LS1: STRUCTURED ASSESSMENT OF BRT PERFORMANCE

DRIVERS OF BUS RAPID TRANSIT SYSTEMS – INFLUENCES ON RIDERSHIP AND SERVICE FREQUENCY

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ABOUT ACROSS LATITUDES AND CULTURES BRT CENTRE OF EXCELLENCE

Across Latitudes and Cultures - Bus Rapid Transit (ALC-BRT) is a Centre of Excellence for Bus Rapid Transit development implemented in Santiago, Chile, and financed by the Volvo Research and Educational Foundations (VREF).

This CoE was established in May of 2010 and is working as a consortium of five institutions that include Pontificia Universidad Católica de Chile (PUC), Instituto Superior Técnico (IST) Technical University of Lisbon, Institute of Transport and Logistics of Sydney (ITLS) University of Sydney, Massachusetts Institute of Technology (MIT), and EMBARQ - The WRI Center for Sustainable Transport, including its network of centers of sustainable transport.

ABSTRACT OF THIS REPORT

This document reports the findings of a comparative analysis of bus rapid transit (BRT) performance using information on 121 BRT systems throughout the world, in which random effects regression is employed as the modelling framework. A number of sources of systematic variation are identified which have a statistically significant impact on BRT patronage in terms of daily passenger numbers such as fare, frequency, connectivity, pre-board fare collection, and location of with-flow bus lanes and doorways of a bus. In addition to the patronage model, a bus frequency model is estimated to identify the context within which higher levels of service frequency are delivered, notably where there exists higher population density, more trunk lines, the corridor provides bus priority facilities such as priority lanes for many bus routes, and where there is the presence of overtaking lanes at more than half of all stations along the heaviest section of the corridor. The findings offer important insights into features of BRT systems that are positive contributors to growing patronage which should be taken into account in designing and planning BRT systems.

Keywords: Service quality, value for money, bus rapid transit, ridership, connectivity, frequency

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1 Introduction

Public transport investment is touted as a key springboard for a sustainable future, especially in large metropolitan areas with growing populations. Public transport, however, is very much multi-modal and should not be seen as a single mode solution as is so often the case with many ideologues (Hensher 2007, 2007a). Hence, any commitment to improve public transport has a growing number of options to pursue. Although enhancement in rail systems typically loom dominant in many strategic statements on urban reform (Sislak 2000; Edwards and Mackett 1996), ranging from heavy rail to metro rail and light rail, there is a growing interest worldwide in making better use of the bus as a primary means of public transport, and not limited as a service that in many counties (especially Western societies) predominantly feeds a rail network (Hensher 1999, 2007, 2007a; Canadian Urban Transit Association 2004; Callaghan and Vincent 2007).

It is 20 years since the influential paper by Hensher and Waters on choice versus blind commitment to specific public transport modes (Hensher and Waters 1993), and follow up papers by Hensher (1999 and 2007) in which the merits of a bus based system were promoted as a serious alternative to light rail in particular, but also heavy rail in some situations. Central to the argument to give bus-based systems (especially bus rapid transit (BRT) systems) credibility is recognition that services for a metropolitan area must be regarded as a system in which the key elements of connectivity, frequency and modal visibility must be dominant considerations in establishing value for money public transport. Connectivity refers to the provision of door-to-door services with minimum delay and almost seamless interchanges, and visibility is knowing where the mode is coming from and going to, and when[1].

BRT as a 'mass transit' system has typically been characterised by high running speeds, passenger capacity, frequency and operating on an exclusive right-of-way (ROW). In assigning 'mass transit' in its name, BRT shares these characteristics with Mass Rapid Transit (MRT) and Light Rapid Transit (LRT) but with the major difference

[1] Despite all the efforts to explain that Bus Rapid Transit involves buses on dedicated roads, and not mixing with cars and trucks, the message has failed in many jurisdictions where the word 'bus' is immediately interpreted as buses in mixed traffic competing with cars and trucks. It is time for a radical move – a name change for BRT. We have been thinking about this for many years and we now believe that we should no longer be talking about BRT but about **Dedicated Corridor Rapid Transit** (DCRT). This places the matter fairly and squarely where it belongs – the corridor delivering transit services, with transit defined as all candidate public transport modes, or as defined online as "public transportation system for moving passengers". That is the big sell, and not whether it is steel track or bitumen.

of the vehicles running with pneumatic tyres rather than on rails. BRT systems can be delivered at a fraction of the cost of a rail based system, between four to twenty times less than a LRT system and between ten to 100 times less than a metro system for the equivalent level of service (in contrast to vehicle) capacity per hour (Wright and Hook 2007, see also Levinson et al 2003; Menckhoff 2005; Transit Cooperative Research Program 2007). It is this lower cost system, but one which emulates the performance and amenity characteristics of a modern rail system, which has led to the growing global interest in BRT as a urban passenger transport solution in situations typified by maximum peak hour ridership at least up to 20,000 passengers, but often in the range 20,000 to 45,000 passengers per hour.

In examining BRT systems around the world, it is clear that these characteristics are combined in a myriad of different ways, giving rise to the concept of a continuum of quality in a BRT system definition. It would be easy to define 'good' BRT as having the highest quality possible on each of these characteristics. But the real world evidence shows that BRT systems in place are a response to the needs of the urban area and have a mixture of quality standards for these characteristics, giving rise to a labeling of the spectrum from BRT 'lite (better than a high quality bus system) to 'good' BRT. In particular it is difficult to compare a BRT system with several state of the art characteristics perhaps in operation and frequency against a BRT system which is a good 'all rounder' in terms of desirable characteristics.

The primary purpose of this paper is to investigate the features of BRT systems that promote patronage growth. This paper is organised as follows. The following section defines the data used for econometric modelling. This is followed by the econometric model form, random effects regression, and its advantages over simple regression. We then present the key empirical findings, and discuss how these influence BRT patronage in terms of total system passengers per day. In addition to the patronage model, a frequency model was also estimated where some sources of systematic variation are revealed. Important findings are summarised and conclusions are drawn in the last section.

2 Ridership Drivers of Bus Rapid Transit Systems

A number of studies have conducted reviews of BRT systems (see e.g., Hidalgo and Graftieaux 2008; Hensher and Golob 2008; Deng and Nelson 2011; Hensher and Li 2012). Among these existing BRT review studies, only Hensher and Golob (2008) and Hensher and Li (2012) conducted formal statistical analyses to comparatively assess

BRT systems (e.g., their infrastructure costs and ridership). In the most recent study, Hensher and Li (2012) collected information on 46 BRT systems from 15 countries to investigate the potential patronage drivers. A number of sources of systematic variation are identified which have a statistically significant impact on daily passenger numbers. These sources include fare, headway, the length of the BRT network, the number of corridors, the average distance between stations; whether there is an integrated network of routes and corridors, modal integration at BRT stations, pre-board fare collection and fare verification, and quality control oversight from an independent agency, as well as the location of BRT.

The empirical study herein focuses on patronage drivers to deliver greater comparative and analytical power relative to traditional literature reviews, to determine which BRT system factors systematically affect BRT patronage. This study uses a sample of 121 systems, including BRT systems which have opened between 1974 and 2011. The results should be taken into account alongside the 'best practice' approach described above when designing and planning BRT systems.

2.1 Data

Information on 121 BRT systems[2] from 12 countries opened between 1974 and 2010, was collected from Across Latitudes and Cultures - Bus Rapid Transit (ALC-BRT), a Centre of Excellence for Bus Rapid Transit development financed by the Volvo Research and Educational Foundations (VREF). The countries are Brazil, Colombia, Venezuela, Ecuador, Peru, Guatemala, Chile, Mexico, India, Turkey, Republica de Panama, and Australia.

A descriptive profile of the key data items is given in Table 1. In addition to a number of continuous explanatory variables such as fares and frequency, the role of a number of categorical variables has been investigated. These include whether the BRT system has pre-board fare collection, fare integration to a feeder system, doorways located at both the left and right, longitudinal location of with-flow bus lanes on sides, real time connection between buses and traffic signals (on-line priority for buses), and low-level platform and level boarding. All categorical variables are coded as dummy variables (yes or no) in the regression model.

[2] Given that some variables have missing data (see Table 1), the final models reported have less than 121 observations, with the final sample size determined by the dependent or explanatory variable that has most missing observations.

Table 1: Profile of the dependent variable and candidate variables

Dependent variable	Unit	Mean	Standard deviation	Missing
Number of daily passengers	Passengers/day	168,738	225,610	48
Candidate variables				
Quantitative variables	Unit	Mean	Standard deviation	Missing
Minimum fare	US$2010	0.63	0.31	0
Maximum fare	US$2010	1.55	0.81	0
Frequency	Buses/hour/direction	116.10	115.17	44
Corridor length in both directions	km	19.20	21.93	0
Number of stations	Number	17.63	16.10	16
Number of transfer stations	Number	4.28	5.05	1
Number of trunk lines	Number	2.81	9.93	4
Extension of segregated with-flow lanes	km	17.07	17.94	0
Extension of contra-flow lanes	km	0.46	2.20	0
Extension of exclusive lanes	km	0.53	2.88	0
Public transport share	%	43.65	12.95	0
Mode share by car	%	28.80	9.67	0
Average commercial speed during peak hour	km/h	20.47	4.53	36
Population density of metropolitan area	Persons/km²	1393.21	1894.61	0
GDP per capita in 2010	Thousand US$2010	10.17	3.96	0
Number of years that a BRT system has been in operation (compared to 2012)	Years	11.82	11.88	13
Qualitative variables (whether the BRT system has)	Percentage as "Yes"			Missing
Fare integration to feeder system	86.8%			0
Pre-board fare collection	28.1%			0
Doorways for passengers on left and right sides of bus	5.1%			0
Longitudinal location of with-flow bus lanes on sides	32.2%			0
Real time connection between buses and traffic signals (on-line priority for buses)	3.3%			0
Conventional bus services: corridor provides bus priority facilities (such as priority lanes) for many bus routes	53.7%			0
Overtaking lanes at more than half of all stations along the heaviest section of the corridor	30.6%			0
Low-level platform, level boarding	9.9%			0

US$2010: All monetary values are converted into a common currency (US$) and period (2010)

2.2 Methodology

In Hensher and Golob (2008), ordinary least squares (OLS) regression is used to investigate potential sources of systematic variation in BRT patronage. A key assumption of OLS regression is that all observations are independent. However, in this study, multiple BRT systems are located within one country. Given this, observations within a single country could be correlated to some extent, given some common characteristics of the country. To capture this, instead of an OLS regression model, a random effects regression model (equation 1) is used.

$$y_{it} = a + \boldsymbol{\beta}^{'}\mathbf{x}_{it} + u_i + \varepsilon_{it} \tag{1}$$

Here, x is a vector of regressors associated with the i^{th} country and t^{th} BRT system; ε_{it} is a random error term, with $E[\varepsilon_{it}]=0$ and $\mathrm{Var}[\varepsilon_{it}]=\delta^2$; u_i is a country-specific disturbance with $E[u_i]=0$ and $\mathrm{Var}[u_i]=\varphi^2$, also $\mathrm{Cov}[\varepsilon_{it},u_i]=0$; *i* represents a country (in this paper, *i*=1, 2 … 12), and *t* is the number of BRT systems located within each country.

A random effects regression model operates by allowing each i^{th} country to have a unique disturbance (u_i); hence within a set of observations drawn from the same country, the disturbances are no longer independent. The model is estimated by generalised least squares.

2.3 Sources of Systematic Variation in BRT Ridership

The best patronage model is reported in Table 2. This model explains 85 percent of the variation in daily passengers of the 54 BRT systems without missing data items, where all parameter estimates are statistically significantly different from zero at or over the 95 percent confidence level.[3]

In this model, the natural-logarithmic transformation is further applied to the maximum fare divided by GDP per capita variable. Given that this is a multi-national study, fares should be normalised by some form of cost-of-living. We used the maximum fare divided by GDP per capita to capture this potential effect. The dependent variable (ridership) is already in the natural logarithm form; therefore the double-logarithmic form directly delivers the mean estimate of direct fare elasticity. The estimated mean direct fare elasticity is -0.27, which is substantially higher than the estimate of Hensher

[3] The correlation matrix for listed variables in Table 2 is given in Appendix B.

and Golob (2008) at -0.12, but is closer to estimates of fare elasticities associated with conventional and bus and rail systems. Hensher (2008), in a meta analysis of 241 observations, reports a mean estimate of -0.395 for fares which is close to -0.38 reported in Holmgren (2007) for 81 observations and other reviews such as Goodwin (1992), Oum et al. (1992), Nijkamp and Pepping (1998) and Litman (2005).

The natural-logarithmic transformation is also applied to the frequency variable to directly identify the ridership elasticity with respect to frequency of 0.87. Compared to existing evidence, the frequency elasticity estimated in this study has a higher value. For example, the highest value of frequency elasticity sampled in Hensher (2008) is 0.70.

Table 2: Patronage model (dependent variable: natural logarithm of daily passengers)

Explanatory variable	Parameter	t-ratio
Continuous variables		
Nature logarithm of (maximum fare divided by GDP per capita)	-0.2703	-1.96
Nature logarithm of frequency	0.8737	10.35
Mode share by car	-0.0140	-2.13
Nature logarithm of (Number of BRT stations interacted with extension of segregated with-flow lanes)	0.3222	4.75
Dummy variables		
Pre-board fare collection (Yes)	0.5016	2.94
Doorways for passengers on left and right sides of bus (Yes)	-0.7846	-3.20
Longitudinal location of with-flow bus lanes on sides (Yes)	-1.0885	-3.87
Constant	6.6186	11.11
Disturbance term effects		
Country-specific disturbance (u_i)	0.050	
Random error term (ε_{it})	0.1439	
Sample size	54	
Adjusted R^2	0.85	

In addition to fare and frequency, we identified other systematic sources of variation which significantly influence ridership. As expected, the mode share of car travel, which proxies for the relative attractiveness of the car, has a negative impact on BRT patronage. The interaction of the number of BRT stations and extension of segregated with-flow lanes has a positive parameter estimate, which highlights the importance of *connectivity* (as defined in an earlier section) in encouraging patronage, i.e., the shorter distance between BRT stations (or having more stations) would improve access and egress, even though in-vehicle times might be increased if the service is an all-stop one. This also translates into a cost effective potential advantage of BRT over other mass transit such as heavy rail, as it is much easier to add a new station in a BRT system, both at a relatively low cost and also in terms of design constraints.

A number of categorical variables are found to have a statistically significant influence on ridership, providing further insights into the design and planning of BRT systems. Other things being equal, this model suggests a BRT system equipped with pre-board fare collection would attract more ridership. Pre-board fare collection and fare verification would significantly reduce the boarding time, and hence contribute to the reduction in total journey time and time variability, as well as less crowding at stations and reduced congestion amongst buses. These improvements would substantially improve user benefits and consequently increase public transport patronage. This finding is in line with Tirachini and Hensher (2011) who found that the pre-board system is the optimal choice for bus fare collection from a cost-effective perspective. We also find that buses with doorways for passengers on the left and right sides relative to other configurations (i.e., either on left or right side), has a negative influence on patronage. A BRT system with longitudinal location of with-flow bus lanes on sides tends to negatively impact patronage, relative to where with-flow bus lanes are located on centre.

3 Correlates of BRT service Frequency

In addition to the patronage model (Table 2), we estimated a frequency model summarised in Table 3. Four explanatory variables explain 43 percent of the variation in frequency of the 77 BRT systems, where all parameter estimates are statistically significantly different from zero at or better than the 95 percent confidence level.[4] Frequency is positively related to population density, indicating that the higher population density supports potentially higher demand for BRT ridership, and hence more frequent service is needed. The implied direct elasticity of frequency with respect to population density of 0.312 is strong evidence on the opportunities that avail BRT when population density increases.

The number of trunk lines has a positive parameter estimate, representing the ability of a BRT system to provide more frequent service. With regard to the type of service

[4] The correlation matrix for listed variables in Table 3 is given in Appendix C.

operation along the corridor, conventional bus services (i.e., corridor provides bus priority facilities such as priority lanes for many bus routes) tend to support higher frequency than other types of services (e.g., trunk lines only: specific bus lines serving the corridor with no physical or fare integration with bus feeder routes; and trunk lines with feeder routes: specific bus lines serving the corridor complemented by bus feeder routes to transfer stations or terminals). Moreover, frequency tends to be higher if it is associated with a BRT system that has overtaking lanes at more than half of all stations along the heaviest section of the corridor. These sources of systematic variation in service frequency influence patronage via the levels of frequency offered[5].

Table 3: Frequency model (dependent variable: natural logarithm of frequency)

Explanatory variable	Parameter	t-ratio
Continuous variables		
Nature logarithm of population density	0.3122	4.20
Number of trunk lines	0.0180	2.34
Dummy variables		
Conventional bus services: corridor provides bus priority facilities such as priority lanes for many bus routes (Yes)	0.9799	4.62
Overtaking lanes at more than half of all stations along the heaviest section of the corridor (Yes)	0.4812	2.69
Constant	1.1966	2.24
Disturbance term effects		
Country-specific disturbance (u_i)	0.1914	
Random error term (ε_{it})	0.4943	
Sample size	77	
Adjusted R^2	0.43	

4 Conclusions

Using information on 121 BRT systems from 12 countries to investigate potential patronage drivers, this paper has provided new evidence to describe features of BRT that are positive contributors to supporting patronage growth. The empirical study shows that a number of sources of systematic variation are identified which relate to

[5] We investigated a joint ridership and frequency model, as two and three stage least squares, but we were unable to find any improvement over separate models. We suspect this is linked to the sample size.

elements of design and these have a statistically significant impact on daily passenger numbers.

It is useful to summarise the key drivers that have been revealed from our recent studies, as shown in Table 4. There are some clear consistencies across all three studies, based on 99 separate systems, notably the average fare, service frequency, station spacing, pre-board fare collection, and location of doors. There are also study-specific evidence supporting a number of other features such as vehicle capacity, modal and network integration and corridor length.

Table 4: Accumulated Evidence on Key Drivers of BRT patronage

The Current Study	Hensher and Golob (2008)	Hensher and Li (2012)
Maximum fare	Average fare per trip	Average fare per trip
Service frequency	Peak headway	Headway
Car mode share	Trunk vehicle capacity	Average distance between stations divided by population density
Number of BRT stations interacted with extension of segregated with-flow lanes	Number of stations	Number of existing truck corridors
Pre-board fare collection		Pre-board fare collection and fare verification
Doorways for passengers on left and right sides of bus		Doorways located on median and curbside
Longitudinal location of with-flow bus lanes on sides		Existence of an integrated network of routes and corridors
		Modal integration at stations
		Total length of BRT corridor
		Opening year relative to 2011
		Quality control oversight from an independent entity/agency
		Latin America (Location of BRT)

The findings offer valuable advice on what characteristics of BRT systems contribute to growing ridership, which can be used to assist in planning and designing BRT systems to attract more users to public transport, especially from cars[6]. BRT has great potential as a sustainable transport system, to deliver high levels of frequency, regularity, connectivity and visibility for a relatively lower cost than other fixed rail systems, resulting in an attractive value for money outcome for an entire metropolitan area.

[6] This would be helped by some appropriate pricing mechanisms such as congestion pricing so that private car uses face more realistic price signals.

Framing the implementation of BRT with an eye on the design principles which generate high performance, tempered by the evidence on the elements of design which contribute most highly to patronage, is a key to developing a successful BRT system.

5 References

Canadian Urban Transit Association (2004) Bus rapid transit: A Canadian perspective. Issues Paper #10, CUTA, Toronto.

Callaghan, L. and Vincent, W. (2007) Preliminary evaluation of Metro Orange Line bus rapid transit project. *Transportation Research Record* 2034, 37-44.

Deng, T. and Nelson, J.D. (2011) *Recent developments in Bus Rapid Transit: A review of the Literature, Transport Reviews, 31(1), 69-96.*

Edwards, M. and Mackett, R. L. (1996) Developing new urban public transport systems: An irrational decision making process. *Transport Policy* 3, 225-239.

Goodwin, P. (1992) A review of new demand elasticities with special reference to short and long run effects of price changes, *Journal of Transport Economics and Policy*, 26, 155-163.

Hensher, D.A. (1999) Bus-based transit way or light rail? Continuing the saga on choice versus blind commitment. *Roads and Transport Research* 8(3), September 3-21.

Hensher, D.A. (2007) Sustainable public transport systems: Moving towards a value for money and network-based approach and away from blind commitment. *Transport Policy* 14 (1), 98-102.

Hensher, D.A. (2007a) *Bus Transport: Economics, Policy and Planning.* Research in Transportation Economics, Volume 18. Elsevier, Oxford.

Hensher, D.A. (2008) Assessing systematic sources of variation in public transport elasticities: some comparative warnings, *Transportation Research Part A* 42(7), 1031–1042.

Hensher, D.A. and Golob, T.F. (2008) Bus rapid transit systems – A comparative assessment. *Transportation* 35 (4), 501-518.

Hensher, D.A. and Li, Z. (2012) Ridership Drivers of Bus Rapid Transit Systems, *Transportation*, online 26 February 2012, DOI: 10.1007/s11116-012-9392-y.

Hensher, D.A. and Stanley, J.K. (2008) Transacting under a Performance-based contract: the role of negotiation and competitive tendering. *Transportation Research A* Special Issue on Public Transport Reform (Thredbo 10), 42A(10), 1295-1301.

Hensher, D.A. and Waters, W.G. II (1994) Light Rail and Bus Priority Systems: Choice or Blind Commitment? February 1993. Plenary paper delivered at 3rd International Conference on Competition and Ownership of Land Passenger Transport (Canada September 1993). An earlier version was presented at the IIR Conference on Urban Transport, Sydney March 1993. in *Research in Transportation Economics*, Vol. III (ed. B. Starr Macmullen), JAI Press, Greenwich, Connecticut, 139-162.

Hidalgo, D. and Graftieaux, P. (2008) BRT systems in Latin America and Asia: results and difficulties in 11 Cities*, Transportation Research Record: Journal of the Transportation Research Board,* No. 2072, 77–88.

Holmgren, J. (2007) Meta-analysis of public transport demand, *Transportation Research Part A*, 41(10), 1021–1035.

Levinson, H., Zimmerman, S., Clinger, J., Rutherford, S., Smith, R. L. and Cracknell, J. (2003) *Bus Rapid Transit: Case Studies in Bus Rapid Transit,* Transportation Research Board of the National Academies, Washington, DC.

Litman, T. (2005) Transit price elasticities and cross-elasticities, *Journal of Public Transportation,* 7(2), 37-58.

Menckhoff, G. (2005) Latin American experience with bus rapid transit. Paper presented at the Annual Meeting*, Institution of Transportation Engineers*, Melbourne, Australia.

Nijkamp, P. and Pepping, G., (1998) Meta-analysis for explaining the variance in public transport elasticities, *Journal of Transportation and Statistics* 1, 1–14.

Oum, T.H., Waters, W.G. and Yong, J. (1992) Concepts of price elasticities of transport demand and recent empirical estimates - an interpretative survey, *Journal of Transport Economics and Policy*, 26(2),139-154.

Sislak, K.G. (2000) Bus rapid transport as a substitute for light rail: A tail of two cities. Paper presented at *8th Joint Conference on Light Rail Transit, Transportation Research Board and American Public Transportation Association*.

Tirachini, A. and Hensher, D.A. (2011) Bus congestion, optimal infrastructure investment and the choice of a fare collection system in dedicated bus corridors, *Transportation Research Part B: Methodological*, 45:5, 828-44.

Transit Cooperative Research Program (TCRP). 2007. *Bus Rapid Transit Practitioner's Guide*. *TCRP Report 118*. Transportation Research Board, Washington DC.

Wright, L. and Hook, W. (2007) *Bus Rapid Transit Planning Guide*, 3rd edition. Institute for Transportation and Development Policy, New York.

Appendix A: Patronage model descriptive statistics and correlation matrix (for variables in Table 2)

Variable	Definition	Mean	Std.Dev.	Minimum	Maximum	Missing
LPASS	Natural logarithm of daily passengers	11.54	1.04	8.80	14.40	48
LRMAXFAR	Nature logarithm of (maximum fare divided by GDP per capita)	-1.95	0.53	-3.27	0.00	0
LFREQUN	Nature logarithm of frequency	4.22	1.11	1.79	6.21	44
CARSHARE	Mode share by car	28.80	9.67	6.0	68.0	0
LSTNEXTK	Nature logarithm of (Number of BRT stations interacted with Extension of segregated with-flow lanes)	2.89	1.24	-0.41	4.81	16
PREBOARD	Pre-board fare collection (Yes)	0.28	0.45	0.0	1.0	0
LRDOOR	Doorways for passengers on left and right sides of bus (Yes)	0.04	0.20	0.0	1.0	0
LOCSIDE	Longitudinal location of with-flow bus lanes on sides (Yes)	0.32	0.47	0.0	1.0	0

Cor.Mat.	LPASS	LRMAXFAR	LFREQUN	CARSHARE	LSTNEXTK	PREBOARD	LRDOOR	LOCSIDE
LPASS	1.00000	-.01582	.68092	-.48600	.39329	-.04443	-.17780	-.36920
LRMAXFAR	-.01582	1.00000	.49914	.15723	-.48939	-.49675	-.19633	-.17207
LFREQUN	.68092	.49914	1.00000	-.17455	.02089	-.58228	-.14446	-.19375
CARSHARE	-.48600	.15723	-.17455	1.00000	-.10515	-.29035	.05120	.28774
LSTNEXTK	.39329	-.48939	.02089	-.10515	1.00000	.11947	.17451	.12145
PREBOARD	-.04443	-.49675	-.58228	-.29035	.11947	1.00000	.05423	-.10847
LRDOOR	-.17780	-.19633	-.14446	.05120	.17451	.05423	1.00000	-.05882
LOCSIDE	-.36920	-.17207	-.19375	.28774	.12145	-.10847	-.05882	1.00000

Appendix B: Frequency model descriptive statistics and correlation matrix (for variables in Table 3)

Variable	Definition	Mean	Std.Dev.	Minimum	Maximum	Missing
LFREQUN	Nature logarithm of frequency	4.22	1.11	1.79	6.21	44
LPOPDEN	Nature logarithm of population density	6.46	1.29	2.20	9.25	0
NOTRUNK	Number of trunk lines	2.81	9.94	0.0	104.0	4
CONVBUS	Conventional bus services: corridor provides bus priority facilities such as priority lanes for many bus routes (Yes)	0.54	0.50	0.0	1.0	0
OVERLANE	Overtaking lanes at more than half of all stations along the heaviest section of the corridor (Yes)	0.31	0.46	0.0	1.0	0

Cor.Mat.	LFREQUN	LPOPDEN	NOTRUNK	CONVBUS	OVERLANE
LFREQUN	1.00000	.31395	.09300	.56695	.26813
LPOPDEN	.31395	1.00000	.02750	.18364	.01289
NOTRUNK	.09300	.02750	1.00000	-.26285	.18812
CONVBUS	.56695	.18364	-.26285	1.00000	-.01501
OVERLANE	.26813	.01289	.18812	-.01501	1.00000

Appendix C: BRT Data Dictionary

Country: the country where the BRT is located

1=	Brazil	9=Turkey
2=	India	10=Republica de Panama
3=	Venezuela	11=Chile
4=	Australia	12=Ecuador
5=	Colombia	
6=	Peru	
7=	Guatemala	
8=	México	

PGDP2010: GDP per capita in 2010

Pop2010: Population of the city in 2010 where the BRT is operated in

PopMet: Population of metropolitan area

PopDens: Population density of metropolitan area (persons/square km)

Modal split in the whole city

PTShare: %public transport

CarShare: % private transport

WakCycl: %non-motorised: pedestrians + cyclists

Fare within the system charged in local currency

MinFare: minimum fare

Maxfare: maximum fare

NoTermnl: Number of integration terminals

NoTran: Number of transfer stations

FeedKM: Total length of all existing bus feeder routes (km)

Year: Year the corridor was inaugurated

Service: Typical service operation along the corridor

1= trunk lines only: specific bus lines serving the corridor with

	no physical or fare integration with bus feeder routes
2=	trunk lines with feeder routes: specific bus lines serving the corridor complemented by bus feeder routes to transfer stations or terminals.
3=	conventional bus services: corridor provides bus priority facilities (such as priority lanes) for many bus routes
4=	2+3
5=	1+2

PeakLoad: Peak load of the corridor (passengers/h/direction)

NoPass:Total passenger corridor demand per day (passengers/day)

CoLength: Corridor length in both directions (km)

ExtSeg:Extension of segregated with-flow lanes (km)

ExtCon: Extension of contra-flow lanes (km)

ExtExc: Extension of exclusive lanes (km)

LonLocW: Longitudinal location of with-flow bus lanes

1=Centre

2=sides

3=centre and sides

LonLocC: Longitudinal location of contra-flow bus lanes

1=Centre

2=sides

3=centre and sides

LocDoor: Location of doorways for passengers inside the buses

1=left

2=right

3=left and right

SurRun: Type of surface material predominant on runways excluding stations

1=asphalt

2=concrete

3=1+2

SurSta:Type of surface material on runways at the stations

1=asphalt

2=concrete

GraSep: Grade-separation in more than half of the critical intersections

1=yes

0=no

FixTraf: Fixed traffic signal phases specially calculated/programmed for buses (off-line priority for buses)

1=yes

0=no

Rtcon: Real time connection between buses and traffic signals (on-line priority for buses)

1=yes

0=no

NoStatns: Number of stations along the corridor

DisbwSta: Average distance between stations (metres)

EnhSta: Enhanced station environment along the heaviest section of the corridor

1=yes

0=no

Preboard: Pre-board fare collection

1=yes

0=no

OverLane: Overtaking lanes at more than half of all stations along the heaviest section of the corridor

1=yes

0=no

BoardCh: Boarding characteristics along the heaviest section of the corridor:

1 = high level platform, level boarding

2 = low-level platform, level boarding

3 = on-street, no level boarding

FuelType: Typical propulsion of the predominant bus services operating along the corridor

1=diesel

2=Natural gas

3=diesel and petrol

4=diesel/biofuel, diesel/Electric

5=Electric

NoTrunk: Number of trunk lines

WithOCC: Existence of an Operational Control Center

1=yes

0=no

FareInt: Fare integration to feeder system

1=yes

0=no

BusGuid: Type of bus guidance

0=none

1=physical

Frequn: Frequency (bus/h/direction)

PHSpeed: Average commercial speed during peak hour (km/h)

RTInfm: Real time next bus information display at stations and terminals

1=yes

0=no

PhyIntg: Physically integrated feeder system at stations and terminals

1=yes

0=no

Perceptn: User perception of quality of services along the corridor

1= Excellent;

2=Good;

3=Regular;

4= Poor;

5=Very Poor.

NameLogo: Special name and logo

1=yes

0=no

Colour: Specific colour that characterizes buses operating trunk lines

1=yes

0=no