

Guangzhou, China Bus Rapid Transit Emissions Impact Analysis

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Executive Summary

The city of Guangzhou is located in southwestern China, an hour's flight from Hong Kong. It is the third largest city in the country, with a population of over 6 million in the city and nearly 12 million in the metropolitan area.

When the city of Guangzhou, China opened its new 22.5-kilometer Bus Rapid Transit corridor in 2010 it aimed to cut congestion on one of the city's busiest roads, Zhongshan Avenue, and to improve the efficiency of the city's bus system. This analysis shows that the system has succeeded in doing that and more.

Today the Guangzhou BRT has a whopping 805,000 daily boardings, making it the most well-used bus corridor in all of Asia, with more riders in fact than even any other metro line outside of Beijing. It has improved trip times for bus riders as well as drivers in the corridor by 29% and 20% respectively for an aggregate annual time saving of 52 million hours, a value of 158 million yuan. The system has also made the city's bus operations more efficient. After an initial capital investment of 950 million yuan for BRT stations and lanes, the system is reducing annual operating costs by over 90 million yuan.

In addition to the BRT, the city created a new high-quality greenway along the corridor and provides bike parking and bike share at each of the stations, as well as in locations in adjacent neighborhoods. This means that the BRT can attract passengers from a wider radius, and provide an option for passengers who would ordinarily board for only one or two stops, helping alleviate potential crowding.

Beyond the transportation improvements, the system also has a large positive effect on the environment and public health. The Institute for Transportation and Development Policy (ITDP) estimates that Guangzhou's BRT will reduce an average of 86,000 tonnes of CO₂ per year over its first ten years (for a yearly CER value of 19 million yuan). It will also create an average annual reduction of 4 tonnes of particulate matter emissions that cause respiratory illness.

The Guangzhou BRT demonstrates the viability of metro-scale BRT in China. The system is a model of highly cost-effective urban transport that should be employed as more Chinese cities pursue local and global environmental sustainability.



Introduction

The first phase of the Guangzhou Bus Rapid Transit (GZ BRT) opened in February of 2010, and it has already become an important demonstration of the efficacy and efficiency of high-capacity, full-featured BRT in Asia. In recent years over a dozen low-volume bus rapid transit systems have sprung up throughout Asia. GZ BRT breaks this trend, with the first BRT system outside of South America with a daily volume comparable to, and in many cases in excess of, an urban metro-rail. Before GZ BRT, Zhongshan Avenue's traffic speeds were plummeting and hundreds of buses blocked traffic while struggling to pick up passengers on crowded curbs. Today, travel speeds are up 29% for buses and 20% for mixed traffic, and bus riders wait in safety and comfort in new high-quality center-median stations.

The analysis of GZ BRT presented here, after just one year of operation, examines aspects of the system design, performance, cost-recovery, and emissions reduction of Asia's first metro-scale BRT.

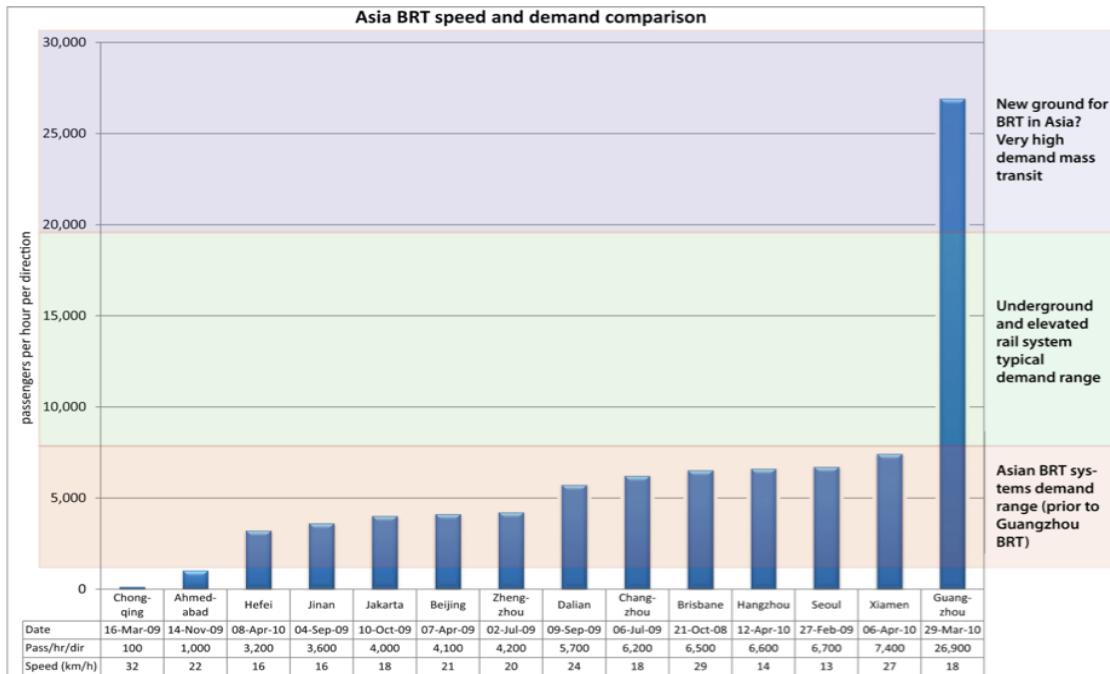
After less than a year of operation, overall bus ridership in the corridor was up 18% over the year before¹ and GZ BRT was averaging 805,000 total daily trips on the thirty-plus routes which use all or part of its 22.5-kilometer corridor of fully-segregated rapid bus lanes. At peak hour in the peak direction, GZ BRT carries 27,000 people per hour—more than triple the peak passenger flows of any other BRT system in Asia and more than any metro line in mainland China except Beijing's Lines 1 and 2. The speed of buses and mixed traffic in the corridor has increased significantly, by 29% and 20% respectively. GZ BRT also significantly decreased fuel consumption and the emission of pollutants in the corridor, such as the particulate matter that causes respiratory illness locally and the greenhouse gases (GHGs) that contribute to global warming.

GZ BRT is not just a stand-alone system, but the backbone of one of the best multi-modal corridors in Asia. GZ BRT is paralleled by separated Class I bike lanes and high-quality pedestrian areas on both sides of the corridor. Several stations provide direct access to metro-rail stations, and all offer high-quality bike parking, a public bike-sharing system, and improved flow for private automobiles.

The first phase of GZ BRT was developed after several years of planning and design led by the Guangzhou Municipal Engineering Design and Research Institute (GMEDRI) and ITDP, and planning continues for future system expansion. With rapid development happening along the BRT corridor, a newly expanded fleet of high-capacity 18-meter buses, and the further refinement of BRT operations, continued growth of GZ BRT ridership and associated benefits are expected. As Karl Fjellstrom, Director of ITDP in China, points out in a recent article, "Indeed within the next few years it is possible that the Guangzhou BRT will exceed the one-directional passenger flows of all the metro systems in mainland China."

¹ As indicated by ITDP's before and after corridor screenline counts in Dec. 2009 and Jan. 2011.

Figure 1: Asia BRT speed and demand comparison



System Planning and Implementation

Preliminary planning for a BRT system in Guangzhou began in 2003. With no exemplary high-capacity BRT systems in China, the city was considering other corridors with significantly lower demand for BRT implementation. In 2005, GMEDRI and ITDP conducted a demand analysis and corridor comparison that revealed that Zhongshan Avenue would provide the greatest passenger time-saving and operational cost benefits: meeting the high demand while relieving severe bus congestion that limited vehicle speeds in the corridor, all at a fraction of the cost and time it would take to implement a metro-rail.

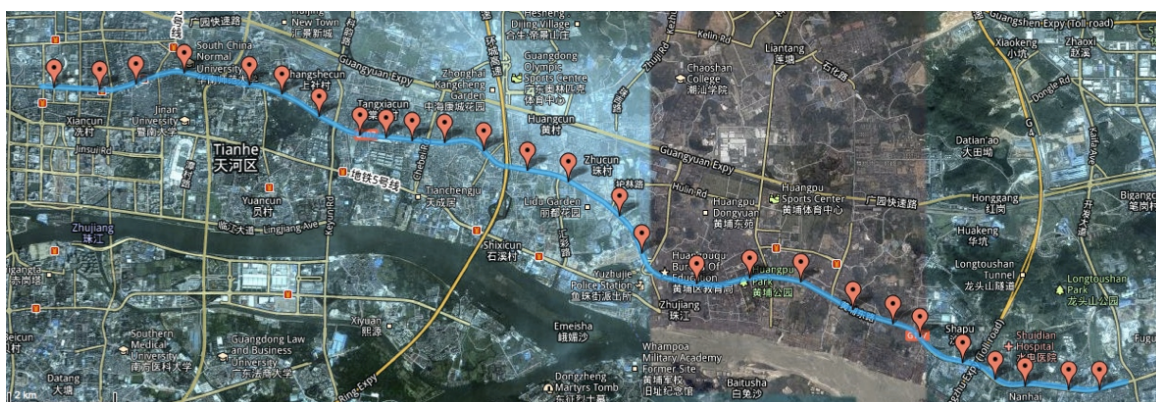
In 2006, GMEDRI and ITDP commenced with further BRT design planning, demand analysis, and traffic engineering. In 2008 they completed station location planning, basic operational plans, BRT institutional planning, station architecture, roadway engineering, and multi-modal integration planning with the metro, bikeways, and sidewalks. All infrastructure related to the BRT was constructed in 2009 while work continued for the fare collection system, intelligent transport systems, operations refinement, vehicle procurement, public outreach, and ancillary measures such as parking and urban design.

Urban Context of BRT Corridor

The GZ BRT corridor along Zhongshan Avenue links some of Guangzhou's most developed areas to places where future growth is expected, in the northeast sector of central Guangzhou. The corridor begins on its western end in the Tianhe District, which has seen intense development over the last twenty years including the Tianhe Sports

Complex, the Guangzhou East Rail Station, many high-rise residential developments, large shopping complexes like TEEM mall, and office towers like CITIC plaza (currently the fourth tallest skyscraper in China). The corridor continues 22.5 kilometers through eastern Tianhe and into the Huangpu District, which, while dense and diverse in land uses is also growing quickly. Eastern Tianhe and Huangpu have old, ultra-dense, unplanned, low-rise “urban villages” like Tangxia; large new gated communities filled with dozens of high-rise residential towers like Junjing Huayuan; large public parks; universities; large industrial sites; and even agricultural sites can be found near the corridor on the currently under-developed far eastern end of the corridor.

Figure 2: 22.5-km GZ BRT corridor area with 26 stations



GZ BRT System Planning, Design, and Operations Features

BRT Lanes and Routes

The BRT corridor along Zhongshan Avenue features 22.5 kilometers of fully segregated bus lanes, twenty-six BRT stations, and thirty-one different bus routes (not including very short overlaps).

All stations have overtaking lanes allowing multiple sub-stops and express routes, and are designed and dimensioned according to the projected passenger demand and bus flows. Access to the center median stations is via a combination of pedestrian bridges, at-grade crossings, and pedestrian tunnels where combined with metros. Intersections along the corridor have restricted left turns.

The system uses a “direct service” or “flexible” operational plan which allows buses to enter and leave the segregated lanes, instead of requiring transfers to/from feeder routes. Most bus routes that use all or part of the BRT corridor also expand well beyond the BRT corridor itself, covering another 250-plus kilometers in total.

Prior to the implementation of the BRT, over forty bus routes serviced curbside stops in the Zhongshan corridor. Since curbside bus stops did not have sufficient length or capacity, buses were often prevented from stopping on the curb or close to the specified route stops making rider access difficult and unsafe. Without segregated lanes for buses and mixed traffic, the frequently stopping buses slowed mixed traffic in the corridor, worsening travel times. The 12-meter buses in use before the BRT required on-

board payment, which slowed boarding times. In recent years Guangzhou has been replacing its aging fleet of diesel buses with new buses fueled by liquefied petroleum gas (LPG). In 2009, before the BRT was implemented, 36% of buses operating in the corridor were burning diesel fuel. LPG now fuels all buses operating within the BRT lanes.

Figure 3: Before BRT—bus and traffic congestion, Ganding Station area



Figure 4: After BRT—efficient traffic flow at Ganding Station area



Buses & Stations

Throughout 2010, the BRT bus fleet consisted of mostly 12-meter long, low-floor buses powered by liquefied petroleum gas (LPG) and manufactured domestically by Kinglong

in Xiamen. The buses have front- and rear-boarding doors with twenty-eight to thirty-six seats, but often have peak occupancies 2.5 times greater than the number of seats. Beginning in 2011 has been expanded to include higher-capacity 18-meter buses with three doors for boarding. Stations and buses are equipped with intelligent transportation systems that support real-time station arrival signage and enable centralized monitoring and control.

Figure 5: GZ BRT basic statistics

Length of corridor	22.5 km
Number of stations	26
BRT route coverage area	273 km
Bus manufacturer	Kinglong (China)
Fuel type	LPG
12-meter, low-floor bus seated capacity	26–38
18-meter, low-floor bus seated capacity (early 2011)	47
Station length	55–250 m

GZ BRT is the first BRT system in China to contract multiple bus operating companies for service provision. It consolidated operators into three corporate groups consisting of a total of seven different bus-operating companies, all of which operate separate routes within the BRT corridor. Bus operators are each paid a percentage of the total passenger revenue including inside and outside the BRT corridor. This percentage is based on the number of total bus-kilometers provided, with the BRT control center specifying the frequency of each route at a monthly meeting between the regulators and operators. The payment amount is then adjusted again based on performance factors including: maintenance of the stipulated frequency and operational plan, passenger complaints, punctuality, accidents, breakdowns in the BRT corridor, and adherence to tasks given to them by the government.

Figure 6: GZ BRT operational control center

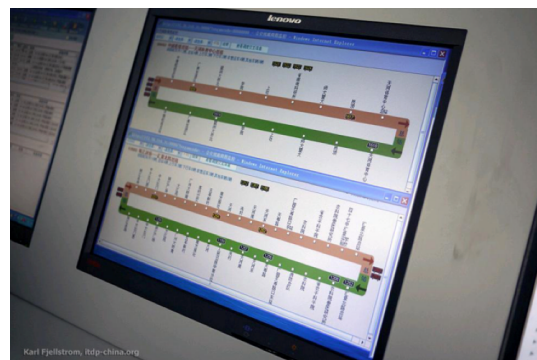


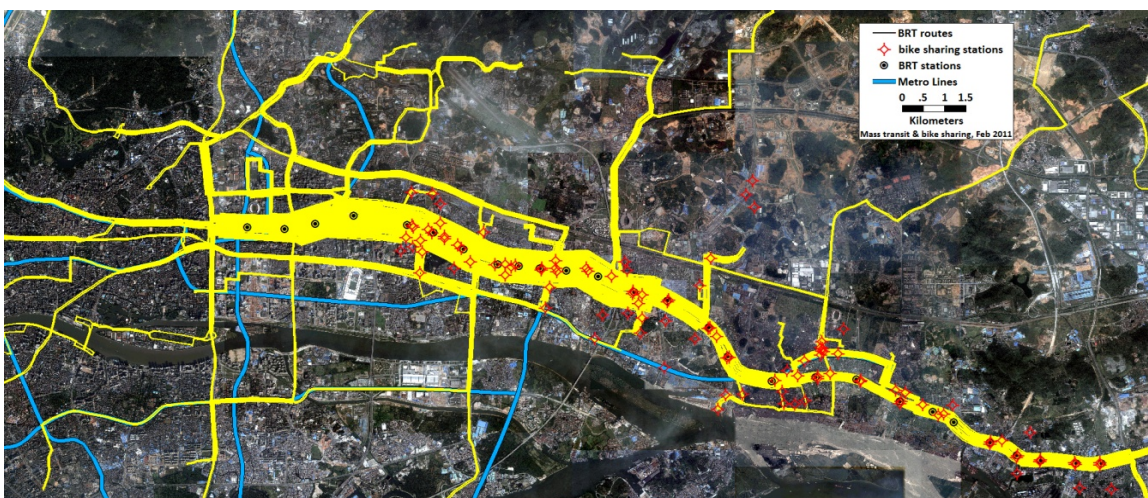
Figure 7: GZ BRT loading platform, real-time signage, and pre-board payment



Passengers pay fares at station-entry turnstiles, instead of on buses. All stations have at-grade boarding, and low-floor buses provide easier entry and exit on and off the BRT route. Real-time digital displays alert passengers to which buses will be arriving at which gates. Each bus-boarding gate has sliding glass panels that open only when a bus has arrived at the gate, for safety. Each station has separate east- and west-bound waiting platforms located on corresponding sides of the bus lanes. Stations have a sleek, modern aesthetic, are clean, and well lit at night. Their sizes have been calibrated to meet modeled demand and the needs of bus operations. Some stations are as short as 55 meters while Ganding, the busiest station in the world at 55,000 daily boardings, is 250 meters long (the world's largest) and has multiple pedestrian bridges for access.

Creating a Truly Multi-Modal Corridor

Figure 8: BRT-connected mass transit routes and bike-sharing stations



GZ BRT is also fully integrated with other transport modes. It is the first in the world to have a direct tunnel connection to a metro-rail station; four BRT stations will provide access to four different metro lines.² Full-length, physically-separated (Class I) bikeways were built along both sides of the 21-kilometer BRT corridor, and improved sidewalks run through the full corridor. In mid-2010, 5,000 bicycles were made available at 113 stations along the BRT corridor during Phase 1 of the Guangzhou public bicycle-sharing scheme. The city of Guangzhou says the bicycles are currently used for over 20,000 trips per day, and ITDP's user surveys show that this reduces at least 7,500 motorized trips per day. Secure, high-density bicycle parking is also available at BRT stations for private bicycle users. Some BRT station bridges also connect directly into adjacent buildings for convenience. Corridor urban design and parking management plans are also being developed. All of these facilities were made possible without appropriating a larger right-of-way and while improving flow for automobile traffic.

Figure 9: Safe, high-quality walking and bicycling spaces along GZ BRT corridor



Figure 10: Public bicycle-sharing station with secure bicycle parking (rear)



² Two tunnels are open as of 2011, two more will open in 2012 or later.

Figure 11: GZ BRT system key features

At-grade boarding	High-quality, secure bicycle parking
Restricted left turns at over 75% of intersections	5,000 public bicycles at 113 bike sharing stations along corridor
Full-length separated BRT-only lanes	Parallel Class I bicycle lanes
Real-time bus arrival signage for passengers at stations	Parallel safe sidewalks
Pay-before boarding	Multiple sub-stops with overtaking lanes and express routes
Branding and public outreach campaign	Performance-based bus operator contracts
System control center and supporting ITS components	High-capacity, triple-door 18-m buses (forthcoming)
Pedestrian bridge access with escalators	Direct tunnels to metro stations

GZ BRT Passenger Volume and Performance Indicators

Figure 12: Key ridership statistics

GZ BRT is already breaking passenger records, revolutionizing perceptions of bus-based transit. An average of approximately 805,000 daily trips (not including transfers) were made on GZ BRT during its first year of operation—more than any of Guangzhou's metro lines. Its peak directional passenger flows of 26,900 are more than triple that of any other BRT system in Asia and even higher than all metro lines except Beijing's lines 1 and 2. This is also far in excess of traditional capacity limits thought to apply to direct-service BRT systems in which BRT vehicles operate both inside and outside the BRT infrastructure. Only Bogotá's TransMilenio System has higher demand. Peak hour passenger boardings at the largest stations are 8,500—the highest in the world for BRT stations and Ganding Station has boardings in excess of 55,000 per day, also the world's highest.

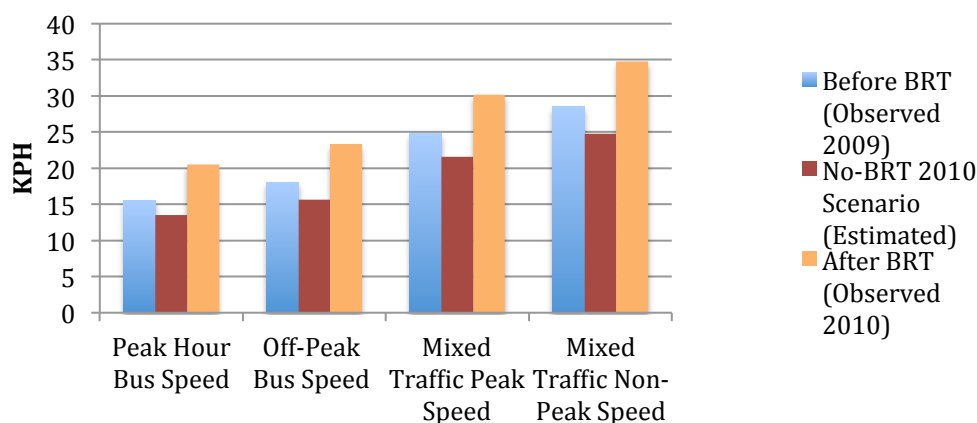
Average trips per day (not including transfers, Dec. 2010)	805,000
Maximum persons carried past a single point (passengers per peak hour direction)	26,900
Average buses per minute per direction at busiest section	6
Number of routes operating in corridor (excluding short overlaps)	31
Highest peak hour passenger boardings for a single station (not including transfers)	8,500
Max hourly station boardings	55,000

Impact on Bus and Mixed Traffic Speed

GZ BRT has improved speed and travel time for buses and mixed traffic alike. Daily average bus speed has increased by 29% from 17 kph to 22 kph. Peak bus speed increased from 15 to 20 kph and off-peak increased from 18 kph to 23 kph. These speeds translate to an average time saving of 4.7 minutes per trip within the BRT corridor, as applied to the average trip length of 5.8 kilometers. This speed and time

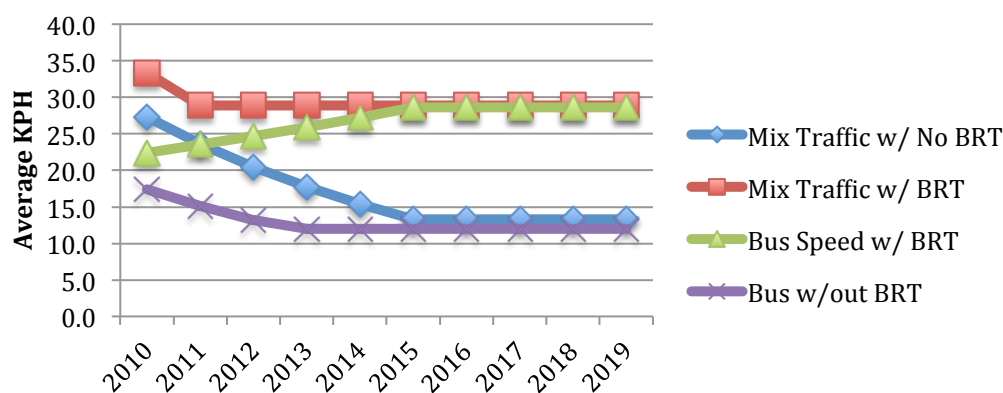
benefit is also expected to increase in future years based on the future deployment of more 18-meter BRT buses and as the trend for bus speeds in corridors without BRT declines. Average passenger-reported waiting times also decreased 19% from 17 minutes to 14.5 minutes.

Figure 13: GZ BRT observed speed and time improvements 2009–10



The time-saving figures cited above are a direct comparison between 2009 pre-BRT and 2010 post-BRT observations and do not factor in the trend of increasing congestion in Guangzhou. The figure above provides direct comparison on the observed differences in vehicle speed from 2009 to 2010, and the projected speed if no BRT was implemented in 2010. Figure 14 extrapolates these trends through 2019, positing that mixed traffic speeds will stabilize just above the BRT speed, as drivers would switch to BRT rather than choose to drive more slowly than the buses on the parallel BRT route. Both projections rely on a Guangzhou Transportation Institute study that showed the average speed on trunk roads in Guangzhou decreased 13% from 2008-9. Other city offices have estimated that peak-hour speed in Guangzhou decreased by 30% in 2010 on main trunk roads.³ Studies are ongoing to determine a corridor-specific baseline.

Figure 14: Daily average operating speed projections, 2010–19



³ <http://news.21cn.com/guangdong/guangzhou/2010/10/20/7888233.shtml>, English speakers can translate using Google translate.

Figure 15: Bus trip time savings for corridor users with BRT

Average total trip time savings after BRT	7.2 minutes (19% decrease)
Average mixed traffic trip time savings	2.3 minutes (18% decrease)

Combining the improvements in bus trip time⁴ and improvements in average passenger-reported bus waiting times,⁵ GZ BRT saves the average passenger 7.2 minutes per trip, a 19% improvement. Aggregating these time savings for the 805,000 daily trips in 2010 bears out a yearly time saving of 35 million hours, valued at 107 million yuan (USD 16 million).⁶ The BRT also resulted in an aggregate time saving of 17 million hours per year for passengers in cars on Zhongshan Avenue, a value of 51 million yuan (USD 8 million). **In total, the BRT generated 52 million hours in time savings for travelers in the Zhongshan corridor in 2010, an annual value of 158 million yuan per year (USD 24 million).**

Figure 16: Aggregate time savings and value

Yearly time savings for BRT passengers (2010)	35 million hours per year
Yearly time savings for mixed traffic passengers (2010)	17 million hours per year
Aggregate time savings for mixed traffic and BRT passengers 2010	52 million hours per year
Aggregate yearly value of time savings for mixed traffic and bus passengers (2010)	158 million yuan per year (USD 24 million)

Public Opinion Performance

ITDP conducted surveys with randomly selected bus riders on Zhongzhan Avenue before and after the implementation of the BRT system. The results show large, positive impacts in public opinion of bus service and civic pride after the implementation of the GZ BRT. Riders reporting satisfaction with public transport jumped from 29% in late 2009, before the BRT was implemented, to 65% satisfied one year later. The number of those dissatisfied with public transport decreased by 21% over the same period. The portion of bus passengers agreeing that “the environment in Zhongshan Avenue is good” quadrupled from 17% before the BRT to 67% after BRT. Those who disagreed fell from 52% to 9%. Additionally, the number of people in the corridor that agreed with the statement, “I feel safe walking along Zhongshan Avenue,” more than doubled from 28% before, to 68% after the BRT and associated bikeway and sidewalk improvements were implemented. The portion of bus riders agreeing with the statement “I am proud of Guangzhou” increased in the BRT corridor from 40% before the BRT to 73% afterwards.

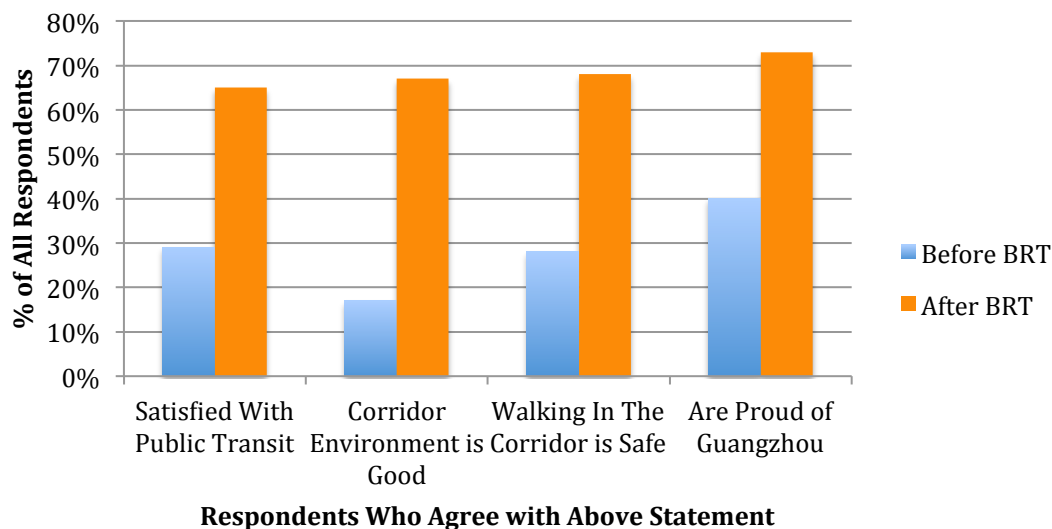
⁴ Travel time change: -4.7 minutes, calculated by applying average speed change to distance (ITDP surveys).

⁵ BRT wait time reduction: 2.5 minutes (ITDP surveys).

⁶ Value of travel time based on 1/3 the average local wage rate in urban China.

That figure was unchanged amongst car users and in a control survey in a different bus corridor without a BRT, civic pride amongst riders decreased over the same period.

Figure 17: Impacts on public opinion



Corridor traffic counts show that after the implementation of the new bikeways, sidewalks, bike parking, and bicycle-share system, bicycle trips on the busy corridor increased by an average of 45% from 2009-10, for a reduction of approximately 2,200 tonnes of CO₂ per year.

Researchers are closely following the impact of the GZ BRT on property values and rents along the corridor. Preliminary data collected by ITDP suggests that rental values along the corridor have increased by as much as 20% along the corridor since the BRT and bike/pedestrian improvements have been made.⁷

GZ BRT Performance Issues

Already during peak hour it is common for buses to be too crowded to allow additional boardings. The addition of the 18-meter articulated buses in 2011 should help to solve this problem. Another issue holding back improved BRT speeds has been GZ BRT's planning authority's inclusion of thirty to forty bus routes within the segregated lanes, including many routes with a short BRT overlap. This appears to be causing some congestion in the system and conflicts with an operations analysis, which concluded that speed and capacity would be optimized by only including twenty-eight or so of the highest-capacity bus routes. Unfortunately for the disabled population, most stations are currently wheelchair inaccessible. Lastly, despite major improvements in the sidewalks, public space, and bikeways, the space allocated to pedestrians and bicyclists at many stations is inadequate given the large volumes. There are also many small but problematic gaps in the bikeway. While expansion of sidewalks, bikeways, and other public space is often constrained by right-of-way, planning is in place to convert parking areas to public space to better accommodate bicyclists and pedestrians where possible.

⁷ ITDP is conducting an ongoing BRT impact analysis study that will be published during 2011.

Cost-Recovery of GZ BRT

Capital Cost

The BRT's total capital cost was 950 million yuan (USD 103 million),⁸ or about 30 million yuan (USD 4.5 million) per kilometer constructed. This is about one-tenth to one-twentieth of the per-kilometer cost of recent metro projects in Asia, and GZ BRT's capacity is higher than most metros,⁹ making it a more cost efficient investment.

Figure 18: Operating and capital costs of GZ BRT

Total capital cost of GZ BRT	950 million yuan (USD 146 million)
Capital cost per kilometer	42 million yuan (USD 6.4 million)
Capital cost per km of typical Chinese metro-rail	100 million yuan (USD 15 million)

Consumer Costs

Figure 19: Consumer cost impacts

Average individual consumer per trip bus cost reduction	2.3 yuan (47% lower with BRT)
Annualized consumer trip cost reduction from BRT	672 million yuan (USD 103 million)

Bus fares have undergone substantial simplification and restructuring as a part of a city-wide low-fare program. Previously most bus fares were 2 yuan (USD 0.30), though some longer routes had fares as high as 5 yuan. As of 2010, all route fares cost 2 yuan. Also, within the BRT system, riders are allowed free bus transfers, whereas outside the BRT system they must pay a second fare to transfer. Smart Cards provide frequent BRT users a discount as well: after the first fifteen rides in a month subsequent fares are 1.2 yuan. All of these changes have led to a lowering of the average fare price for BRT riders. In ITDP's user survey, the average reported cost of a bus trip was nearly halved from 4.9 yuan in 2009 to 2.6 in 2010 with the BRT. This equals a yearly consumer savings of over 672 million yuan (USD 103 million). It is not known how this restructuring of bus fares has affected bus ridership as it was implemented at approximately the same time as the new BRT facilities.

⁸ Fjellstrom, Karl; project cost estimate figure based on City of Guangzhou's Project Cost Breakdown. The city of Guangzhou has publicly estimated the BRT cost to be lower at 650 million yuan, but this higher number is considered more realistic. It does not include the cost of bicycle, pedestrian, or public utility upgrades.

⁹ See Ximing, Lu, "Car Based Transport and Transit Oriented Metropolis," 2008; Madhav G. Badami, ["Urban Transport Policy as if People and the Environment Mattered,"](#) 2009.

Operating Costs

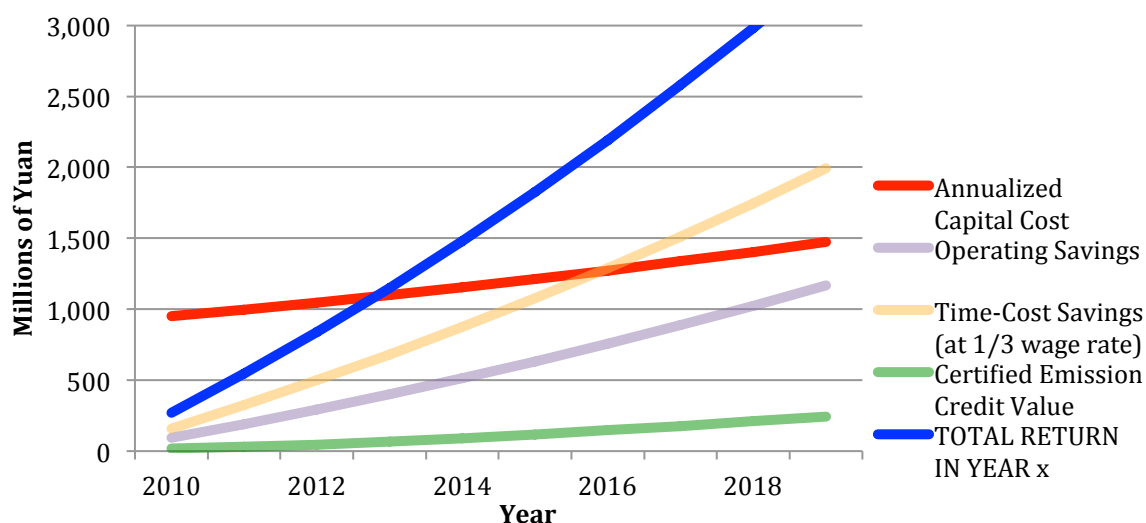
The city government deliberately keeps bus fares low, and hence subsidizes the operating costs of the bus system. The city government, however, reports that on the BRT routes, its operational subsidy decreased by 66% from 0.9 yuan per bus-vehicle-kilometer traveled (VKT) before the BRT to 0.3 yuan per bus VKT after the BRT was implemented. This yields a total annual operating cost savings of over 93 million yuan (USD 14 million). Though the city government was not able to detail exactly how these savings are achieved, the majority of the savings is assumed to come from fuel savings. While the fuel cost savings should continue to drive down operational costs over time given vehicle speed projections, they would generate enough income (roughly 1.2 billion yuan with interest) to pay off 79% of the BRT's capital cost and interest by 2019, even if they hold steady.

The Value of Other Co-Benefits

Figure 20: Yearly value generated by GZ BRT

Aggregate yearly operating cost savings	93 million yuan (USD 14 million)
Value of aggregate time savings (2010)	158 million yuan (USD 24 million)
Average yearly value of certified emission credits	25 million yuan (USD 4 million)
Aggregate consumer savings on trip cost in 2010	672 million yuan (USD 103 million)
Yearly reduction in health costs from respiratory illness	Unknown

Figure 21: Value generation streams and capital cost 2010–19

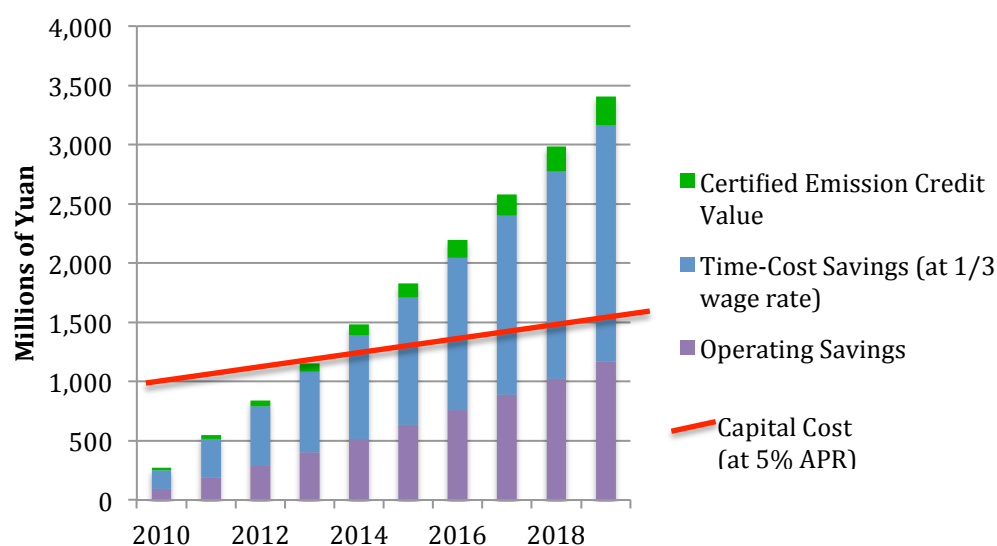


As shown earlier, the value of the time savings created by the BRT is equal to 158 million yuan in 2010 alone, and will increase significantly in future years as ridership and time savings increase over the no-BRT baseline and salaries rise. Further, although this study did not attempt to calculate this value, many more millions of yuan per year are no doubt saved in health costs by reducing the particulate matter (PM) from transport in the corridor that causes respiratory illness. Lastly, while the city did not apply for CDM carbon-finance for Phase I of the GZ BRT, the average yearly value of the carbon emissions avoided from 2010-19 due to this project is worth an additional 25 million yuan (USD 4 million), based on the current price of \$34 per tonne of CO₂e reduced.¹⁰

Capital Cost Recovery and Value Added of GZ BRT

As stated earlier, annualizing the city of Guangzhou's reported cost savings from the BRT in 2010 over time shows that even with a conservative estimate, the operational cost savings from the BRT will return 79% of the capital costs to build the BRT within ten years. If one considers the public benefits such as the value of time savings for corridor users, GZ BRT pays for its own capital cost within just two years, as illustrated in Figure 22. **With conservative estimates of the value of the local and global benefits accounted for (not including health impacts), the 950 million yuan investment in the GZ BRT will produce a 131% return on investment after ten years.**

Figure 22: Total return on investment of GZ BRT by year, 2010–19



¹⁰ <http://www.reuters.com/article/2011/04/12/us-carbon-barcap-idUSTRE73B2JY20110412>

GZ BRT EMISSIONS IMPACT

Vehicular CO₂ emissions in Guangzhou increased by 320% from 3.6 million tonnes in 1995 to 11.4 million tonnes in 2005.¹¹ The emissions from the urban transport sector are a cause for both local and global concern. The World Health Organization estimated that 650,000 people died prematurely from urban air pollution in developing countries in 2000. The transport sector alone contributes to 23% of energy-related GHG emissions, and despite advances in vehicle technology, transport is the fastest growing sector in terms of GHG emissions in developing countries.¹² BRT systems provide a cost-effective solution to cities looking to improve air quality and reduce GHG emissions of urban transport. GZ BRT has made significant reductions in the greenhouse gas CO₂, and in criteria pollutants PM, CO, and NO_x.

Figure 23: Emissions impact of GZ BRT, 2010–19

	CO ₂	PM	CO	NO _x	SO ₂
Emissions reduction from BRT mode shift (t)	216,243	3	6,478	699	23
Emissions reduction from BRT VKT reduction (t)	190,078	0	1,904	502	0
Emissions reduction from BRT speed increase (t)	85,759	0	859	321	0
Mixed traffic speed increase emissions reduction (t)	396,561	37	23,005	2,910	200
Total direct emissions reduction (t)	864,641	40	32,246	4,432	223

Emissions Impact Estimation Methodology

Estimating GHG impacts in the transport sector is a complex task often requiring a great deal of data on transport activity as well as vehicle fleet and fuel consumption cycles to model the impact of a transportation intervention on emissions. Over the past several years, ITDP has collected a robust set of data about the transport activity of Zhongshan

¹¹ Wang, Haikun et. al., Huo, H., et al., Trends in vehicular emissions in China's mega cities from 1995 to 2005.

¹² Kahn Ribeiro, et. al., 2007: Transport and its infrastructure. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IPCC, Cambridge University Press, Cambridge, UK.

Avenue including: traffic counts, speed surveys, passenger questionnaires, ridership statistics, and bus operations statistics both before and after the BRT was implemented. An *ad hoc* methodology was developed that is based on the general ASIF¹³ approach and comparable to the UNFCCC's CDM AM0031 methodology for calculating the GHG impacts of BRT systems.

BRT systems can have at least six potential impacts on a corridor's transport emissions:

1. Induced modal shift to BRT from more emission-intensive modes
2. Increased fuel efficiency due to increase in mixed traffic speeds
3. Reduced transit VKT due to rationalized routes
4. Increased fuel efficiency of buses due to improved transit vehicle speed
5. Improved bus fuel efficiency of new buses and the scrapage of old buses
6. Decreased auto trips due to the development of transit-supportive land uses and decreased household motorization rates

This methodology includes impacts 1-4 in its calculations. Impact 5, replacement of old buses with low-carbon buses, is not relevant to this case as most of the 15-meter LPG buses used at the time of the study were similar to those used before the implementation of the BRT system and it is not known whether old vehicles are scrapped. It should be noted, however, that many 18-meter buses will be purchased for the BRT corridor only in 2011 and will have significant CO₂ reductions, yet are not accounted for here due to incomplete data. Impact 6, land-use and motorization impacts, are long-term indirect impacts that must be measured over time and cannot be accurately measured within just one year of the BRT's implementation.

This methodology calculates the impacts from each of the four impact circumstances separately and then adds them together to find the total GHG impact of the GZ BRT:¹⁴

$$E_{\text{modal shift}} + E_{\text{bus operations}} + E_{\text{bus operations}} + E_{\text{mixed traffic speed}} = I_{\text{BRT}}$$

I_{BRT} = Cumulative Yearly Emissions Impact of Implementation of Guangzhou BRT

E_x = Emissions Avoided Annually, by Source X

The following sections will discuss the methodology for calculating each of the four different types of emissions impacts of the BRT separately for both 2010 and 2010–19.

One critical data point in these calculations has been the selection and calibration of vehicle emission factors from the available body research, since large-scale fleet surveying, modeling, and in-field fuel economy testing was beyond the scope of this study. All emissions factors used in the study were selected from the regionally specific studies or averages from the International Vehicle Emissions model combined with running speed adjustment factors.

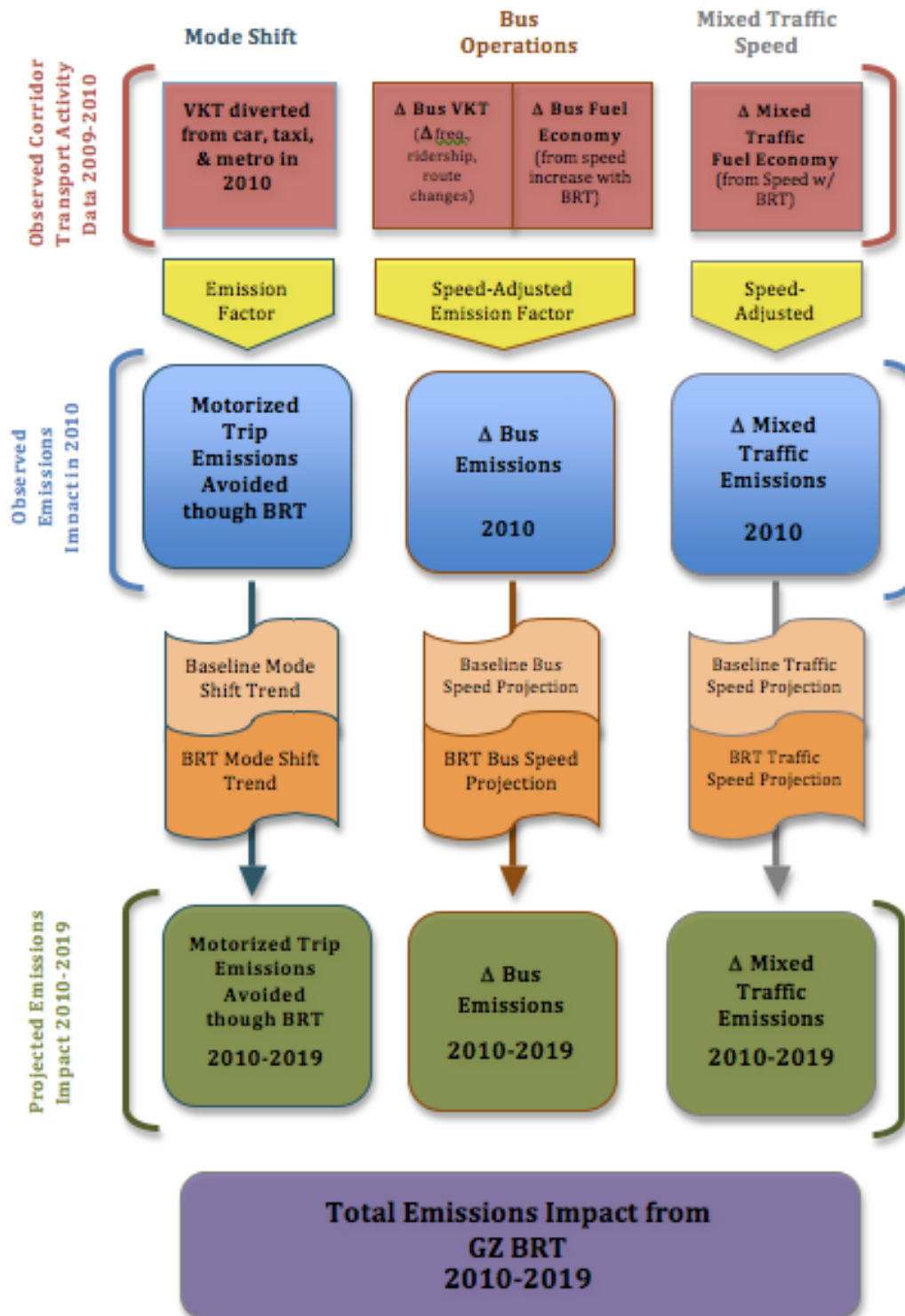
To calculate the emissions impact of GZ BRT, empirical data from 2009 (pre-BRT) was compared with data from 2010 (post-BRT) to find the observed CO₂ impact in 2010. In

¹³ Schipper et al., 2007.

¹⁴ The impacts of bus speed on fuel efficiency and changes in bus VKT are necessarily combined, as both an emissions factor and travel activity are needed to calculate CO₂ emissions.

order to estimate the long-term impact of the BRT over its first ten years of operation, the city of Guangzhou's projections on vehicle speed and modal share were applied to the observed impacts in 2010, as illustrated below.

Figure 24: Methodology for finding GZ BRT emissions impact



Difference from CDM

The *ad hoc* methodology used here accounts for all the same variables as the CDM methodology and would yield exactly the same emissions calculations. The main difference is in its order of operations: the AM0031 methodology calculates a per-passenger emission factor (which is determined, in part, by average occupancy numbers) for all modes, including the bus, and then multiplies it by the per-passenger travel activity of that mode in both baseline and project scenarios.

In the case of GZ BRT, the bus ridership and occupancy data needed for the per-passenger approach were not highly reliable because the old bus operators did not track ridership (they were paid based on VKT). However, ITDP had exact bus VKT figures from both before and after the BRT implementation as well as a large-sample BRT passenger survey on modal shift, and exact numbers on BRT ridership numbers. Thus, instead of using unreliable data on occupancy, ridership, and average trip length to find per-passenger-based emissions estimates, the *actual* bus VKT was used to create pre-BRT and post-BRT emissions. While it is estimated that bus ridership grew 18% with implementation of the BRT, attracting trips from other motorized and non-motorized modes, actual emissions from the BRT went down due to a reduction in VKT due to route rationalization and an improvement in fuel economy from an increase in average running speed. The emissions saved from the BRT riders who switched from car, taxi, or metro are calculated separately from the BRT emissions created through riding the BRT.

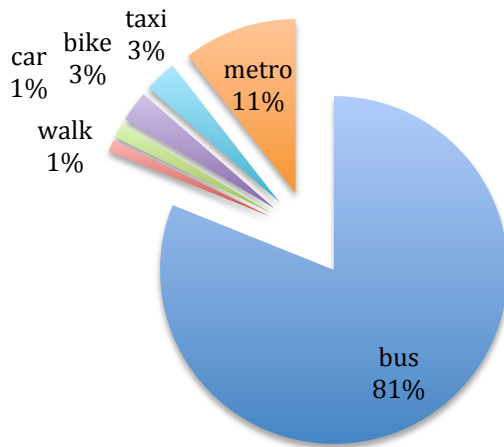
Calculating Emissions Impact of Motor Trips Avoided by BRT

The emissions avoided when a traveler takes the BRT instead of taking a car, taxi, or the metro are calculated by finding the amount of VKT avoided for each mode and multiplying that by the appropriate emissions factor. ITDP conducted a survey of over 700 bus riders that asked “What transport mode would you have used to make this trip a year ago, before the BRT was in place?” The “previous mode” data, illustrated in Figure 25, showed that 81% of BRT riders rode the bus previously and 19% switched from another mode. This figure is supported by BRT operator estimates that bus ridership increased in the corridor by 18%. The mode share from pre-BRT trip mode was applied to ridership totals and used in conjunction with average trip length, occupancy, and emission factors for cars, taxis, and the metro. It should be noted of course, that the BRT trips that were shifted from other modes (motorized and non-motorized) still have emissions associated with their BRT trip. However, all BRT emissions are accounted for in the “BRT Operations” emission calculation—this step only focuses on calculating the emissions avoided from other motorized trips, so BRT trips and non-motorized trips are not included in the below equation.

$$\left[\sum M_{\text{car, taxi, metro}} (R_{2010}) (S_M)(D_M) (E_M) \right] = I_{\text{mode shift}}$$

- I* = Cumulative yearly emissions avoided from other modes in tonnes of emissions
- M* = Mode used before BRT implementation: car, taxi, metro
- R* = Yearly cumulative ridership for bus routes included in BRT corridor
- S* = Modal shift for mode (*M*)
- D* = Average travel distance for mode (*M*)
- E* = Emissions factor for mode (*M*)

Figure 25: BRT passengers previous mode



Emissions factors for cars were obtained from a study of Chinese passenger cars' average emission factors.¹⁵ Emissions factors for LPG taxis were taken from a study prepared for a CDM application in Pune, India.¹⁶ All other emission factors are from average values of the International Vehicles Emissions model, except where otherwise noted. The data points are given in the table below.

Figure 26: Data for modal shift emissions impact calculation

Daily Boardings	805,000		
Average BRT Trip Distance	8.3		
	Avg. Private Auto	LPG Toyota Taxi	Metro (per-pax-km)
Average load factor	1.6	1.5	1.0
Days of operation	365	365	365
CO ₂ base emfac (g CO ₂ /km)	192.00	140.00	11.80
PM ₁₀ base emfac (g PM/km)	0.01	0.00	-
CO base emfac (g CO/km)	10.5 ¹⁷	4.90	-
NOx base emfac (g NOx/km)	1.38	0.42	-
SO ₂ base emfac (g SO ₂ /km)	0.03	0.02	-
% BRT trips avoided from mode	1.40%	3.00%	10.60%
Avoided trips in base year	2,570,969	5,876,500	31,145,450
Yearly VKT avoided	21,339,041	48,774,950	258,507,235

¹⁵ Oliver et al., Harvard University, 2010.

¹⁶ ARAI, 2007.

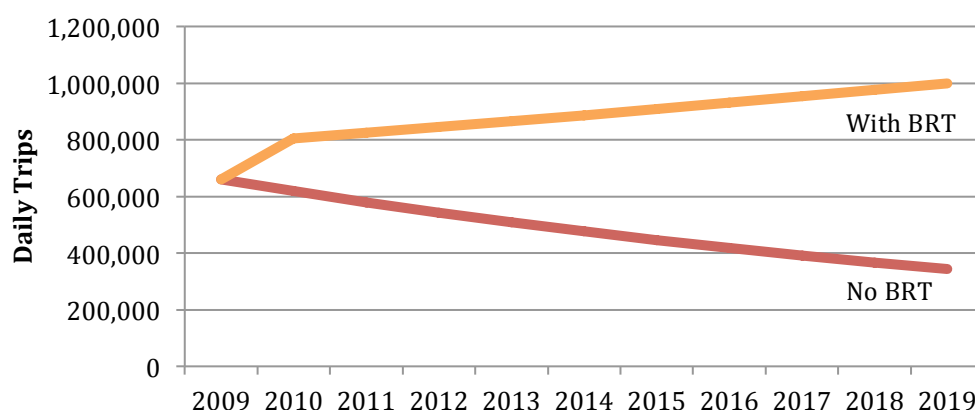
¹⁷ Huo, H., et al., Modeling vehicle emissions in different types of Chinese cities: Importance of vehicle fleet and local features, Environmental Pollution (2011).

ITDP's survey results showed that a relatively small portion of BRT riders had shifted from other motorized modes: only 1.4% of BRT riders switched from private auto, 3% from taxi, and 11% from metro (which actually has a lower emission factor than BRT). However, after less than one year in operation and given current crowding problems on BRT buses, this is still significant and expected to improve. Further, since Zhongshan Avenue has always had a high volume of public bus trips (approximately 660,000 trips/day before the BRT), the opportunity for very high modal shift is smaller. Lastly, despite small shares of overall BRT ridership coming from motorized modes (4.3%), given the large population, this still equates to 30,000 auto trips avoided daily for a total of 90 million VKT avoided in 2010 due to the BRT.

Figure 27: Emissions impact from modal shift to BRT, 2010–19

	CO ₂	PM	CO	NO _x	SO ₂
Emissions reduction from BRT mode shift (t)	186,969	3	6,015	668	22

Figure 28: Projected BRT ridership baseline and BRT scenario 2009–19



In order to project the emissions impact of modal shift over the period of 2010-19, ITDP used data on expected bus mode share in 2015 from the City of Guangzhou, which projected a yearly decrease of 6.3% in bus ridership for the “no-project” baseline scenario.¹⁸ The growth in trips on the corridor was estimated using city-wide estimates of trip growth from the city of Guangzhou’s twelfth Five-Year Plan, which predicted 2.6% growth each year through 2020. Though development along the corridor is increasing rapidly, there was no strong data on the rate of growth in demand for the new BRT service, so this calculation conservatively assumed that bus ridership in the BRT scenario would hold steady at 2010 levels, instead of declining sharply as in the “no-project” baseline scenario, as illustrated in Figure 28. The emissions avoided from other modes are shown in Figure 27.

¹⁸ Based on 2010-15 modal shift projections of *City of Guangzhou's 12th 5-Year Plan*.

Calculating the CO₂ Impact of Changes in Bus Speed and VKT from BRT Operations

While the previous formula calculates the emissions avoided when passengers switch to BRT, the following formula calculates the emissions emitted by the BRT, inclusive of any changes in ridership from modal switch, speed/fuel economy, and VKT. The emissions impact of changes in average bus operating speed and yearly VKT due to route rationalizations are calculated together because in order to find the operating emissions of the BRT system, the VKT and the speed-adjusted emissions factor of the BRT must be applied to each other in order to produce an emissions estimate. The formula below finds emissions impact of BRT operations, including changes in VKT due to route rationalization and changes in fuel efficiency due to operating characteristics. The formula subtracts total yearly BRT emissions from yearly emissions without the BRT in place, in order to find the total emissions impact from BRT operations. Yearly bus emissions are found by multiplying a speed-adjusted emissions factor by the total VKT for the year.

$$[(E_{\text{BRT}} * T_{\text{BRT}}) - (E_{\text{No BRT}} * T_{\text{No BRT}})] = I_{\text{operations}}$$

$I_{\text{operations}}$ = Cumulative yearly emissions impact from changes in bus operations

E = Emissions factor for buses in a given year, including changes from average speed

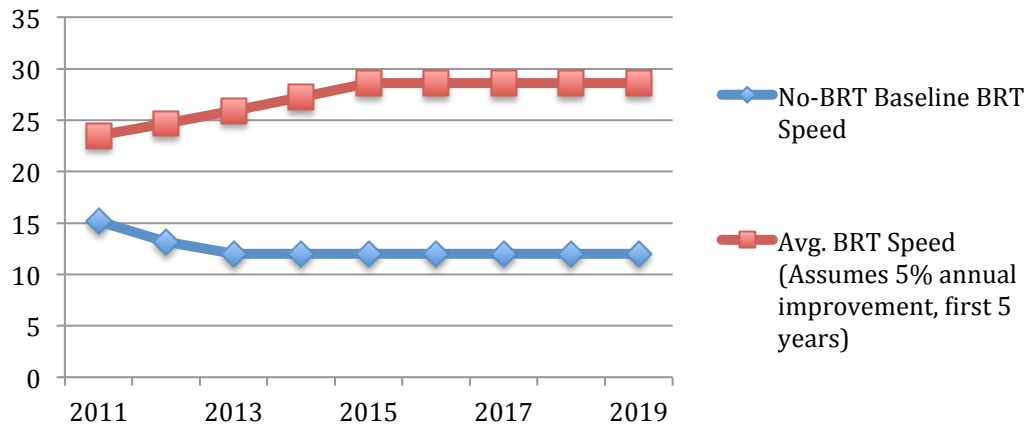
T = Cumulative vehicle kilometers traveled for all buses in BRT corridor in a given year

There is limited research and reporting on the fuel economy and emission factors of LPG buses. Several sources on the fuel economy of an LPG bus were evaluated in-depth, including fleet-wide figures given to ITDP by the GZ BRT authority, which were considered to be unreliable. In the end, the running emission factors for the range of LPG buses within the IVE database were averaged. The average running emission factor of a loaded LPG bus (532 g/km of CO₂) was then calibrated for pre-BRT (830 g/km) and post-BRT (770 g/km) in 2010 average operating speeds using a speed-to-fuel-economy curve from the COPERT emissions model. As discussed earlier, the average operating speed of Zhongshan buses has gone up 29%, creating a fuel efficiency gain of about 6%.

Figure 29: Emissions impact from BRT operations

2009 Pre-BRT VKT	142,238,106
2009 Emissions speed-adjustment factor	1.56
2010 BRT VKT	118,497,938
2010 Emissions speed-adjustment factor	1.45
2009 Speed-adjusted emfac (g CO/km) at 17.5 kph	8.3148
2010 Speed-adjusted emfac (g CO/km) at 22.5 kph	7.7285
Base IVE emfac for heavy LPG PM (g/km)	0
Base IVE CO ₂ emfac for heavy LPG g/VKT	532
Base IVE CO emfac for heavy LPG	5.33
Base IVE emfac for heavy LPG NO _x (g/km)	0.98
Base IVE emfac for heavy LPG SO ₂ (g/km)	0

Figure 30: Assumed speed changes for BRT and no-BRT baseline



To calculate the emissions impact from changes in BRT operations for 2010-19, two assumptions were made: 1) the BRT improves its speed 5% per year for the first 5 years (reaching 28.5 kph), and 2) the comparative no-BRT scenario sees BRT speeds dropping from its pre-BRT speed of 17.5 kph by 13% per year (as reported by the Guangzhou Institute of Transportation Planning) until it reaches 12.5 kph in 2013, and bottoming out at that level through 2019. Note that there is no significant reduction in particulate matter of sulfur dioxide from BRT operations as the buses in Guangzhou are powered by LPG, which emits almost no particulate matter when combusted.

Figure 31: Emissions Impact from BRT Operations, 2010–19

	CO ₂	PM	CO	NO _x	SO ₂
Emissions reduction from BRT VKT reduction (t)	190,078	0	1,904	502	0
Emissions reduction from BRT speed increase (t)	85,759	0	859	321	0

Calculating the CO₂ Impact of Changes in Mixed Traffic Speed in the Corridor

The GZ BRT corridor has removed hundreds of buses from Zhongshan Avenue's mixed traffic lanes and concentrated them in just two center lanes, leaving three lanes clear of buses for mixed traffic. Similar to what was observed with the Mexico City Insurgentes BRT, significant increases in overall traffic speed were achieved by removing many frequent-stop buses from the mix. The last formula of this methodology calculates emissions impact of increases in speed for the mixed traffic speeds on

Zhongshan Avenue, which allows the other vehicles to operate with higher fuel efficiency.

In order to calculate this impact, the number of trips made on the corridor by each basic vehicle class is estimated from ITDP traffic counts and multiplied by the average trip distance in the corridor to get the VKT of each vehicle class. Next, average running emission factors from the IVE database are calibrated for observed pre-BRT and post-BRT operating speeds on Zhongshan Avenue and applied to the VKT estimates to create pre-BRT and post-BRT mixed traffic emissions estimations. Pre-BRT mixed traffic emissions are subtracted from post-BRT mixed traffic emissions to find the annual emissions impact from speed increases in mixed traffic.

$$\sum V_{\text{vehicle class}} [(T) (D) (F_{\text{pre-BRT}} - E_{\text{post-BRT}})] = I_{\text{mixed traffic}}$$

I = Cumulative yearly emissions avoided from other modes in tonnes of emissions

T = Total trips estimated from screen line traffic counts

V = Vehicles classes: car, truck, taxi, coach bus

D = Average travel distance in corridor

E = Emissions factor for a given year including changes from average speed

Comprehensive corridor counts were not possible in a corridor the size of Zhongshan so total corridor trip estimates were made based on screen line counts and average trip lengths. Daily average mixed traffic speeds increased from 26 kph to 33.5 kph from before the BRT to after it.

Figure 32: CO₂ impact from speed increase of mixed traffic in BRT corridor

	VKT	Base CO ₂ emfac (g/VKT)	Base PM emfac (g/VKT)	Base CO emfac (g/VKT)	Base NOx emfac (g/VKT)	Base SO ₂ emfac (g/VKT)	2010 No-BRT emfac speed adjust factor	2010 BRT emfac speed adjust factor
Car	159414	191	0.01	10.5	1.39	0.03	1.16	1.0675
Taxis	57,952	140	0.00	4.97	0.42	0.02	1.16	1.0675
Trucks	8,134	410	0.23	43.58	5.73	0.06	1.255	1.13
Coach Bus	2,932	683	0.23	43.58	5.73	5.73	1.31	1.17

The estimation of the emissions impact of mixed traffic from 2010-19, is based on two assumptions of travel speed for buses and mixed traffic: 1) Mixed traffic in the corridor will decline over time at the same rate observed before the BRT was implemented¹⁹

¹⁹ Travel speed declined on trunk road is -13% per year, as measured by GMEDRI, 2008-2009.

stabilizing once it reaches the speed of the BRT (28 kph) because if the speed decreased further, travelers will switch modes to the BRT for a faster journey. 2) Mixed traffic in the no-BRT baseline scenario would also continue to decline at the observed rate until bottoming out at 15 kph in 2015. Without a BRT on the corridor, mixed traffic would stay subject to large decreases in average speed and associated fuel efficiency over time, thus large emissions impacts are realized over the long term.

Figure 33: Speed projections for bus and mixed traffic in BRT and no-BRT scenarios, 2010–19



Figure 34: Emissions impact of BRT effect on mixed traffic speed

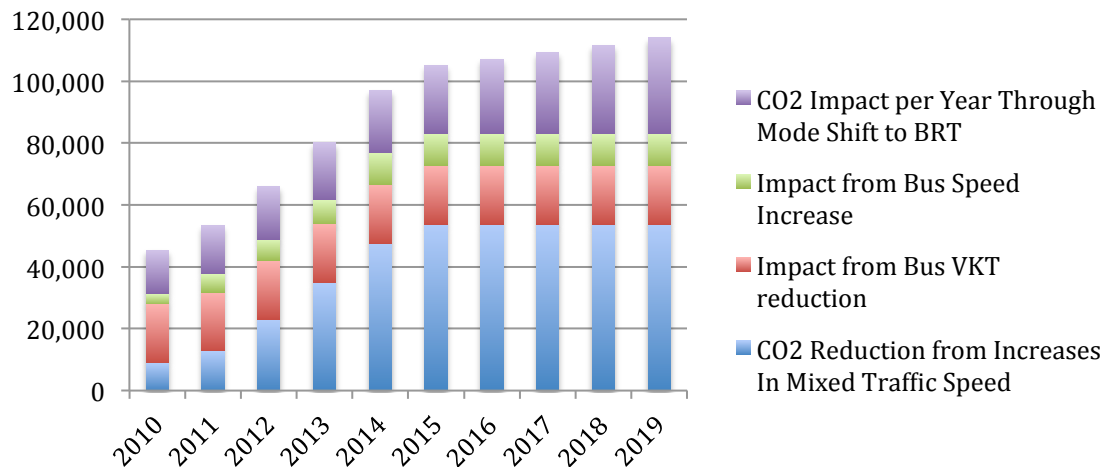
	CO ₂	PM	CO	NO _x	SO ₂
Mixed traffic speed increase emissions reduction (t)	396,561	37	23,000	2,910	200

Leakage Factors

Based on the Global Environmental Facility’s “Transport Emissions Estimation Model for Projects,” the GZ BRT would have produced 24,000 tonnes of CO₂ for project construction, based on general assumptions for cement, bitumen, and steel needed. Leakage from the “Rebound Effect” on mixed traffic trips and speeds is currently unknown as data collection is on-going and construction on and around the corridor distorted vehicle counts. Leakage from the construction of new transit vehicles or the re-use of old transit vehicles is not relevant as this study claims no emissions impact for vehicle technology upgrades.

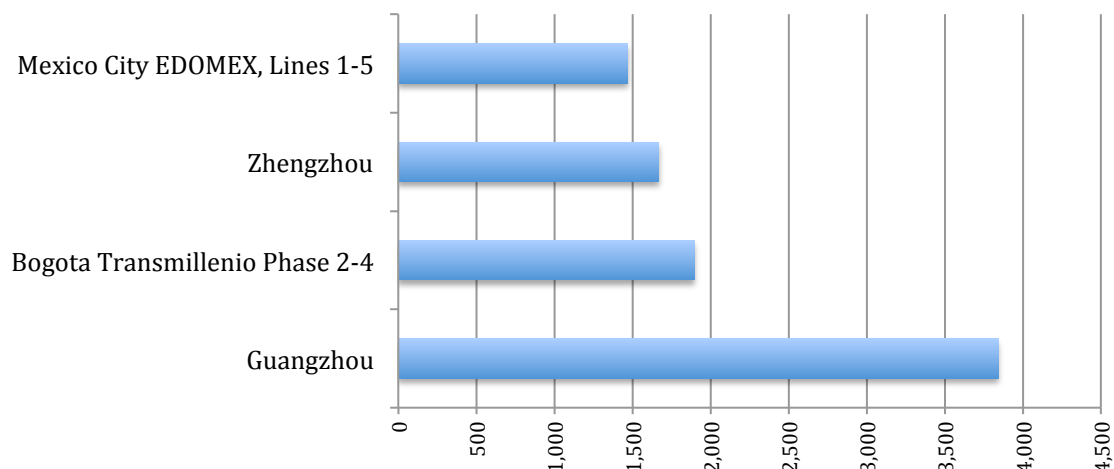
Carbon Dioxide Emission Reductions

Figure 35: GZ BRT yearly CO₂ reductions by source, 2010–19
Total: 865,000 tonnes CO₂ reduced



In its first year of operation, the Guangzhou BRT is estimated to have reduced 45,000 tonnes of CO₂, based on observed changes in modal share, bus speed, mixed traffic speed, and bus VKT. However, due to the divergence of baseline and project scenario modal shares and vehicle speeds over time, the yearly CO₂ impact will double by 2014, stabilizing in 2015 (when decreases in vehicle speeds in the no-BRT scenario have bottomed out) at over 100,000 tonnes of CO₂ reduced per year over the no-BRT baseline scenario.

Figure 36: Annual GHG reduction per km of BRT lanes of various systems

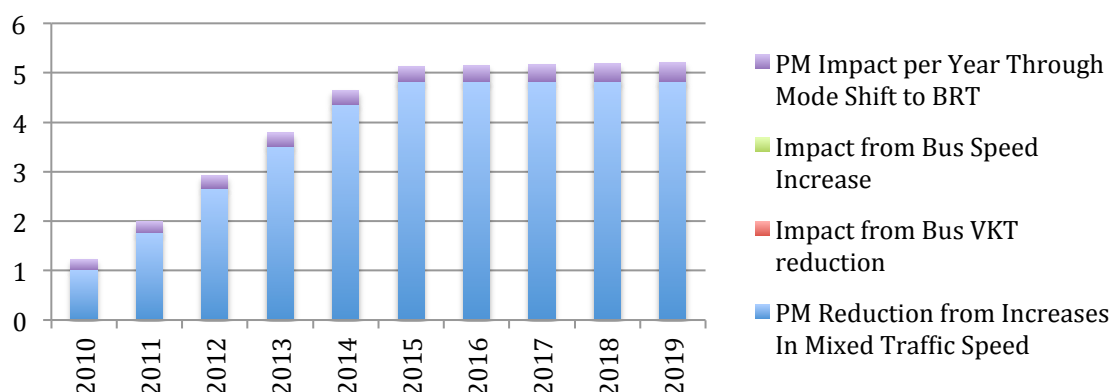


Several other BRT systems that have quantified their emissions for CDM financing have higher absolute numbers of GHG reduction over time. However, these systems generally have many more kilometers of BRT corridor(s). While the GZ BRT is only 22.5 kilometers

in length, its ultra-high ridership, operational efficiency, and reversal of precipitous declines in vehicle speed combine to create what is, by far, the highest CO₂ reductions per kilometer of BRT infrastructure, as illustrated in Figure 36. GZ BRT's average yearly CO₂ reduction, normalized per kilometer of BRT infrastructure, is over 3,800 tonnes—approximately double that of Zhengzhou, Mexico City, and Bogotá.

Particulate Matter Emissions Reduction

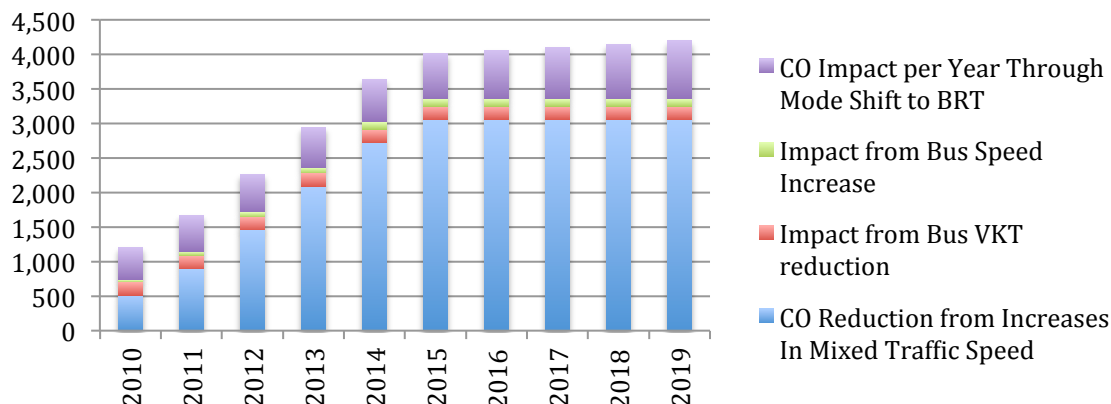
Figure 37: GZ BRT yearly PM reductions by source 2010–19
Total: 40 tonnes PM Reduced



The particulate matter reduction from GZ BRT, while significant with a total of 114 tonnes over ten years, is low because Guangzhou's buses and taxis are already powered by LPG, which releases nearly insignificant amounts of PM. Therefore PM was only reduced from mode shift and speed/fuel economy improvements of private automobiles.

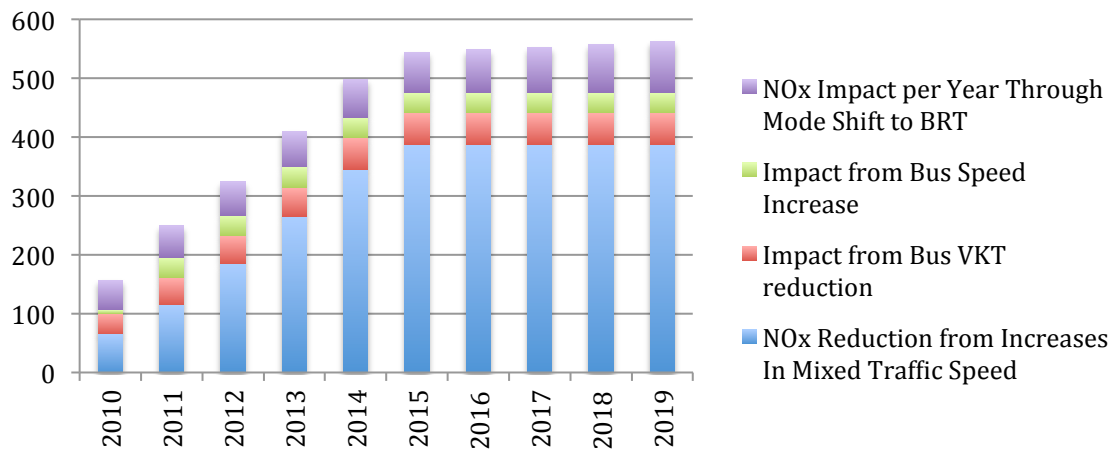
Carbon Monoxide Emissions Reduction

Figure 38: Annual reductions in CO by source, 2010–19
Total: 32,246 tonnes CO reduced



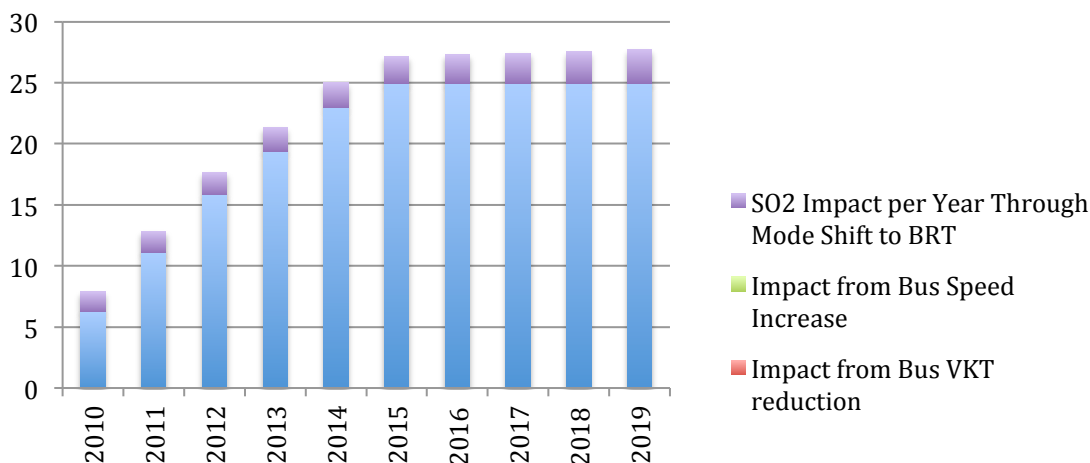
Nitrogen Oxides Emission Reduction

Figure 39: Annual NO_x reductions by source, 2010–19
Total: 4400 tonnes reduced



Sulfur Dioxide Emissions Reduction

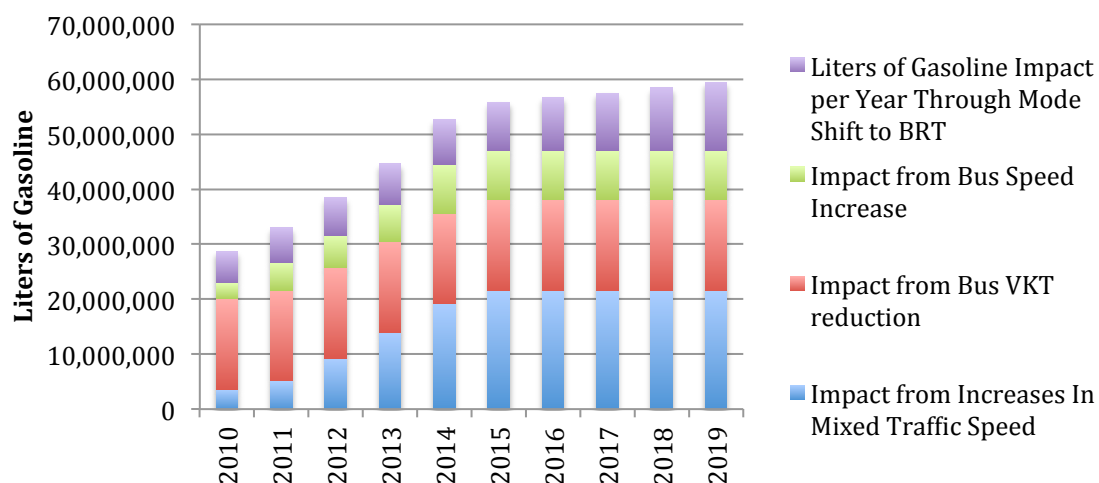
Figure 40: GZ BRT yearly SO₂ reductions by source, 2010–19
Total: 222 tonnes SO₂ reduced



Gasoline Consumption Reduction

Gasoline savings were estimated roughly by back-calculating the emissions impact of the system to fuel volume by dividing the tonnes of CO₂ reduced by the CO₂ emission rate of the combustion of one liter of fuel. LPG fuel volume saved from bus operations was converted to gasoline using their ratio of BTU content. The project is estimated to save an average of 48 million liters (12.5 million gallons) of gasoline per year, from 2010-19.

Figure 41: Gasoline consumption reduction from GZ BRT, 2010–19
10-year total: 485 million liters



Final Remarks

GZ BRT is exciting proof that “metro-scale” BRT is not only viable, but can be highly successful in Asia’s rapidly growing cities. It offers large local and global environmental benefits, significant time savings for users, and financial return on capital investment.

The largest impacts of GZ BRT are likely still to come. It is still too early to know the impact the system will have on land use patterns and household automobile ownership rates. Guangzhou is undergoing massive growth of population, economy, and cars. With rapid increases in wages and standard of living, Guangzhou residents registered more than 300,000 new cars in 2010 alone for an increase in private vehicles of 22% annually over the past five years.²⁰ Prior to recent investments in the GZ BRT and Metro, transit in Guangzhou had been declining quickly in terms of speed, quality, and mode share.

Yet evidence from around the world shows that when high-quality transit service is in place, it encourages denser, more mixed-use land uses, setting a land use pattern more conducive to walking, biking, and transit in place of automobile trips. If this investment in multi-modal transportation encourages even a very small fraction of the several million people who live along the Zhongshan corridor to forgo a car purchase the impacts on GHGs is very large. Further, if local developers capitalize on these alternative transport assets and build dense, walkable, mixed-use housing developments with low parking ratios, the impact will grow larger than estimated here and be better sustained over time.

²⁰ <http://guangzhou.auto.sohu.com/20110118/n278948754.shtml>

Acknowledgements

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