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Exploring BRT Ridership Drivers: An Empirical Study on European Systems

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ABSTRACT

Bus Rapid Transit (BRT) systems are becoming internationally popular as a viable public transport option. However, it is not exactly clear which features of BRT systems affect the demand. The hypothesis tested in this paper is whether the BRT design features contribute to higher ridership above and beyond any increase in service frequency when compared to conventional bus routes. An empirical methodology is adopted using multiple regression analysis to analyze data collected on 40 European BRT systems, covering the operation, infrastructure, traffic management and user demand for the selected systems, in addition to other factors like speed and design features. Two models were developed using regression analysis. The models highlighted the three variables which significantly impact the demand: population density, operation span and average commercial speed. The paper concludes with a discussion of the various influences on BRT ridership and recommendations for future research.

KEYWORDS: Bus rapid transit, Ridership, Service level, Public transport infrastructure, Transit operation.

INTRODUCTION

Mobility represents a challenge in modern cities where traffic congestion continues to increase at an alarming rate. Transportation agencies are employing operational and management strategies, as well as public transit system improvements instead of the traditional infrastructure expansions to address the traffic congestion problem. With the financial constraints present in most economies, Bus Rapid Transit (BRT) system are emerging as a viable alternative to rail-based public transit systems. Strengthened bus systems built on rapid bus corridors and improved bus technologies could play an important role in putting cities on a more sustainable path.

The essential seven features of BRT systems are: running ways, frequent services, faster passenger boarding, off-board fare collection, modern stations, cleaner vehicles and a system image that is uniquely identifiable (Jarzab et al., 2002). The components of BRT relate to the key quality transit attributes of speed, reliability and identity. Collectively, they form a transit system that can improve customer convenience and reduce delays compared to local bus and street/trolley car systems (Levinson et al., 2002). In addition to the running ways or busways, the infrastructure also includes stations and pedestrian facilities like crossings. These components make up the backbone of the whole system and determine the potential capacity, reliability and speed of the system. The efficiency of the system is measured by these operational characteristics, but it is also important to assess safety when space sharing is involved; particularly with soft modes like walking and cycling.

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The hypothesis tested in this paper is whether the BRT design features contribute to higher ridership above and beyond any increase in service frequency when compared to conventional bus routes. The theoretical framework of the paper is to explore this hypothesis by measuring the links between service levels and infrastructure design features of existing BRT routes and how these relate to ridership or demand. An empirical methodology is adopted using multiple regression analysis to analyze data collected on 40 European BRT systems, located in both the northern and southern countries of the continent, covering the operation, infrastructure, traffic management and user demand for the selected systems, in addition to other factors like speed and reliability.

RESEARCH BACKGROUND

From the literature review, high service levels, measured in terms of frequency and span of hours covered, were cited as the most important influence on route demand (FitzRoy and Smith, 1998). This was confirmed by Currie and Wallis (2008), who found service quantity to be the single most effective influence on ridership. The other important primary influence is the population density of urban development (Seskin and Cervero, 1996; Johnson, 2003). Overall, past research on bus and light rail ridership suggests that service levels are a principal influence (Currie and Delbosc, 2011). The aim of this research is to suggest, test and identify other factors from a wide range of BRT design features.

RESEARCH APPROACH AND METHODOLOGY

The 40 case studies examined for this research were reduced to 32 due to outliers or inaccuracies in the data provided by the operators. Table 1 summarizes the BRT systems used in this research.

Graphical and tabular analysis of ridership data against other variables was used to initially explore these relationships. Multi-variable linear regression analysis was later performed on the data adopted to explore relationships between the daily ridership variable and the explanatory variables. Two analytical procedures were applied in the analysis:

1. All independent variables were forced into the model to predict the dependent variable.
2. Stepwise Iteration (SI) procedure: the termination of the independent variables elimination process is based on the t-test and F-test outcomes. However, at each stage of the procedure, the deletion of early selected independent variables is permitted. The probability of F entry (0.05) and removal (0.1) criteria were adopted.

Weekday ridership in passenger trips (trips/day) was the dependent variable explored in this research. The daily ridership had an average value of 17,020 and a standard deviation of about 9,590. The explanatory variables were selected based on previous research and the aim to explore how factors related to BRT infrastructure and operations might impact ridership. Both exogenous (socio-economic) and endogenous (service-related) variables were selected. The following variables were selected:

a. Average Population Density (persons/km^2): calculated by dividing the urban population from the census data by the urban area.
b. Percentage of Dedicated Lanes: found by dividing the length of the dedicated sections by the total route length.
c. Type of Right of Way (RoW): could be segregated, exclusive or shared with other modes. This research has adopted the classification presented by Vuchic (2007), and each type is explained in Table 2.
d. Position of the Dedicated Lanes: could be central, lateral or fully segregated.
e. Average Stop Spacing (m): calculated by dividing the route length by the number of stops minus one.
f. Type of Fuel: diesel, biodiesel, compressed natural gas (CNG) or electric power.
g. Operation Span (h): the hours of operation per day (usually more than 16 hours).

Table 1. The Locations of the 32 BRT Systems

Country	City	Line Name	Length of Corridor (km)
Czech Republic	Prague	Line 213	10.5
Finland	Helsinki	Jokerilinja 550	27.5
France	Rouen	Line 1 TEOR	8
	Rouen	Line 2 TEOR	6
	Rouen	Line 3 TEOR	10
	Nantes	Line 4	7
	Lorient	Triskel	5
	Grenoble	Ligne1	9
Germany	Oberhausen	The ÖPNV-Trasse	7
Ireland	Dublin	Malahide corridor	12
Italy	Brescia	LAM 1	28
	Brescia	LAM 2	26
	Pisa	Red Line	17
	Pisa	Green Line	8
	Pisa	Blue Line	8
	Prato	Blue Line	16
	Prato	Green Line	11
	Prato	Red Line	17
Netherlands	Almere	Line 1	38
	Amsterdam	Zuidtangent Line 1	41
	Amsterdam	Zuidtangent Line 2	13
	Purmerend	Line 1	20
	Twente	Line 3	10
	Utrecht	Line 11	7
	Utrecht	Line 12	6
Romania	Lasi	Line 1	30
Spain	Madrid	Line 651	13
	Castellon	TVRCAS Línea 1	10
Sweden	Gothenburg	Line 16	16.5
	Jonkoping	Line 3	39
	Lund	Lundalanken	6
UK	Manchester	A6 Corridor	15.5

h. Average Commercial Speed (km/h): calculated by dividing the route length by the runtime for peak and off-peak, then averaging the resulting values out.

i. Weekday Frequency (buses/h): a measure of service level. Frequency is calculated using the timetables provided by each operator.

Table 3 summarizes the independent variables used and illustrates the average and standard deviations of these explanatory variables for the BRT systems analyzed in this study.

Table 2. Classification of Right of Ways

Right of Ways Categories	Type of System
Category A: is a fully controlled RoW without at grade crossings or any legal access by other vehicles or persons. It is called "grade separated" or "exclusive" RoW. It can be a tunnel, an aerial structure or at grade level.	Rapid transit systems
Category B: includes RoW types that are longitudinally physically separated by curb, barriers, grade separation and the like from other traffic, but with at grade crossings for vehicles and pedestrians, including regular street intersections. This B category is most frequently used in Light Rail Transit (LRT) systems.	Semi-rapid transit systems
Category C: represents surface streets with mixed traffic. Transit may have preferential treatment, such as reserved lanes separated by lines (mostly lateral) or special signals or travel mixed with other traffic.	Street transit systems

Table 3. List of Independent Variables

Variable	Mean	Standard Deviation
Average Population Density (p/ km^2)	2,360	1,320
% of Dedicated Lanes	0.5	0.3
Type of RoW(A, B, C)	2.4	0.6
Position of the Dedicated Lanes	1.8	0.7
Average Stop Spacing (m)	510	330
Type of Fuel	1.5	1.0
Operation Span (h)	18.5	2.3
Average Commercial Speed (km/h)	21.1	5.5
Frequency (buses/h)	11.3	5.8

Table 4a. Model 1 Regression Analysis

Model 1 Predictors	Un-standardized Coefficients		Standardized Coefficient (β)	Significance (*p*)
	B	**Std. Error (SE)**		
Constant	-14494.38	15223.979		0.351
Average Population Density (p/ km^2)	3.69	1.045	0.509	0.002
% of Dedicated Lanes	-9942.44	7411.823	-0.337	0.193
Type of RoW (A, B, C)	-3166.22	3086.355	-0.218	0.316
Position of the Dedicated Lanes	-3398.89	2058.254	-0.238	0.113
Average Stop Spacing (m)	-8.53	6.361	-0.294	0.194
Type of Fuel	-851.51	1110.709	-0.093	0.451
Operation Span (h)	1191.99	550.997	0.285	0.042
Average Commercial Speed (km/h)	1013.22	402.798	0.581	0.02
Frequency (buses/h)	324.23	223.342	0.196	0.161

Table 4b. Model 1 Results

R	0.858
R^2	0.735
R^2 Adjusted	0.627
F	6.792*
Degrees of Freedom	9,31

* Significant at $p < 0.05$.

Table 5a. Model 2 Regression Analysis

Model 2 Predictors	Un-standardized Coefficients		Standardized Coefficient β	Significance (*p*)
	B	**Std. Error (SE)**		
Constant	-26865.38	8497.016		0.004
Average Population Density (p/ km^2)	3.624	0.833	0.501	0
Operation Span (h)	1334.52	495.76	0.319	0.012
Average Commercial Speed (km/h)	516.335	214.051	0.296	0.023

Table 5b. Model 2 Results

R	0.817
R^2	0.668
R^2 Adjusted	0.632
F	18.756
Degrees of Freedom	3,31

Table 6. Model 2 Summary

Model	Predictors	R	R^2	R^2 Adjusted	Std. Error (SE)	Significance (P)	F-Value
1	Population Density	0.654	0.428	0.409	7372.97	0.000	22.44
2	Population Density Operation Span	0.774	0.599	0.571	6280.76	0.000	21.63
3	Population Density Operation Span Average Commercial Speed	0.817	0.668	0.632	5816.11	0.000	18.76

Table 7. Correlation between Commercial Speed and % of Dedicated Lanes

		Average Commercial Speed (km/h)	**% of Dedicated Lanes**
Average Commercial Speed (km/h)	Pearson Correlation	1	0.405*
	Sig. (2-tailed)		0.021
	N	32	32
% of Dedicated Lanes	Pearson Correlation	0.405*	1
	Sig. (2-tailed)	0.021	
	N	32	32

*Correlation is significant at the 0.05 level (2-tailed).

Table 8. Correlation between Commercial Speed and Average Stop Spacing

		Average Commercial Speed (km/h)	**Average Stop Spacing**
Average Commercial Speed (km/h)	Pearson Correlation	1	0.833*
	Sig. (2-tailed)		0.001
	N	32	32
% of Dedicated Lanes	Pearson Correlation	1	0.833*
	Sig. (2-tailed)		0.0001
	N	32	32

*Correlation is significant at the 0.01 level (2-tailed).

ANALYSIS AND RESULTS

The linear regression analysis was performed by using the BRT trips per day as a dependent variable and all the variables listed in Table 3 as independent variables. The results of Model 1 are presented in Tables 4a and 4b. The resulting and adjusted R^2 values were 0.74 and 0. 63, respectively. The significance *p*-values show that the variables: average population density, operation span and average commercial speed had the dominating influence on the model.

The Stepwise Iteration (SI) procedure was performed using the BRT trips per day as a dependent variable and all the independent variables listed in Table 3. The results of Model 2 are presented in Tables 5a and 5b. The resulting and adjusted R^2 values were 0.67 and 0.63, respectively. The average population density, operation span and the average commercial speed were again the significant independent variables. The *p*-values for the significant independent variables were less than 0.05. Table 6 shows the effect of each independent variable on the R^2 values. The average population density had the highest effect, while the average commercial speed had the least influence.

Nevertheless, these results could be used to suggest that the demand for this transit service increases when systems operate:

- in densely populated urban areas;
- longer weekday service spans;
- at a higher commercial speed;

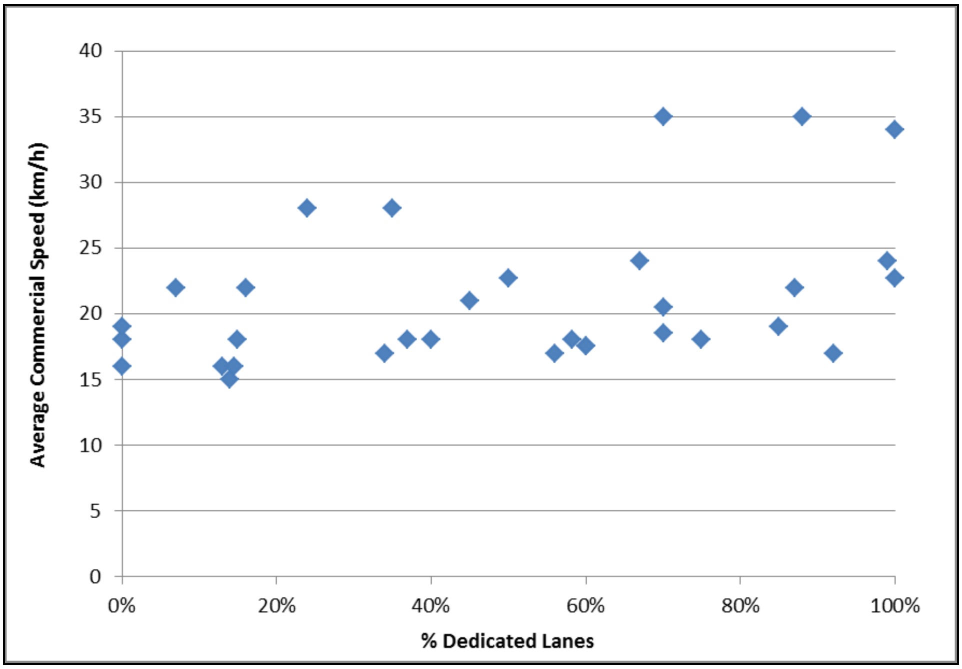

Figure 1: Average Commercial Speed *vs.* % of Dedicated Lanes

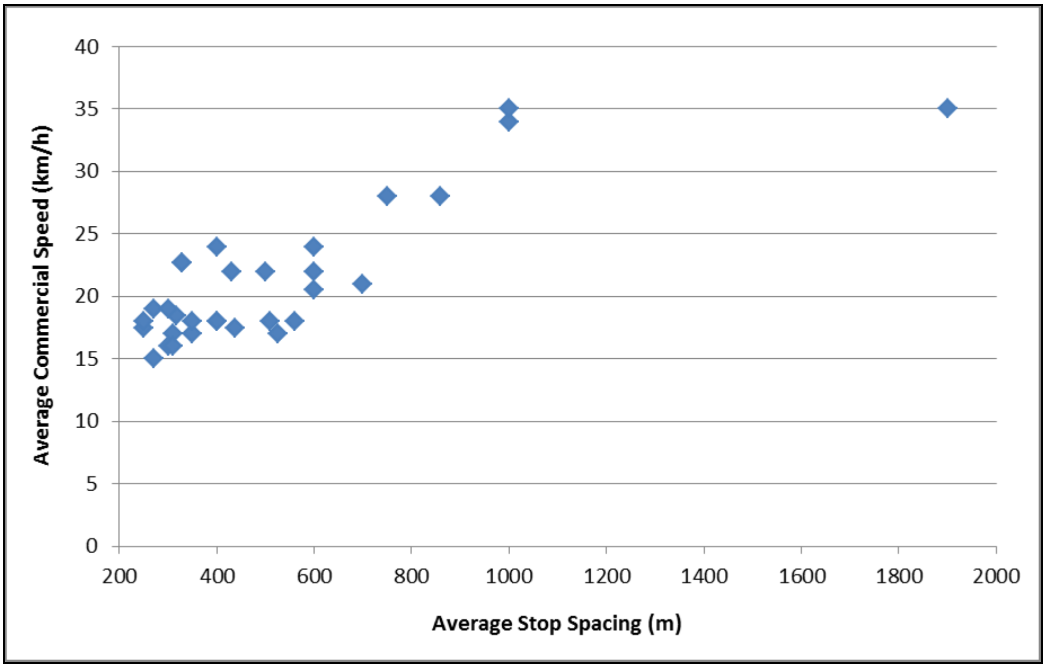

Figure 2: Average Commercial Speed *vs.* Average Stop Spacing

The first factor depends on geography, while the second depends on bus regulations and legislations. The last significant variable affecting the demand is operational; which is the average commercial speed. There is a number of ways to improve the commercial speed of a BRT system. The most obvious one is to segregate or separate the buses from the traffic. This can be achieved increasing the percentage of lanes dedicated to the transit service (bus-only lanes). Figure 1 is a plot of the average commercial speed *versus* the percentage of dedicated lanes for the 32 BRT systems investigated. The Pearson's correlation coefficient is used to find the correlation between any two variables. The value of the coefficient falls between 0.00 (no correlation) and 1.00 (perfect correlation). Generally, correlations above 0.80 are considered high. The analysis showed that Pearson's correlation coefficient was 0.41 between the average commercial speed and the percent of dedicated lanes, which is significant at the 0.05 level. The results are presented in Table 7.

The other important factor that affects the commercial speed is the stop spacing. It is a challenging task that requires compromising a group of objectives, such as: proximity to crossings or other stops, closeness to strategic interchanges, safety of pedestrians, adequate bays, easy entrance/docking for buses, sufficient platform width, as well as maintaining an attractive and accessible design. The spacing between the BRT stops of the systems varied between (250m-1900m). If the spacing is more than 500m, it results in high walking distances for a significant percentage of the population. On the other hand, the fewer the stops along the route, the less dwell time is spent for boarding/alighting passengers resulting in a shorter total trip time. Figure 2 is a plot of the average commercial speed *versus* the average stop spacing for the 32 BRT systems investigated. The Pearson's correlation coefficient was found to be 0.83 between the average commercial speed and the average stop spacing. This is considered a high correlation and was significant at the 0.01 level. The results are shown in Table 8.

CONCLUSIONS

The step-wise regression model highlighted 3 variables which significantly impact the demand. The first is exogenous (population density), the second is connected to service level (operation span), while the third is the only operational factor (average commercial speed). BRT achieves improvements in commercial speed when compared to conventional bus routes because of its main components: the dedicated lanes and properly spaced accessible stations or stops. The overall results therefore suggest that the BRT infrastructure treatments, such as right of way and optimal stop spacing, have a significant impact on the speed of operation which in turn has a positive impact on ridership. Together, these findings tend to confirm the research hypothesis that design aspects of BRT lead to an increase in ridership. BRT systems face the challenge of being related to regular bus service, which studies suggest are unattractive to users. To overcome this image problem, many BRT systems use these unique design features, for both the vehicles and infrastructure, which are substantially different from those of traditional buses to emphasize this distinction.

For future research, other explanatory variables could be incorporated in the models to test their influence on ridership, such as car ownership levels, system capacity and fare structures. Including more variables could improve the R^2 levels of the models and help gain a more complete understanding of their influences on transit demand.

In conclusion, with the continuing rise in traffic congestion levels, a backlog of infrastructure needs and renewed environmental concerns, more and more focus is given to public transportation and new technologies that enhance the performance of transit systems. BRT is considered one of the promising high-performance, cost effective solutions that provide high quality services to the users. The case studies presented showed the ability of BRT systems to attract customers while providing flexibility and cost effectiveness when compared to rail based transit systems.

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