Rea Vaya is included here. We estimate this to include a senior manager and administrative staff in the Department of Transportation's Rea Vaya project office and a senior development manager in the Johannesburg Development Agency. Annual salary and benefits rate are estimated from JDA annual financial reports. These positions are estimated to continue through 2026 and their salaries are projected to increase annually with inflation.

13.4.3 REA VAYA BENEFITS ANALYSIS AND ASSUMPTIONS

The sources and assumptions made for the Rea Vaya benefit calculations are presented in Table 50. Benefits considered include those accruing to BRT users, non-users on the corridor and city-wide residents including travel time and cost savings, vehicle ownership and operation cost savings, road safety improvements, health impacts and carbon emissions reductions.

13.4.3.1 TRAVEL TIME IMPACTS

Between 2007-2026, an estimated 73 million hours will be saved by BRT users shifting from other transport modes to BRT. The present value of this travel time savings is 2.7 billion Rand (2012 Rand). This savings is presumed due to the more organized Rea Vaya system, which not only removed 585 minibus taxis from informal operation along the corridor, but also provides the BRT buses a dedicated lane in which to operate away from mixed traffic.

Travel time increases for non-BRT users on the corridor are estimated as 734,000 hours as a result of reduced roadway capacity for non-BRT vehicles. The BRT segregated lanes replaced taxi-priority lanes along a portion of the corridor. This is a very rough estimate as detailed data on number of daily trips and travel times for non-BRT users on the corridor was not available. Total delays during Rea Vaya construction in 2008 and 2009 are estimated at 5.4 million hours.

Table 51 Sources of Information and Assumptions Used in Calculating Rea Vaya Benefits

Travel Time Impacts	
Travel Time Savings (BRT Users)	• 2010/11 Survey of BRT users in Orlando, Soweto found on average users saved 13 minutes per trip compared to their previous mode (Venter & Vaz 2011). • Annual passenger trips from Rea Vaya. Assume 313 days/year for public transport operations in South Africa. • Time saved per trip estimated to increase annually (comparedq to worsening congestion without BRT) by 3%. • Rea Vaya annual passengers estimated to increase 3% annually
Travel Time Savings (BRT Users)	• Estimated time lost to non-BRT users on the corridor equal to 1% of the travel time savings accruing to BRT users
Time lost during construction	• Estimate time lost to construction in 2008 and 2009 equal to the travel time savings of BRT users in 2011 (when passenger demand reached peak of 40,000 per day).
Value of Time	• Using household income and economically active population, estimated annual income of R116k (2011 Rand) of economically active population (Statistics South Africa 2012a) • •Assuming 177.3 working hours per month, estimate average hourly wage of R56 (2011). Use this as value of time saved. • Average hourly wage increases annually with inflation.
Vehicle Operation & Ownership Cost Impacts	
BRT users' car kilometers replaced by BRT	• 11% of Rea Vaya Phase 1A passengers shifted to BRT from car and previously their average car trip length was 18.6km (McCaul 2012). • Using annual passenger figures from Rea Vaya, and assuming 313 travel days per year, estimate BRT users' annual car km replaced by Rea Vaya. • 2009 average vehicle occupancy in Joburg 1.61 ((CoJ) 2013b) • Assumes 3% annual BRT passengers increase
Car ownership & operation cost savings	• R0.94/km (2013 Rand) for fuel cost and R0.35/km (2013 Rand) for maintenance (Deloitte 2013) • Fuel and maintenance cost/km increases annually with inflation
Scrapped taxis operation cost savings	• 585 taxis scrapped • R140k (2004 Rand) annual operating cost per taxi (City of Johannesburg 2004)
Road Safety Impacts	
Road Fatalities Avoided	• 1 fatality avoided/year/km estimated from EMBARQ's analysis of Guadalajara, Bogota, Ahmedabad, Mexico City and Melbourne
Value of Road Fatalities Avoided	• Using EMBARQ's methodology described in Section 13.1.2, the VSL for South Africa is set at R4.5 million (2009 Rand) • VSL increases annually with inflation
Traffic Injuries	• 3 injuries avoided per km per year estimated from EMBARQ's analysis of Guadalajara, Bogota, Ahmedabad, Mexico City and Melbourne
Value of Traffic Injuries Avoided	• Using EMBARQ's methodology described in Section 13.1.2, the average cost of injury is set at R23,914 • Cost per injury increases annually with inflation
Property damage-only (PDO)Crashes	• 6.8 PDO crashes avoided per km per year estimated from EMBARQ's analysis of Guadalajara, Bogota, Ahmedabad, Mexico City and Melbourne
Value of PDO crashes avoided	• R32,532 (2002 Rand) property damage per accident from SA National Department of Transport road safety study (de Beer and van Niekerk 2004) • Property damage increases annually with inflation.

Road Safety Impacts	
Increased Physical Activity	• Walk times by mode (Venter and Vaz 2011) • 14.47 annual premature deaths avoided (WHO Heat Model)
Value of reduced mortality from increased physical activity	• Using VSL of R4.5million per EMBARQ's methodology
Carbon Emission Impacts	
Annual CO_2 emissions reductions	• Average 19,798 annual CO2 reduction estimated as half of Phase 1A and 1B combined total reduction specified in Verified Carbon Standard project application indicates (Grütter 2011). • Although VCS has a 10-year crediting period from Jan 2012 through Dec 2021, analysis assumes same rate of emissions reductions for future years
Social value of emissions reductions	• Social cost of carbon $29 (2000 USD) (Stern 2007) • Increases annually with inflation • Discount rate of 1.4% (Greenspan Bell and Callan 2011)

13.4.3.2 VEHICLE OWNERSHIP AND MAINTENANCE COSTS

A 2010 BRT user survey revealed 11 percent of BRT users shifted from a car to BRT (McCaul 2012), resulting in from fewer vehicle kilometers travelled. On average these car trips were 18.6km and vehicle occupancy in Joburg averages 1.61 (McCaul 2012, (CoJ) 2013b). This results in 346 million car kilometers being replaced by BRT over the 20-year time horizon. Furthermore, there is an operational cost savings from the 585 scrapped taxis. Together the present value of the private car and taxi operational costs savings totals R1.4 billion (2012).

Changes in vehicle ownership and maintenance costs for the non-BRT users on the corridor have not been estimated.

13.4.3.3 ROAD SAFETY IMPACTS

Estimates for annual fatalities, injuries and PDO crashes avoided per kilometer of BRT are derived using EMBARQ's road safety methodology (see Section 4.3.1). Over the lifetime of the project, along the Rea Vaya BRT corridor, an estimated 459 road fatalities, 1,377 injuries and 3,121 property damage-only crashes will have been avoided. Over the 20-year time horizon 260 premature deaths are avoided from BRT users' increased physical activity after shifting to BRT from other modes. Valuation of these benefits also followed EMBARQ's methodology as described in 13.1.2.

13.4.3.4 GREENHOUSE GAS EMISSIONS REDUCTIONS

Johannesburg has registered the carbon reductions from Rea Vaya Phase 1A and 1B with the Verified Carbon Standard (VCS). The project documents indicate together Phase 1 A and 1B will reduce 398,292 tons of CO2 over the ten-year reporting period of January 2012-December 2021. This analysis attributes half of those emissions reductions to Phase 1A, or an annual average reduction of 19,914 tons. The methodology for estimating the carbon emissions reductions takes into account displaced taxis, user mode shift, reduced congestion on the corridor for other modes, improved BRT bus technology and leakage during construction.

13.4.4 REA VAYA SENSITIVITY ANALYSIS

The stability of the positive benefit-cost ratio was tested with a multi-dimensional sensitivity analysis.

The results are stable in most, but not all, scenarios. The benefit-cost ratio remains positive with an increase in annual ridership and bus operations input costs as well as with reductions in physical activity and road accident benefits. In addition, eliminating the CO2e emissions reductions benefit also has a minimal effect. Reducing the social discount rate from 12 to 8 percent which is recommended by the Government of South Africa, results in a 17 percent increase in the discounted net present value.

The results are most unstable when the value of time or value of statistical life are reduced by 50 percent which is expected since these constitute the majority of the project benefits.

Table 52 Rea Vaya Sensitivity Analysis Results

Sensitivity Scenario	Discounted NPV (millions ZAR 2012)	Discounted NPV (millions USD 2012)	NPV Change	Benefit/ Cost Ratio	IRR
Base scenario	R2,031	$247		1.33	15%
Annual ridership increase of 6% rather than 3%	R1,859	$226	-8%	1.30	14%
Bus operating contract input costs increase annually 10% (rather than keeping pace with inflation)	R644	R78	-68%	1.10	10%
50% lower value of time	R45	$5	-98%	1.01	9%
50% lower value of statistical life	R-432	$(53)	-121%	0.93	7%
50% reduction in fatalities avoided from physical activity	R590	$72	-71%	1.10	10%
Zero road accident benefits	R1,012	$123	-50%	1.16	12%
CO2e emissions reduction benefit equal to zero	R1,022	$124	-50%	1.18	12%
Social discount rate of 8%	R2,381	$290	17%	1.36	12%
5% discount rate of carbon	R1,140	$139	-44%	1.19	12%

Lower quintile	2nd quintile	3rd quintile	4th quintile	Upper quintile
Up to 4,543	4,544 – 9,886	9,887 – 21,002	21,003 – 57,099	>57,100

13.4.5 REA VAYA DISTRIBUTIONAL ANALYSIS ASSUMPTIONS

For the Johannesburg distributional analysis, per capita annual income quintiles were generated based on a 2010-2011 Income and Household Expenditure Survey published by Statistics South Africa (Statistics South Africa 2012b).

Costs were grouped according to the source of the funds: National Treasury, municipal revenue or Rea Vaya fare revenue and distributed across income quintiles based on data or assumptions about how each quintile contributed to the revenue source (See Table 53). Likewise, benefits were distributed across income quintiles according to whom the benefits accrue – either BRT users or the citywide population. As Table 54 illustrates, each quintile's contribution to revenue sources and representation of beneficiary groups were estimated. Using these percentages, the project costs and benefits were distributed across quintiles (see Table 55 and Table 56).

Table 53 Assumptions Used to Distribute Rea Vaya Costs

Sensitivity Scenario	Discounted NPV (millions ZAR 2012)	Discounted NPV (millions USD 2012)
National treasury	37% of total project costs. National gov't contributed approximately R2.5 billion to Phase 1A capital costs (Allen 2011) and committed to cover operational subsidies which are estimated at R50m per annum (Seftel and Rikhotso 2013)	According to quintile's contribution to national income tax. Individuals earning less than R 63,556 per year are not obligated to pay income tax
Municipal revenue	38% total project costs. Remaining capital, planning and operational costs	According to quintile's contribution to city property taxes.
Rea Vaya Fare Revenue	25% total costs. Annual fare revenue estimated ((CoJ) 2013a)	According to quintile's representation of Rea Vaya users.

Table 54 Factors Used to Distribute Rea Vaya Costs and Benefits by Quintile

	Lower quintile (<4544)	2nd quintile (4544 - 9886)	3rd quintile (9887 - 21002)	4th quintile (21003 - 57009)	Upper quintile (>57100)
Income tax revenue	0.00%	0.00%	0.00%	0.00%	100.00%
Johannesburg property rates contribution	2.93%	7.67%	20.10%	23.10%	46.20%
Johannesburg population	19.70%	4.40%	10.70%	22.20%	43.00%
Rea Vaya users (fare revenue)	4.25%	4.25%	13.00%	58.50%	20.00%

Table 55 Distribution of Type of Costs by Quintile

	Lower quintile (<4544)	**2nd quintile** (4544 - 9886)	**3rd quintile** (9887 - 21002)	**4th quintile** (21003 - 57009)	**Upper quintile** (>57100)
Nat'l treasury costs	R0	R0	R0	R0	R2290.52
City costs	R68.02	R178.05	R466.48	R536.21	R1072.42
Fare revenue	R65.33	R65.33	R199.84	R899.28	R307.45
Total Costs	**R133.35**	**R243.38**	**R666.32**	**R1435.49**	**R3670.38**

Table 56 Distribution of Benefits by Quintile

	Lower quintile (<4544)	**2nd quintile** (4544 - 9886)	**3rd quintile** (9887 - 21002)	**4th quintile** (21003 - 57009)	**Upper quintile** (>57100)
Travel Time Benefits	115.6	115.6	353.5	1590.8	543.9
CO_2eq benefits	29.4	6.6	16.0	33.1	64.2
Road safety benefits	93.7	93.7	286.6	1289.5	440.9
Vehicle operating cost reductions	59.4	59.4	181.8	818.3	279.8
Reduced mortality from increased physical activity	49.3	49.3	150.9	679.0	232.1
Time lost during construction	-61.6	-13.8	-33.4	-69.4	-134.4
Total Benefits	**285.9**	**310.8**	**955.3**	**4341.4**	**1426.4**

13.5 Appendix E – Metrobüs Case Study: Data, Assumptions, Analysis

13.5.1 METROBÜS MAIN ASSUMPTIONS

We follow the general assumptions detailed in the methodology section including a 20-year time horizon, 12% discount rate, and a GNI-adjusted VSL value. In addition, we assume a 5% inflation rate based on the Turkish government projection and a 5% cost of capital. We assume that buses are operational for 301.5 days a year based on 251 weekdays, 50% operation on weekends, and 13 public holidays. IMF deflation data is used to deflate benefits and costs, as in the other cases.

13.5.2 METROBÜS COST ESTIMATES

The sources and assumptions used for the Metrobüs cost calculations are presented in Table 57 and Table 58.

Table 57 Sources of Information and Assumptions Used in Calculating Metrobüs Cost Flows

Planning Costs	
In the absence of information from IETT regarding the planning of Metrobüs, we do not attribute additional planning costs to the project beyond those captured in the USD $9.08 million per km implementation and construction estimate.	
Operational & Maintenance Costs	
Operating costs (estimate based on secondary source with undefined parameters)	We utilize an estimate of USD $3.56 per km operating cost from Alpkokin and Ergun 2012 as the basis of our analysis. Operating costs are expanded as each phase was completed and the Metrobüs system expanded, up to its current distance of 51.3km. Operating costs increase with inflation (5% per annum) from 2013-2026. Metrobüs is operated by the Istanbul municipal government and is not by a contracted operating entity. Alpkokin and Ergun (2012) estimate that Metrobüs operating costs are slightly higher than conventional bus operating costs, but are covered by fare revenue.
Maintenance Costs	As part of the Metrobüs bus procurement deal, maintenance costs are included for first five years of bus operation. We assume a 10 year bus lifespan and apply additional maintenance costs of TL 1.28 per bus-km for the final five operational years based on average maintenance cost in U.S. adjusted to Turkey based on the GNI ratio from Sullivan (2013). Additional capital improvement investments are included over years 2017-2020 (see below). We did not have an estimate of additional maintenance cost for station maintenance beyond capital improvements.
Capital Costs	
Construction and Equipment Cost (based on a secondary source and assumed to include all initial implementation costs)	We assume construction and implementation costs of USD $9.08 million per km, as estimated by Yazici et. al.. (2013) and Hidalgo and Bulay (2008). Total construction and implementation costs are estimated to be $466 million for the 51.3 km system. We apply capital costs in the year prior to completion of a given phase based on the length of the Metrobüs system. No depreciation costs are included.
Rehabilitation costs	We assume capital investment of 50% of the construction and implementation costs over the 2017-2020 period, as was assumed in the Bogota case.
BRT bus procurement	Initial bus procurement is assumed to be included as part of the initial cost estimate. We assume an operation life of 10 years, requiring the buses to be replaced around year 2018. We assume that 400 new buses will be purchased at an average cost of USD $400,000 per bus over the 2018-2020 period, based on information collected by EMBARQ Turkey. We also examine a 50% increase in the price per bus to $600,000 in our sensitivity analysis.

13.5.3 METROBÜS BENEFITS ESTIMATES

The sources and assumptions made for the Metrobüs benefit calculations can be found below. Benefits considered include those accruing to BRT users, non-users on the corridor and city-wide residents including travel time and cost savings, vehicle ownership and operation cost savings, road safety improvements and carbon emissions reductions.

Table 58 Sources of Information and Assumptions Used in Calculating Metrobüs Benefits

Travel Time Impacts	
Daily passengers	A number of estimates are available for average daily passengers on Metrobüs, ranging from around 600,000 to over 800,000. After reviewing these estimates, we chose to use the most conservative estimate of 600,000. We assume no increase in ridership over the time horizon, as stations are currently at capacity.
Travel Time Savings	Istanbul's transit operating authority conducts annual passenger surveys. A detailed write up on the 2010/2011 survey's findings can be found in Yazici et. al.. (2013). IETT estimates that the average Metrobüs user saves 52 minutes per day in travel time savings. We assume an average number of two trips per day, or 26 minutes saved per trip.
Annual Work Days	For a number of calculations, it is necessary to assume an average number of operating days for Metrobüs. We assume that there are 251 workdays in a given year, 13 public holidays, and that Metrobüs operates at 50% during the weekends (consistent with the Metrobüs weekend operating schedule). As a result, the Metrobüs is assumed to be operational 301.5 days per year.
Value of Time	We base the value of time saved on the monthly income distribution information found in IETT's Metrobüs passenger survey. In 2011, 45% of passengers earned between TL 1,000-2,000. We weighted the income level by the proportion of respondent and found the median income for BRT users to be TL 1,810 per month or TL 21,725 per year. Wage increases with inflation.
Vehicle Operation & Ownership Cost Impacts	
BRT users' car kilometers replaced by BRT	Nine percent of Metrobüs passengers shifted to BRT from car and previously their average car trip length was 15km (Akplokin and Ergun, 2012). Using annual passenger figures from IETT (see above), and assuming 301.5 workdays per year, we estimate BRT users' annual car km replaced by Metrobüs and assume the same average vehicle occupancy as in Johannesburg: 1.69.
Car ownership & operation cost savings	We used the Rotary International estimate for fuel and maintenance compensation of TL 2.04 in 2012, adjusted for inflation.
Road Safety Impacts	
Road Fatalities Avoided	We estimate 30 road fatalities avoided per year based on initial EMBARQ road safety evaluations conducted in Istanbul.

Value of Road Fatalities Avoided	We use the same methodology used in the public health section to estimate the value of a statistical life from Esperato et. al.. (2012), which adjusted U.S. VSL by a GNI per capita ratio. We average income elasticity estimates to 1.25 and derive a VSL of TL 1.95 million. VSL increases with inflation.
Traffic Injuries	1.7 injuries avoided per km per year estimated from EMBARQ's analysis of Guadalajara, Bogota, Ahmedabad, Mexico City and Melbourne
Value of Traffic Injuries Avoided	We base the human cost per injury on Blincoe (2002)'s MAIS level 3 value, as is applied in the public health methodology. The 2002 USD is adjusted to 2012 and then converted to TL. The cost is TL 94,551 in 2012. The cost of injury increases with inflation.
Property damage-only (PDO)Crashes	12.19 PDO crashes avoided per km per year estimated from EMBARQ's analysis of Guadalajara, Bogota, Ahmedabad, Mexico City and Melbourne
Value of PDO crashes avoided	We estimate the value of a PDO crash based on Blincoe (2002) and adjust to 2012 TL as in the value of traffic injuries avoided. The cost is TL 1,411 in 2012 and adjusted with inflation.
Carbon Emission Impacts	
Annual CO_2 emissions reductions	The average 187,835 annual CO2 reduction extrapolated from the 623 tons per day estimate in Yazici *et. al.*. (2013) by applying the figure to annual operating days.
Social value of emissions reductions	Social cost of carbon $30 (2007 USD) according to Stern 2007 report; increases annually with inflation. Discount rate for carbon 1.4%
Physical Activity Impacts	
Premature deaths avoided due to physical activity	We utilize the IETT 2010 passenger survey data found in Yazici et. al.. (2013) to establish assumptions for walking time by mode of transportation in Istanbul before and after the implementation of Metrobus. With a 12% discount rate and an assumed Turkish mortality rate of 611, we estimate that 25.62 premature deaths are saved every year that Metrobus operates over a 20 year horizon. We assume the same VSL that was used to estimate the public health impact (TL 1.95 million), adjusted annually for inflation, to estimate economic impact.

13.5.4 METROBÜS SENSITIVITY ANALYSIS

Metrobüs' positive benefit-cost ratio is sustained in a multi-dimensional sensitivity analysis, including a 50 percent decrease in daily ridership, a 50 pecent decrease in travel time saved per trip, and other scenarios. We also examine the impact of changing the social discount rate from 12 percent to 5 percent, which Halicioglu and Karatas (2013) estimate to be an appropriate value for Turkey. This lower discount rate results in a 47 percent increase in the NPV and benefit-cost ration of more than 3.

13.5.5 METROBÜS DISTRIBUTIONAL ANALYSIS ASSUMPTIONS

We conducted a socioeconomic analysis on top of the cost-benefit analysis to provide insight on how benefits and cost are distributed across the population. We used the IETT passenger survey to determine the socioeconomic distribution of Metrobüs riders and the TurkStat 2011 Income and Living Conditions Survey to estimate the proportion of Istanbul inhabitants that fall into each of the socioeconomic categories. Because of the data availability, we were not able to analyze income by perfect quintiles. Instead, we establish five income buckets and estimate the distribution of the population in each group.

Table 59 Metrobüs Sensitivity Analysis Results

Sensitivity Scenario	DiscountedNPV (2012 USD)	NPV Change	Benefit-Cost Ratio
Base scenario	$ 6,387	N/A	2.80
Rehabilitation cost equal to initial construction	$ 6,280	- 1.8%	2.72
50% increase in bus operating costs	$ 5,091	- 21.3%	2.05
50% Increase in bus procurement cost	$ 6,348	- 0.60%	2.77
Health and safety benefits equal to zero	$ 5,505	- 13.8%	2.55
CO2 emissions reduction benefit equal to zero	$ 6,255	- 2.1%	2.77
5% Discount rate for carbon benefits	$ 6,378	-0.5%	2.80
Vehicle operating cost reduction benefit equal to zero	$ 4,232	- 32.7%	2.20
Value of a statistical life 50% lower	5,925	- 7.2%	2.67
50% lower average travel time (min) saved	$ 3,207	- 49.8%	1.91
Discount Rate Adjusted from 12% to 5%	$ 9,375	+ 46.8%	3.04
Average daily ridership 50% lower	$ 2,125	- 66.7%	1.60

In order to estimate the cost distribution parameters, we began with the Bogota parameters and adjusted them to fit the Istanbul case based on IETT ridership survey and income tax brackets. In Turkey, individuals earning between TL 1 and TL 833 per month are taxed at 15%, between TL 834 and TL 2,083 at 20 percent, and between TL ~2,000 and TL ~7,000 at 27% (KPMG, 2013). We estimated total monthly taxes for each income group and then distributed costs by the proportion of total monthly taxes paid by each income group. We estimate that only ½ a percent of total income taxes collected in Istanbul was collected from the lowest income group (TL <1,000). This is because this income group has the lowest tax rate (15 percent) and represents the smallest proportion of the Istanbul population (7.0 percent). By contrast, the highest income-earning group is taxed at around 35 percent, and 41 percent of the Istanbul population falls into this group. As a result, 55 percent of total income taxes collected come from this highest income-earning group.

Benefits are distributed across the income groups primarily guided by the ridership distribution (based on the IETT ridership survey), with the exception of vehicle operating cost reduction benefits and CO2eq emissions reduction benefits. The operating cost reduction benefits are distributed by an estimate of automobile

Table 7 Istanbul Metrobüs Cost Distribution Parameters

Cost Distribution Parameters	< TL 1,000	TL 1,001 - TL 2,000	TL 2,001 - TL 3,000	TL 3,001 – TL 4,000	TL >4,000
Infrastructure (tax burden)	0.5%	4%	15%	25%	55%
Maintenance (tax burden)	0.5%	4%	15%	25%	55%
Bus costs (tax burden)	0.5%	4%	15%	25%	55%
Operating costs (ridership)	14%	45%	22%	10%	9%

ownership across riders, as this benefit is linked to the proportion of Metrobüs riders who switched from automobiles. As the CO2eq emissions reduction benefits are primarily atmospheric and benefit the entire Istanbul city population, we distribute the environmental benefits based on the income distribution across the city of Istanbul irrespective of ridership.

In order to conduct the socioeconomic analysis of benefits and costs, we multiply each distribution parameter in each income group by the corresponding proportion in the benefits and cost distribution parameters below. This is the same approach that was employed in the Bogota case. In order to estimate the distribution parameters, we began with the Bogota parameters and adjusted them to fit the Istanbul case based on the ridership survey and tax brackets.

Table 61 Istanbul Metrobüs Benefits Distribution Parameters

Benefits Distribution Parameters	< TL 1,000	TL 1,001 - TL 2,000	TL 2,001 - TL 3,000	TL 3,001 – TL 4,000	TL >4,000
Travel Time Reductions (ridership)	14%	45%	22%	10%	9%
BRT Users' Vehicle Operating Cost Reductions (estimated car ownership)	3%	5%	12%	30%	50%
Road Fatalities Avoided (ridership)	14%	45%	22%	10%	9%
Road Accidents Avoided (ridership)	14%	45%	22%	10%	9%
CO2eq Emissions Avoided (citywide population)	4%	20%	19%	16%	41%
Reduction in Premature Deaths due to Increased Physical Activity (ridership)	14%	45%	22%	10%	9%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