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## Abstract

Bus Rapid Transit (BRT) systems are an increasingly popular public transport option in Australia and internationally. They provide rail-like quality for bus services for a fraction of the cost of fixed rail. Many claims of high and increasing ridership have resulted from BRT system development; however it is unclear exactly which aspects of BRT system design drive this.

This paper undertakes an empirical analysis of factors influencing ridership on 77 BRT and non-BRT bus routes in Melbourne, Sydney, Adelaide and Brisbane. Explanatory variables considered included service level, frequency, speed, stop spacing, separate right of way share, vehicle accessibility, employment and residential density, car ownership levels and BRT infrastructure quality.

The paper reviews previous research associated with transit ridership at a route level and then presents the methodology and results.

Two multiple regression analyses were undertaken to explore the influence of the explanatory variables on ridership. The first considers overall ridership (boardings per route km, BRK) and identified a statistically significant model ($R^2$=.81). The largest influence on BRK was vehicle trips per annum (β = .82), consistent with past research, followed by vehicle accessibility (low floor buses, β = .16) and population density (β = .14). The second considered patronage per vehicle kms (PVK) which explores ridership drivers after accounting for service levels. Results for this were statistically significant but with a less powerful model, adjusted $R^2$ = .44. There were four explanatory variables including average speed (β = -.42), weekday frequency (β = .41), BRT infrastructure ranking (β = .29) and vehicle accessibility (β = .25). An alternative form of BRT infrastructure quality was also tested but did not improve the explanatory power of the modelling.

The paper concludes with a discussion of the various influences on ridership and recommendations for existing policy and future research associated with this field.

**Keywords:** Bus Rapid Transit, ridership, service level, public transport infrastructure

# 1 Introduction

## 1.1 Background

Bus Rapid Transit (BRT) systems are being embraced worldwide as an increasingly popular public transport option. They apply rail-like infrastructure and operations to bus systems with offerings that can include high service levels, segregated right of way, station-like platforms, high quality amenities and intelligent transport systems. There are now BRT systems in Sydney, Brisbane, Adelaide and to a lesser extent Melbourne.

As more cities adopt and expand BRT infrastructure, a critical question which must be addressed is the relative value provided by the alternative treatments which BRT infrastructure can provide. While measures such as segregated rights of way clearly provide travel time and reliability benefits, they are also expensive to implement. While the relative costs of measures are reasonably well defined it is unclear what the relative merits of measures are particularly from a patronage viewpoint. The merits of BRT systems are usually compared to heavy and light rail systems where infrastructure is even more costly. It is worth considering whether BRT systems offer additional value for money over and above "conventional" bus services without high infrastructure costs.

## 1.2 Paper Aim and Structure

This paper undertakes an empirical analysis of factors influencing ridership on 77 BRT and non-BRT bus routes in Melbourne, Sydney, Adelaide and Brisbane. The overall aim of the project is to understand what factors drive ridership on BRT systems. The research is particularly interested in assessing ridership benefits associated with different types of BRT infrastructure e.g. busways vs on-street BRT systems and also whether there are significant differences in ridership performance between BRT systems and conventional bus services.

The paper is structured as follows. The paper starts with a summary of previous research in this field. This includes an assessment of relevant research on route level drivers of patronage on public transport and an assessment of research concerning BRT technologies and infrastructure and their impacts on ridership. This is followed by a discussion of the research approach and methodology adopted for the empirical analysis. The results of the analysis are then presented followed by a summary and discussion of the findings. Future areas for research are also discussed.

# 2 Research Context

## 2.1 Previous Research on Route Level Drivers

A great deal of research has examined the drivers of route level ridership on public transport systems (Table 1). High service levels, measured in terms of frequency and span of hours covered, has often been cited as the most important driver of route level ridership. One of the first analyses of bus route level ridership (Stopher 1992), found that service quantity, measured as the number of buses per hour, was the single most significant factor in an empirical analysis of US bus routes. FitzRoy and Smith (1998) in their study of the European Freiburg public transport system state that high service levels are important for achieving high patronage levels. In a review of factors driving ridership growth on bus services, Currie and Wallis (2008) found that service quantity was the single most effective driver. A number of studies have also found that service levels were the principal driver of ridership in US light rail research (e.g. Kain and Liu 1999).

The density of urban development has long been identified as a major driver of ridership although it is rarely cited as a primary driver (Seskin and Cervero 1996a; Johnson 2003). Stopher (1992) found employment density was a significant factor influencing bus ridership but this was not as important as service levels. Kain and Liu (1999) examined the factors determining the high ridership of light rail routes in Houston and San Diego. While stating that factors like urban density and employment levels play a role in determining patronage levels, they concluded that the most important factors to drive patronage are high service levels (measured in vehicle kilometres on a route) and cheap fares.

**Table 1: Previously Identified Route Level Pubic Transport Ridership Drivers**

| Identified Driver | Research Source |
|---|---|
| High Service Levels | (Stopher 1992)<br>(FitzRoy and Smith 1998)<br>(Currie and Wallis 2008)<br>(Mackett and Babalik-Sutcliffe 2003)<br>(Kain and Liu 1999) |
| High Density Residential Development | (Johnson 2003)<br>(Seskin and Cervero 1996b)<br>(Babalik-Sutcliffe 2002)<br>(Kain and Liu 1999)<br>(Kain et al. 2004) |
| Low Car Ownership | (Babalik-Sutcliffe 2002)<br>(Mackett and Babalik-Sutcliffe 2003) |
| Low Fares | (Mackett and Babalik-Sutcliffe 2003)<br>(Kain and Liu 1999) |
| Modal Integration | (Mackett and Babalik-Sutcliffe 2003)<br>(Kain et al. 2004) |
| Ticket Integration | (Mackett and Babalik-Sutcliffe 2003) |
| Reliable Service | (Mackett and Babalik-Sutcliffe 2003) |

Several researchers have suggested that high car ownership can act to reduce route level ridership (e.g. Babalik-Sutcliffe 2002; Mackett and Babalik-Sutcliffe 2003). Although these influences are large between countries of widely differing car ownership levels, they are unlikely to be significant in explaining the large differences in ridership for routes across Australia where car ownership is consistently high.

Cheap fares have been cited as a factor affecting rail ridership (FitzRoy and Smith 1998; Kain and Liu 1999). However Currie and Wallis (2008) note that elasticities of bus demand to fares are low (typically -0.3) and hence very large fare differences are required to show substantive differences in ridership between bus routes. It is unlikely this would be a significant influence on the Australian bus routes examined since fare levels do not significantly vary between Australian cities. Integrated ticketing has been linked to higher ridership in several bus systems. Streeting and Barlow (2007) suggested that integration effects of fares and better marketing and planning explained up to 30% of the 11.6% growth in ridership in Queensland between 2004 and 2006.

Overall previous research suggests a wide range of factors might influence route level ridership but service levels are generally identified as a principal influence.

## 2.2 BRT Technologies and Ridership Effects

> "Bus Rapid Transit (BRT) is a high-quality bus based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing

> and customer service. BRT essentially emulates the performance and amenity characteristics of a modern rail-based transit system but at a fraction of the cost."
> (Wright and Hook 2007 p. 1)

As the above definition implies, Bus Rapid Transit (BRT) aims to deliver rail like service quality using higher quality provision of bus based services. The key features of BRT systems which define this quality are defined by Levinson et al. (2003) as :

A. Running Ways – including mixed traffic lanes, curb bus lanes, and median busways on city streets; reserved lanes on freeways; and bus-only roads, tunnels, and bridges.
B. Stations – Providing higher quality infrastructure than simple bus stops. This can include platforms, more significant forms of shelter, quality information systems and other amenities.
C. Vehicles – BRT vehicles can include conventional standard and articulated diesel buses however there is also a trend toward innovations in vehicle design. These include (1) 'clean' vehicles; (2) dual-mode (diesel-electric) operations through tunnels; (3) low-floor buses; (4) more doors and wider doors; and (5) use of distinctive, dedicated BRT vehicles for image and branding.
D. Intelligent Transport Systems – Use of technologies including automatic vehicle location systems; passenger information systems; transit preferential treatment systems at signalized intersections, controlled tunnel or bridge approaches, toll plazas, and freeway ramps.
E. Service Patterns – Usually with high service levels and can include a mix of express and stopping patterns. Significantly, most networks operate beyond the running ways and onto local streets which can reduce the need to transfer at stations.

Much research on BRT system performance has focussed on the relative cost effectiveness of their design relative to light and heavy rail infrastructure. However little research has considered whether BRT provides significant benefits over traditional bus systems. Little work has been undertaken on the relative patronage performance of BRT system features (Currie 2005).

Hensher and Golob (2008) undertook one of the few comparative assessments of system wide data from 44 BRT systems from around the world to examine a range of performance features including ridership. The variables they considered as drivers for ridership were fares, number of stations, average distance between stations, average speed, average peak and non-peak headways and vehicle capacity. Their final model identified that four of those variables had a significant impact on ridership: number of stations, peak headway, trunk vehicle capacity and average fare. This suggests that more stations and higher service levels (measured as headway and capacity) increases ridership whereas higher fares were negatively correlated with ridership.

This analysis was limited in two important ways. First it did not consider the influence of unique BRT design features (such as right of way) on ridership. Second by only looking at BRT systems it does not consider whether BRT infrastructure provides significant ridership gains over conventional bus systems.

This paper aims to build on the above research base to explore further the factors affecting BRT ridership by focussing on both BRT and non-BRT bus systems, by considering the impact of BRT infrastructure on ridership and by examining these issues using a route level analysis.

# 3 Research approach and methodology

## 3.1 Bus Routes Selected

A total of 77 bus routes were selected for analysis from four Australian cities including:

- 33 Melbourne conventional bus routes
- 6 Melbourne "SmartBus" routes
- 38 BRT system routes including:
  - 17 from the Brisbane Southeast Busway
  - 11 from the Adelaide North East Busway
  - 9 from the Sydney Transitway Network.

Table 2 shows the bus routes selected for analysis. Note that due to data availability limitations, non-BRT routes were limited to Melbourne. However to partially counter this limitation, these bus routes were chosen to represent a range of route types from short-running local services to commuter bus services.

The "SmartBus" routes in Melbourne were chosen because they share some characteristics of BRT systems (high frequency, some real-time information, unique branding and promotion) but lack the heavy infrastructure of a traditional BRT system. This should assist in contrasting effects of BRT system design on performance.

Amongst the BRT systems any route that used the nominated busway (or t-way) for at least part of the route was included. In some cases this includes routes that only use the infrastructure for a small portion of their journey (e.g. in Brisbane, eastern routes that exit at Woolloongabba or Buranda busway station). This variation allows a more rigorous comparison of variables within BRT systems.

**Table 2: Route Services Selected for Analysis**

| 2<br>**Measure** | **Non-BRT** | **Bus Rapid Transit Systems** | | | |
|---|---|---|---|---|---|
| | **Melbourne** | **Melbourne SmartBus** | **Adelaide North East Busway** | **Sydney T-Ways** | **Brisbane South East Busway** |
| **Number of Routes Analysed** | 33 | 6 | 11 | 9 | 17 |
| **Bus Routes Selected** | 220,271,304,305, 307,400,402,404, 407,410,437,442, 443,508,527,552, 561,564,612,623, 624,627,683,685, 766,781,784,785, 800,811,812,850, 926 | 700[1] 703 888 889 900 901 | 503,506, 507,521, 541,542, 545,546, 548,T500, T501 | T61,T62, T63,T64, T65,T70, T71,T75, T80 | 100,111, 120,124, 125,130, 135,140, 150,155, 160,170, 180,200, 210,212, 250 |
| **Rationale for Selection** | Explore a range of variations in ridership | All SmartBus routes | All major routes that use the O-bhan for at least part of the route | All T-Way routes | All routes that use the South East busway for at least part of the route |

Note: [1] In 2008 this was route 700 and it has since been re-branded the 903 SmartBus route. For the purpose of this analysis it was included as a SmartBus service

Table 3 shows the key features of 4 BRT systems selected for analysis and Figure 1 is a map of these BRT systems. Australian BRT systems are highly diverse in nature (Currie

2006) which makes them a useful sample for exploring the potential ridership impacts of alternative technologies.

**Table 3: BRT Systems Key Features**

| Feature Areas | Bus Rapid Transit Systems | | | |
|---|---|---|---|---|
| | **Melbourne SmartBus** | **Adelaide North East Busway** | **Sydney T-Ways** | **Brisbane South East Busway** |
| **Running Ways** | • Mainly mixed traffic<br>• Some queue jump lanes and 'B' lights | • Guided busway fully grade separated (12 kms)<br>• Almost all routes operate in mixed traffic in the suburbs and the CBD. Guideway is about 70% of route length for most routes | • Mixed bus only road (with at grade crossings), bus lanes and mixed traffic operation | • Bus only roads with grade separation (16 kms)<br>• A network of these busways feed to Brisbane CBD and operate underground in the CBD |
| **Stations** | • Kerbside bus stops<br>• Higher quality treatment than usual bus routes | • 3 with wide spacing (5 kms)<br>• Dedicated platforms with shelter – at grade pedestrian crossings | • Dedicated platforms with shelter – at grade pedestrian crossings | • High quality design with dedicated platforms and shelter<br>• Grade separated pedestrian crossings using over bridges |
| **Vehicles** | • Standard rigid bus<br>• Includes 'SmartBus' brand, colour and logo<br>• All buses are low floor accessible and are relatively new | • Standard rigid bus and articulated bus with small guidewheels on sides<br>• In general no particular branding of O-Bahn buses<br>• Buses are a mix of old and new | • Standard rigid bus<br>• No particular branding of buses<br>• Buses are a mix of old and new | • Mainly standard rigid bus (limited articulated bus)<br>• In general no particular branding of busway buses<br>• Buses are a mix of old and new |
| **Intelligent Transport Systems** | • Real time passenger information at stops<br>• Apart from 'B' lights and queue jump lanes, no active traffic signal priority<br>• Tickets sold by driver but with many periodicals offered<br>• Integrated fares | • Apart from 'B' lights and queue jump lanes, no active traffic signal priority<br>• Tickets sold by driver but with many periodicals offered<br>• Integrated fares | • Real time passenger information at stops<br>• Very high quality active traffic signal priority<br>• Tickets sold by driver but with many periodicals offered<br>• No Integrated fares | • Real time passenger information at stops<br>• Apart from 'B' lights and queue jump lanes, no active traffic signal priority<br>• Tickets sold by driver but with many periodicals offered<br>• Integrated fares |
| **Service Patterns** | • Direct routing and high service levels<br>• Minimum 15 minute headway and longer service spans<br>• SmartBus routes spread throughout the city on selected major corridors | • All routes run to and from the Busway with through routing (most riders board off-busway)<br>• Some expresses but most stop all stations<br>• The O-bahn is highly peaked so off peak, evening and weekend routes are very limited service | • Varies – Liverpool-Parramatta T-Way has only one trunk route and feeders. Others have integrated routes which operate on street and on trunk sections<br>• Variable service levels | • Varied, there are major trunk services using the busway only (e.g. 111) but more commonly routes feed from suburbs onto the busway itself. |

*Source: Based on (Currie 2006)*

**Melbourne** is serviced by an extensive network of over 300 bus routes. Unlike the radial tram and train system, Melbourne's buses are primarily concentrated in the middle and outer suburbs. Service levels on Melbourne bus routes are known to be relatively low (Currie 2003) although contemporary policy has seen an increase in investment in bus services and improvements in service levels and ridership (Currie and Loader 2009).

SmartBus routes began with trials in 2002. These selected routes are characterised by extended service span, increased frequency, real-time passenger information at most stops and enhanced signal priority. Some SmartBus routes use bus-only lanes for a small part of their route but this is relatively rare and the services are predominantly in mixed traffic operations. They are predominately located in Melbourne's southeast (see Figure 1) although new routes have recently opened that orbit from the southeast to the southwest of the city.

**Figure 1: Maps of BRT systems in Brisbane, Sydney, Adelaide and Melbourne**


*Note: Dark red lines represent busways whereas white lines represent on-street running. Melbourne map only shows Smartbus routes for ease of interpretation*
*Base map source: Google Earth*

The **Adelaide** O-Bahn or North East Busway is a guided busway. It is the oldest busway in Australia and one of the first BRT systems worldwide (opened in 1989, Currie 2006). The busway was designed to service Adelaide's rapidly expanding north eastern suburbs and is primarily used as a commuting corridor to the CBD so services are concentrated in peak hours with low off peak service levels. Buses on the O-Bahn run on a specially-built track at speeds up to 100 km/hour. The busway is serviced by one station (Klemzig) and two interchanges (Paradise and Tea Tree Plaza) and is 12km in length. The right of way is entirely grade separated and stations on the busway are high quality platform designs (but with at-grade pedestrian crossings). Interchanges allow buses to enter and leave the busway to continue to on-road suburban routes (see Figure 1). Services are operated by Torrens Transit.

Unlike the Adelaide and Brisbane systems, the **Sydney** Transitways do not enter the central business district but run exclusively through the outer western suburbs (see Figure 1). The first of Sydney's T-ways was the Liverpool-Parramatta which was opened in 2003. This T-way connects the Parramatta and Liverpool train stations via a system of bus-only roadways and bus lanes. Only one route (T80) runs on the busway and it does not leave the busway to feed in from surrounding neighbourhoods.

Two more sets of T-ways, collectively called the North-West T-way, run between Parramatta and Rouse Hill and between Blacktown and Parklea and intersect at Burns interchange in Parklea. These T-ways rolled out between 2004 and 2007. Unlike the Liverpool-Parramatta, buses used on these routes exit the busway and continue through the suburbs to varying degrees.

These three T-way systems are run by three different operators: Western Sydney Buses operates the Liverpool-Parramatta, Busways operates the Rouse Hill services and Hillsbus operates the Blacktown services. A range of other bus routes use parts of the T-ways on their runs but only the designated T-way services are used in this analysis. T-Ways stations on busway sections are high quality with platforms, real time information and some shelter. Pedestrian crossing is at grade. The Sydney T-Ways have active traffic signal priority (not a feature of the other systems)

The **Brisbane** South-East Busway is a grade separate (but not guided) bus-only road running from Brisbane CBD south to Eight Mile Plains (see Figure 1). The right of way quality is high with full grade separation and even tunnels underneath the CBD. Like the O-Bahn its primary purpose is to service commuters although it has higher off peak service levels than the Adelaide O-bahn. The busway was completed in 2001 and is over 16km in length. It has 10 stations that allow buses to enter and leave the busway and it is serviced by an extensive network of connecting bus and train services. Stations are of a very high quality design with platforms considerable shelter and air conditioned station over-bridges for pedestrians to cross between platforms. Almost all routes using the South-East Busway are operated by Brisbane Transport.

## 3.3 Variable Selection and Collation

Annual patronage per route km (BRK) and boardings per vehicle kilometre (PVK) were the dependent variables explored in this research. BRK factors in route length to remove the influence impact of longer or shorter routes on demand. PVK is a measure of service effectiveness because it controls for service level.

Yearly patronage, vehicle kilometres and route length were all calculated using 2008 data. Patronage and vehicle kilometres were provided by the Department for Transport (Melbourne), Department for Transport, Energy and Infrastructure (Adelaide), Translink (Brisbane), and the Transport Data Centre (Sydney). The exception is the Sydney T80 (Liverpool-Parramatta) where the vehicle kilometres had to be estimated based on route length and published timetable service levels. Route length was calculated using 'Google Earth' to trace each bus route and calculate the total length.

Explanatory variables were selected based on previous research and also to explore how factors related to BRT infrastructure and operations might impact ridership. The following variables were selected:

a. **Vehicle trips per annum** - Vehicle trips per annum was calculated by dividing the annual vehicle kilometres by the route length in one direction. This is a broad indicator of service levels encompassing both service frequency and service span as well as coverage of nights and weekend services.

b. **Weekday Frequency** - Service level was measured in a number of ways. Services per weekday and weekday service span were both calculated using timetables provided by each operator. Weekday service frequency was then calculated by dividing services by service span. Values are expressed as buses per hour.

c. **Peak Speed -** The average speed was calculated by dividing the route length by the run time at 8am. Values are expressed as km per hour. This value was calculated for the entire route, not just the portions on the busways.

d. **Stop Spacing** - Average stop spacing was calculated by dividing the route length by the number of stops minus one. Where possible this was calculated using each stop, not just timing stops. Two routes in Sydney (T70 and T71) had to be estimated as the number of stops was unavailable. They were assigned the average stop spacing of all Sydney routes (870 metres). This value was calculated for the entire route, not just the portions on the busways.

e. **Separate Right of Way (ROW) Share** - Right of way was defined as the proportion of the route on a busway or bus lane separate from mixed traffic. For the Adelaide, Birsbane and Sydney this was calculated by measuring the sections of the route on a busway or bus lane. For the Melbourne routes, some of the bus lanes are only valid during peak hours. For these routes the proportion of bus-only route was multiplied by the proportion of services during these valid hours.

f. **Vehicle Accessibility** - This was defined as the proportion of buses on a route that were low-floor or otherwise wheelchair accessible. In Melbourne and Sydney this information was available on the timetables of each route. For Adelaide this information was provided by the operator and for Brisbane this had to be estimated as a proportion of the total fleet (e.g., all routes were assigned the same accessibility level).

g. **Employment and Residential Density** - Residential density and employment density were calculated within an 800m catchment of the bus route alignment. In most cases this was calculated as a continuous buffer along the route. For the Adelaide and Brisbane busways each busway stop was assigned a discrete buffer in a circle 800m around each stop until the route left the busway, at which point the rest of the route was calculated as a continuous buffer. Population and employment data were sourced from the 2006 census (Australian Bureau of Statistics 2006).

h. **Car Ownership –** This was calculated using census data using the spatial buffer approach identified above. Car ownership was also sourced from the 2006 census (Australian Bureau of Statistics 2006).

i. **BRT quality ranking** - The quality of the infrastructure of a BRT system is difficult to quantify; nevertheless it is clear that some forms of technology are superior to others. In order to capture something of the differences in BRT infrastructure quality, the different systems were ranked (higher numbers indicating better quality) as follows: Brisbane (5), Adelaide (4), Sydney (3), Melbourne SmartBus (2) and Melbourne route bus (1).

# 4 Results

## 4.1 Overview of Variables

Table 4 shows the boardings per route km (BRK) and passengers per vehicle km (PVK) for the different systems examined. Melbourne SmartBus routes have higher average BRK and PVK than all other systems examined. The Adelaide North-East Busway has the lowest average BRK however its PVK is higher than the Sydney T-Ways. Melbourne's conventional bus routes have higher BRK than Adelaide and Sydney's BRT routes and higher PVK than Sydney.

**Table 4: Dependent Variables by System**

| Measure | | Melbourne conventional | Melbourne SmartBus | Adelaide North East Busway | Sydney T-Ways | Brisbane South East Busway |
|---|---|---|---|---|---|---|
| **Number of Routes Analysed** | No. | 33 | 6 | 11 | 9 | 17 |
| **Boardings per route km** | Mean | 23,999 | 53,586 | 13,843 | 20,914 | 40,010 |
| | SD | 20,618 | 25,283 | 9,846 | 25,523 | 31,868 |
| **Passengers per veh km** | Mean | 1.02 | 1.59 | 1.20 | 0.83 | 1.39 |
| | SD | 0.47 | 0.34 | 0.24 | 0.58 | 0.27 |

Table 5 illustrates the average and standard deviation of values for the explanatory variables for each of the bus systems analysed. Melbourne SmartBus routes have the highest overall service level on both vehicle trips per annum and weekday frequency. Adelaide comes last on most measures as it is a heavily peak-based service with limited weekend services. The high standard deviation of service span in Adelaide indicates the great variation in service times (down to as low as 13 minutes of service for one special route using the busway).

**Table 5: Independent variables by system**

| Measure | | Melbourne | Melbourne SmartBus | Adelaide North East Busway | Sydney T-Ways | Brisbane South East Busway |
|---|---|---|---|---|---|---|
| **Vehicle trips per annum** | Mean | 21,326 | 34,161 | 12,108 | 22,379 | 28,163 |
| | SD | 9,769 | 14,152 | 8,926 | 11,742 | 20,263 |
| **Weekday Frequency** (Buses/Hr) | Mean | 2.3 | 3.2 | 2.1 | 2.0 | 2.9 |
| | SD | 1 | 1 | 0.9 | 1.1 | 1.6 |
| **Weekday service span** (Hours) | Mean | 14:31 | 17:37 | 11:32 | 16:11 | 15:33 |
| | SD | 1:34 | 1:41 | 5:34 | 2:43 | 2:24 |
| **Peak Speed** (kph) | Mean | 24 | 21 | 29 | 23 | 27 |
| | SD | 8 | 4 | 5 | 4 | 7 |
| **Share Separate Right of Way** (%) | Mean | 1% | 3% | 50% | 62% | 37% |
| | SD | 3% | 6% | 12% | 31% | 28% |
| **Stop spacing** (m) | Mean | 394 | 505 | 728 | 870 | 1,563 |
| | SD | 167 | 287 | 165 | 131 | 603 |
| **Population density** ($p/km^2$) | Mean | 2,082 | 1,798 | 1,613 | 2,059 | 1,904 |
| | SD | 846 | 360 | 101 | 336 | 268 |
| **Employment density** ($no/km^2$) | Mean | 1,487 | 955 | 3,933 | 1,576 | 4,473 |
| | SD | 1,822 | 238 | 689 | 650 | 1,262 |
| **Car Ownership** (per 1,000 residents) | Mean | 536 | 560 | 548 | 502 | 520 |
| | SD | 63 | 10 | 20 | 39 | 25 |

Peak speed is highest for the Adelaide North East Busway closely followed by the Brisbane South East Busway. In general peak speeds are related to the share of separate right of way and stop spacing; Adelaide and Brisbane have wide stop spacing and a large portion of separate right of way as much of their routes run along a busway. Interestingly despite long stop spacing and a high share of segregated right of way, the average peak speed of Sydney routes is on the low end of the range. Melbourne routes (including SmartBus) have almost no segregated right of way and close stop spacing and as a result generally have lower peak speeds.

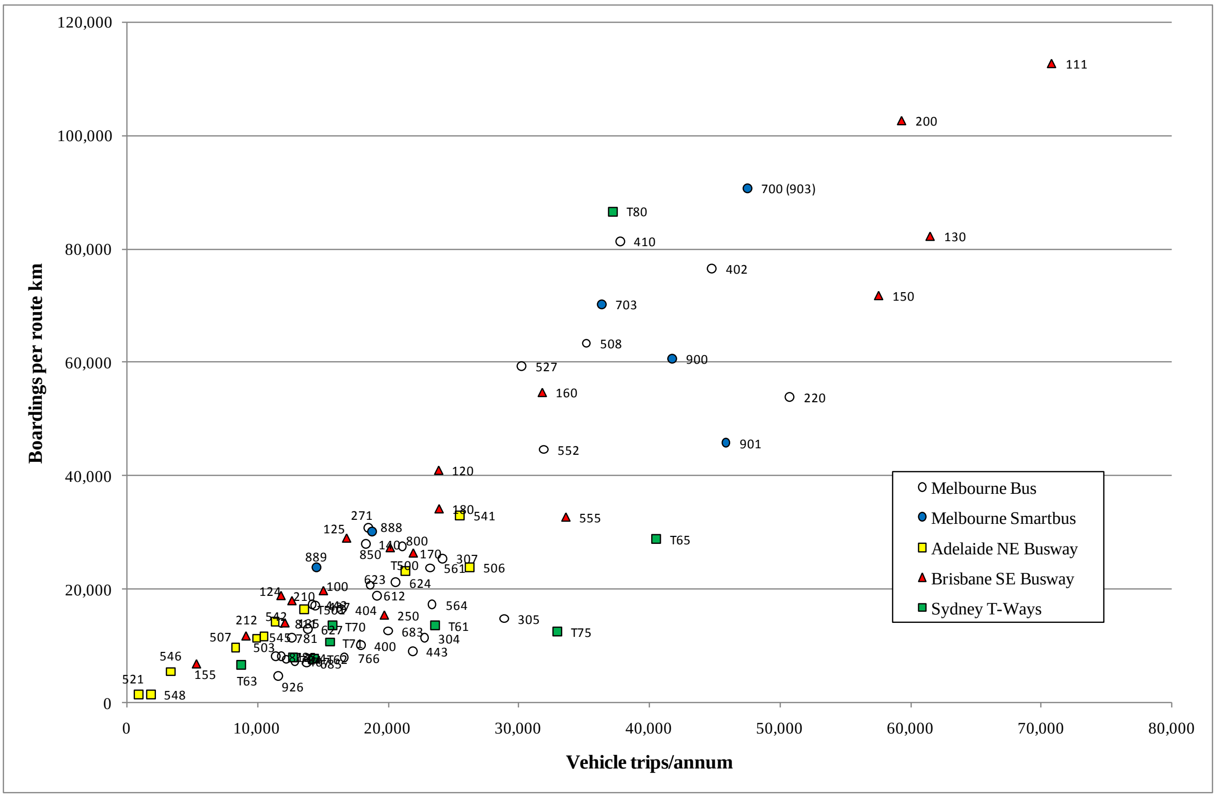
Average population density is fairly uniform across the five systems. The lowest is in Adelaide; this is not surprising as the North East Busway alignment is through a public park with urban land development restrictions. Employment density is highest for the CBD based route services in Brisbane and Adelaide. Sydney T-Ways do well in terms of average employment density despite a non-Sydney CBD location. This is due to their focus on Parramatta which is Sydney's 'second CBD'. Few Melbourne routes and no SmartBus routes enter the CBD and so employment density is lower along these routes.

There is reasonable variation in car ownership between different routes, particularly in Melbourne where it varies between 325 and 631 in different route corridors (hence the relatively high standard deviation). However the difference in average car ownership levels between systems is not great; in general car ownership is high relative to international standards.

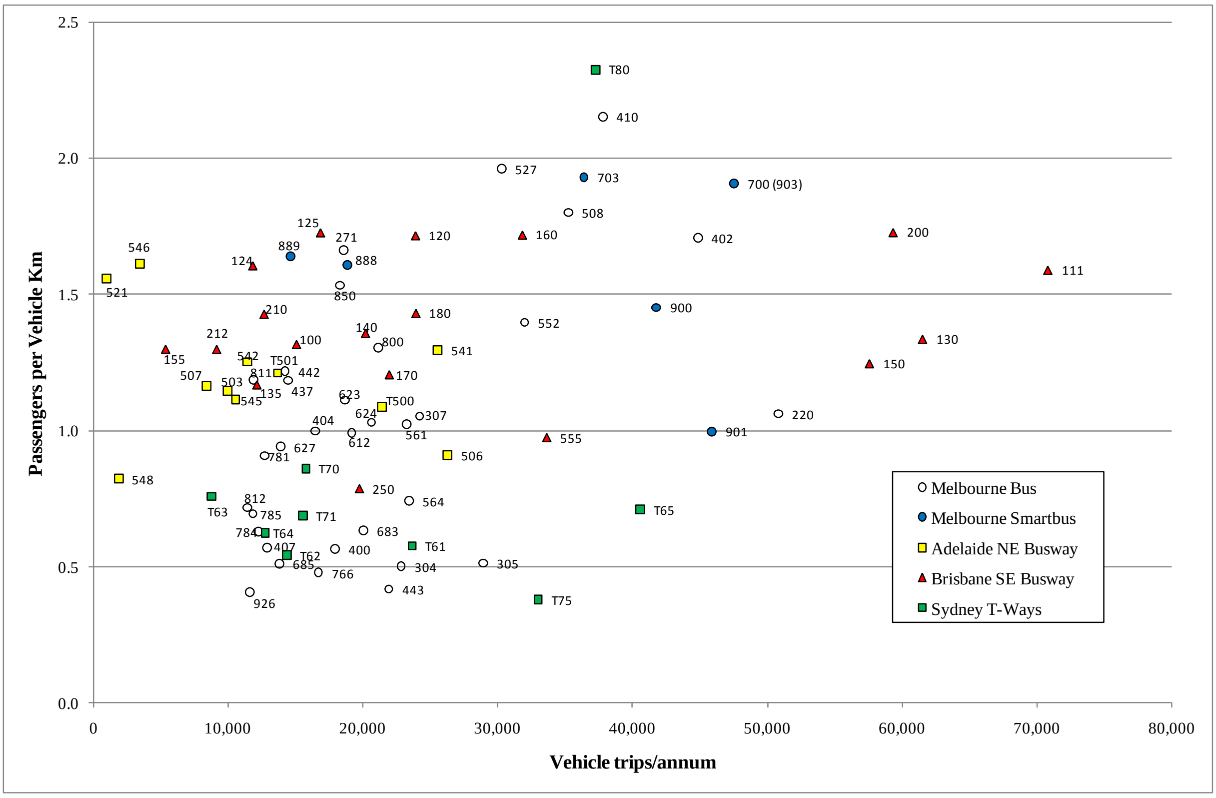
Figure 2 shows the distribution of the service level variable vehicle trips p.a. as it relates to the dependent variables Boardings per Route Km and Passenger per Vehicle Km. Figure 2 top shows a close link between vehicle trips p.a. and boardings/ route km with Brisbane SE busway, SmartBus and selected Adelaide NE Busway routes having higher values of both variables. Sydney T-Way routes have mid to low range values on both variables and a wide range of BRK performance for similar service level (the performance of the T80 is substantially higher than the T65 and T75 for similar service levels). Figure 2 bottom shows a less clear link between service level and PVK however the T80 (the Liverpool-Parramatta transitway route) has the highest overall ridership per vehicle km followed closely by two Adelaide and Smartbus routes.

**Figure 2 : Boardings/Route Km and Passengers/Vehicle Km by Vehicle Trips p.a. Individual Route Services Analysed**

**Boardings/ Route Km**




**Passengers/ Vehicle Km**



## 4.2 Regression Analyses

This section describes the two regression analyses conducted to predict BRK and PVK. A step-wise regression model was chosen where variables were included in the model based on their level of statistical significance (a significance probability of 95% was adopted for inclusion and removal was based on a significance threshold of below 90%).

### *4.2.1 Boardings Per Route Kilometre*

Preliminary correlation analysis showed that vehicle trips per annum, vehicle kilometres and weekday frequency were highly collinear (Pearson's $r$ =.67 to .86) resulting in collinearity of the model. Collinearity is a problem in multiple regression models as it inflates the standard error of the predictors, limits the size of R and makes it difficult to assess the individual importance of a predictor (Field 2009). Vehicle trips per annum was selected because it had the highest correlation with ridership ($r$ = .89).

Variables considered for the model to predict BRK included:

- Vehicle trips per annum
- Weekday service span
- Average speed (8am)
- % right of way
- Stop spacing
- % accessible vehicles
- Population density
- Employment density
- Car Ownership
- BRT quality rank

Step-wise regression resulted in a statistically significant model, adjusted $R^2$ = .81, $F(3, 73)$ = 109.4, $p$ < .0001, with three explanatory variables. These variables together explain 81% of the variance in boardings per route kilometre. Results are shown in Table 6.

The three significant predictors are (in order of influence): vehicle trips per annum, vehicle accessibility and population density. Vehicle trips (β = .82) has a very high positive influence on boardings per route kilometre. Vehicle accessibility (β = .16) and population density (β = .14) have small positive influences on boardings.

**Table 6: Boardings per Route Kilometre Multiple Regression Model**

| $R^2$ (adjusted) = .81 $F(3, 73)$ = 109.4, $p$ < .0001 | | | | |
|---|---|---|---|---|
| **Variable** | **B** | **SE B** | **Beta (β)** | **t-value** |
| **Constant** | -25,312.9 | 5,769.1 | | |
| **Vehicle trips per annum** | 1.47 | .10 | .82 | 15.39 |
| **Vehicle accessibility** | 144.4 | 484.7 | .16 | 3.00 |
| **Population density** | 6.09 | 2.31 | .14 | 2.64 |

Note: all three predictors are significant p < .01

Stop spacing, speed, BRT rank and right of way did not contribute to the model. This suggests that BRT infrastructure is not the primary driver of boardings/route km but that vehicle trips and service frequency are the key influences on ridership.

However the assumptions of regression should be further explored before this model is applied. It is important to determine whether or not outliers are influencing the model results and that the residuals are evenly distributed.

The three service level variables were identified as potentially collinear before the model was run and only one of the three was included. However to be thorough, collinearity was assessed for the regression model. A Variance Inflation Factor (VIF) over 10 is cause for concern (Myers 1990). The VIF for each of the three variables in the model was below 1.2 indicating no evidence of collinearity.

Three criteria were examined to determine whether a single case was having undue influence on the model: Cook's Distance, leverage and Mahalanobis Distance. The average leverage for the model is .052 ($k$+1/$n$ = 4/77); only two cases had a value greater than three times the leverage (Brisbane route 111 at leverage = .17 and Melbourne 402 at .18) raising concern that they may have an undue influence on the model (Stevens 2002). However none of the cases had a Cook's Distance greater than the cut-off of 1 (Cook and Weisberg 1982). With a relatively small sample size, Mahalanobis distances approaching 15 or over may be cause for concern (Barnett and Lewis 1978). Here routes 111 and 402 had a value of 13 and are below the cut off. As these two values only failed one of the three diagnostics, hence they are not likely to be of concern.

The Durbin-Watson value of 1.94 was quite close to the predicted value of 2 suggesting that the residual errors are uncorrelated (Durbin and Watson 1951). The P-P plot of standardised residuals shows that they do not form a perfect straight line but deviate slightly, nevertheless they are quite close to linear.

Results demonstrate that the quantity of service supplied in terms of vehicle trips per annum dominates as a driver of ridership per route km. None of the BRT related infrastructure factors (right of way, BRT quality ranking, stop spacing etc.) were found to be significant in influencing BRK. Indeed the influence of vehicle trips per annum was so strong that the other two significant variables (vehicle accessibility and population density) were quite small in comparison.

Because of the scale of this influence an additional analysis was proposed to test ridership levels irrespective of service level. This measure of demand is often termed 'service effectiveness' (Fielding 1987), that is, the amount of patronage per unit of service supply. The performance measure in this case is passengers per vehicle kilometre (PVK). Use of this measure will remove the direct influence of service level on the data leaving greater scope to explore how a wider range of explanatory variables might influence demand for services.

### *4.2.2 Passengers per Vehicle Kilometre*

As with the BRK analysis, only one service level variable out of three (vehicle trips per annum, vehicle kilometres and service frequency) was included in the model to avoid multicollinearity. In this case weekday service frequency was selected because it had the highest correlation with ridership (.49).

A step-wise regression model was used with the same approach as identified in the analysis of BRK in the previous section. Variables considered for the model to predict PVK included:

- Weekday service frequency
- Weekday service span
- Average speed (8am)
- % right of way
- Stop spacing
- % accessible vehicles
- Population density
- Employment density

- Cars per 1,000
- BRT quality rank.

Step-wise regression resulted in a statistically significant model, adjusted $R^2$ = .44, $F(4, 72)$ = 15.71, $p$ < .0001, with four explanatory variables. These four variables together explain 44% of the variance in passengers per vehicle kilometre.

**Table 7: Passengers per Vehicle Kilometre Multiple Regression Model**

| $R^2$ (adjusted) = .44 $F(3, 72)$ = 15.71, $p$ < .0001 | | | | |
|---|---|---|---|---|
| **Variable** | **B** | **SE B** | **Beta (β)** | **t-value** |
| **Constant** | 1.02 | .175 | | |
| **Average speed (8am)** | -.028 | .006 | -.42 | -4.55 |
| **Weekday service frequency** | .158 | .034 | .41 | 4.68 |
| **BRT rank** | .079 | .025 | .29 | 3.20 |
| **Vehicle accessibility** | .004 | .001 | .25 | 2.77 |

Note: all four predictors were significant p < .01

The four significant predictors are (in order of influence): average speed (negatively related), weekday service frequency, BRT rank and vehicle accessibility. Average speed (β = -.42) has a moderate negative influence on PVK; slower services have higher PVK. Weekday service frequency also had a moderate influence on PVK (β = .41); frequent services are more effective than infrequent ones at carrying demand. BRT rank (β = .29) and accessibility (β = .25) had small but significant influences on PVK. Once again stop spacing was not a significant predictor, although it may be somewhat subsumed by average speed.

The statistical assumptions of regression were tested for this model. There was no evidence of collinearity (all VIF were close to 1. No Cook's distances were near 1 and no leverage values were more than three times the average. One case had a Mahalanobis Distance near 15 (Melbourne route 402) but re-running the regression without this case does not change the model. The Durbin-Watson value was 1.78, quite close to the predicted value of 2. The P-P plot of standardised residuals was fairly straight. Overall the results were therefore considered to be statistically sound.

### *4.2.3 Alternative Representation of BRT Quality*

Since one of the major objectives of the research was to explore how BRT system infrastructure quality affects ridership a separate representation of this variable was considered in the modelling. The BRT Rank variable used initially assumes a qualitatively based ranking whereby the Brisbane busway infrastructure is effectively considered to be five times the 'value' of local Melbourne bus routes. This is a somewhat exploratory and subjective judgment.

An alternative representation of BRT quality was considered using a series of BRT system dummy variables representing each system individually. This approach provides the opportunity for the modelling to identify any ridership effects specific to separate system designs, although it would also capture any other unrelated differences between the systems.

Modelling of BRK replacing the BRT Rank with the BRT system dummy variables and all the other explanatory variables identified in section 4.2.1 provided exactly the same outcome. The results excluded all the BRT system dummy variables because they were not significant predictors of Boardings per Route Km. This is a consistent finding for all means of representing BRT system quality.

A regression model of PVK replacing BRT Rank with the BRT system dummy variables established a model with an adjusted $R^2$ = .41, F(4, 72) = 14.3, p < .0001, with four explanatory variables. These four variables together explain 41% of the variance in passengers per vehicle kilometre.

**Table 8: Passengers per Vehicle Kilometre Multiple Regression Model – Alternative BRT Quality Variable**

| $R^2$ (adjusted) = .41 $F(4, 72)$ = 14.3, $p$ < .0001 | | | | |
|---|---|---|---|---|
| **Variable** | **B** | **SE B** | **Beta (β)** | **t-value** |
| **Constant** | 1.00 | .179 | | |
| **Average speed (8am)** | -.024 | .006 | -.36 | -3.98 |
| **Weekday service frequency** | .146 | .035 | .38 | 4.11 |
| **Vehicle accessibility** | .450 | .146 | .28 | 3.09 |
| **Employment density** | .00006 | .00002 | .24 | 2.63 |

Note: all four predictors were significant p < .01

Frequency, speed and vehicle accessibility remain the major predictors as in the analysis including BRT Rank however the alternative representation of BRT quality using system dummy variables does not become significant in this model. Rather a new explanatory variable, employment density, is significant with a Beta value of .24.

On reflection it is not surprising that employment density replaced BRT rank as a significant explanatory variable in this analysis. The rank variable puts the highest value of 5 on Brisbane busways which also have the highest employment density (see Table 5) while Adelaide has the second highest rank of 4 but also has the second highest employment density. In fact employment density and BRT rank are highly correlated, $r$ = .66, $p$ < .001.

Unfortunately this test does not clarify the findings of the analysis in relation to BRT system quality. It suggests that among Australian systems BRT quality (represented by BRT Rank) and employment density are broadly similar predictors and can replace each other with similar impacts on PVK prediction. It is unclear, then, whether the BRT Rank variable is indeed capturing the quality of the BRT system or is simply acting as a proxy to employment density.

# 5 Summary and discussion

Bus Rapid Transit (BRT) systems are an emerging approach to providing rail like quality to bus services to cost effectively increase ridership. Previous research has suggested that a high quantity of service supplied is one, if not the major, contributor to high ridership (Stopher 1992; FitzRoy and Smith 1998; Kain and Liu 1999; Mackett and Babalik-Sutcliffe 2003; Currie and Wallis 2008). Population and employment density, car ownership, low fares and integration have also been suggested as ridership drivers to varying degrees in the literature (Seskin and Cervero 1996a; Kain and Liu 1999; Babalik-Sutcliffe 2002; Johnson 2003; Kain et al. 2004).

BRT research shows that high quality running ways, stations, vehicles, intelligent transport system and service patterns can improve the quality of bus systems to cost effectively provide rail like infrastructure quality and capacity. However research on ridership impacts of these BRT design factors is limited (Currie 2005). The only previous study identified, by Hensher and Golob (2008), suggested high service levels plus a large number of stations and low fares were important drivers of ridership on international BRT systems.

This research explores how service design factors influence demand for bus services using 77 bus routes in Australia. This included 33 "conventional" bus routes in Melbourne, six

Melbourne SmartBus routes that share some characteristics with BRT systems and 38 routes that use at least part of the BRT infrastructure in Brisbane, Adelaide and Sydney.

As shown in Table 4, Melbourne SmartBus routes have higher boardings per route kilometre (BRK) and passengers per vehicle kilometre (PVK) than any other bus system. The Brisbane South East Busway is second. The Adelaide North East Busway has the lowest BRK but its respectable level of PVK suggests that this is due to its highly peaked nature.

Two multiple regression analyses were undertaken to explore the influence of the explanatory variables on ridership. Results for overall ridership (boardings per route km) identified a statistically significant model ($R^2$=.81). The largest influence on BRK was vehicle trips per annum (β = .82), consistent with past research including the analysis of bus routes (Stopher 1992) and the limited available analysis of BRT systems (Hensher and Golob 2008). This is the single most significant finding of the research: the quantity of service supplied is the most important driver of ridership regardless of the quality of the BRT (or conventional bus) infrastructure.

Vehicle accessibility (β = .16) and population density (β = .14) had small positive influences on boardings. The small influence of population density is highly consistent with previous research (e.g. Seskin and Cervero 1996b). Vehicle accessibility is rarely thought to increase demand by more than few percentage points as a result of reducing barriers to access for the aged and those with physical impairments (Currie and Wallis 2008). The influence of this factor in this analysis is higher than suggested from previous research and might be representing more than just improved physical accessibility. In most cases for the routes analysed, the provision of accessible buses also involve use of better designed and newer vehicles. Branding of these vehicles (or at least identification of these vehicles with a quality service) may also be having an influence. Hence 'accessible vehicles' may represent a range of influences that only further research can untangle.

The implication of the above factors is that bus services should operate at high frequency and with lots of service quantity, using modern low floor accessible vehicles in areas of high population density to achieve higher ridership.

It is possible that the strong influence of service level in the results is to some extent a 'self fulfilling prophecy'. The most common tactical planning response to high ridership is to increase service required particularly in the peak where loading standards might require a matching of demand and supply to reduce crowding. This argument can be used to suggest that service level and ridership are closely related due to planning outcomes not service level generation impacts. As a counter to this argument the service level modelled focussed on all time periods as well as the peak hence the influence of peak loading standards on this link would not be dominant. In addition the theory of matching peak supply to ridership is not always followed in real world operations where limited resources and cost minimisation can limit increases in capacity.

To explore these issues further a second analysis was developed to explore factors affecting ridership after accounting for a given level of service. This is termed a 'service effectiveness' measure and uses passengers per vehicle km (PVK) as the dependent variables.

Results show statistically significant but less powerful model, adjusted $R^2$ = .44, with four explanatory variables. The strongest influence was average speed (β = -.42) and interestingly this value is negative meaning that faster services had lower PVK. This variable may be unduly influenced by the fact that some of the fastest run speeds were not BRT systems but bus routes running in far outer Melbourne (such as the 685 Lilydale route with an 8am run speed of 43kph). Conversely some of the most effective conventional bus routes run through heavily congested areas with average run speeds below 20kph. In addition slow speed can be influenced by boarding and alighting volume at bus stops. This might make high ridership services (whether BRT or not) slower.

Weekday frequency was the second most important variable in the model (β = .41) which is interesting considering that PVK takes vehicle kilometres into account. This suggests that service frequency increases ridership independent of service quantity. This finding suggests that ridership for a given level of service is driven by service frequency. It acts to prove the point that frequency is a driver of ridership rather than an outcome of peak matching of supply and demand.

The BRT ranking variable was significant in this model and of medium influence (β = .29). Along with vehicle accessibility (β = .25) these two variables may be capturing a range of influences such as infrastructure quality or bus modernity. Again, further research will aid in untangling these influences.

A separate analysis using an alternative BRT quality variable (system dummy variables) again found BRT quality was not a significant explanatory factor in boardings per route km. Unlike the BRT rank variable the system dummy variable was not significant in explaining patronage per vehicle km. A new variable, employment density, was found to be significant in the analysis however this was shown to be closely linked to the BRT Rank variable so it is unclear what the relative influence of BRT Rank or Employment Density are in the analysis.

Several elements of the results suggest that Melbourne's SmartBus design elements have superior performance to the high quality, and expensive, BRT infrastructure systems provided in cities like Brisbane, Adelaide and to an extent Sydney. Segregated right of way had no significant influence on either model. Quality BRT infrastructure, represented in the 'BRT Rank' variable, had only a small measured relationship to service effectiveness (β = .29) which may be related to employment density and no measureable influence on route level ridership. SmartBus ridership (using both measures) was consistently high.

This conclusion would be misleading because in practice total BRT system ridership results from the sum of the routes included in the operation. For SmartBus it is rare for more than one route to operate on the same right of way while the major busways identified have numerous component routes using the same infrastructure. Total BRT system wide ridership therefore needs consideration in addition to consideration of the individual ridership performance of separate bus routes. Higher quality BRT infrastructure (such as busways) play an important role in enabling access for multiple routes to a quality right of way and the ridership performance of these systems must be considered relative to system wide-impacts on demand.

On a system-wide basis the busway BRT systems outperform the ridership of SmartBus. However SmartBus has impressive ridership compared to the infrastructure costs involved. The right of way of the Brisbane South East Busway cost between $400M and $660M to construct in 2003 whereas construction costs for SmartBus were comparatively minimal. Local planners estimate infrastructure costs (excluding vehicles) of less than $400K per route km or about $75M for the whole of the network. Although the South East Busway has almost three times the ridership of SmartBus (Currie 2006) its infrastructure costs were around five to nine times higher.

This value for money comparison is even more attractive when SmartBus is compared to the Liverpool-Parramatta Transitway. The T80 had 2.6M boardings p.a. in 2008 while its infrastructure cost between $200M and $350M to construct (in Currie 2006). SmartBus route 700 (now 903) carries a similar loading yet all of the SmartBus network together cost between 20% to 40% of the infrastructure costs associated with the T80. In addition there is an important lesson for the Sydney t-ways in the results of this analysis. The volume of service offered is a critical driver of ridership yet the service level offered on the T-Way routes examined is the lowest of all the systems examined including the Melbourne conventional bus routes.

Do the results imply that significant BRT right of way infrastructure investment is less cost effective from a ridership viewpoint? The answer depends on the scale and focus of the public transport system being designed and the objectives which are used to drive this design. SmartBus is effective at achieving relatively high ridership for modest investment but will never be able to provide a rail like volume of service on a multiple route mass transit corridor. Busway based BRT routes each have lower relative ridership generation compared to a SmartBus route but together busway routes provide rail like capacity and quality creating a mass transit solution for a major transport corridor. In practice therefore the two bus systems are quite distinct and separate types of offerings.

## 5.1 Future Research

Research of this nature relies on the quantity of data points and this one is no exception. Data collection was a major part of the effort of this study yet a larger database would add much value in the quality and strength of the findings. The use of only Melbourne non-BRT routes to represent non-BRT services in general is questionable from a number of viewpoints. Most notably Melbourne non-BRT routes operate mainly in middle and outer suburbs. Hence usage is relatively low compared to cities with high shares of CBD based bus systems. This analysis suggests that a wider data collection program focussed on a wider sample of interstate, non-BRT routes might be beneficial in future research.

Finally, BRT systems are increasingly being adopted worldwide, particularly in North America. Were the data available it would be extremely illuminating to compare these systems to the Australian situation. It would also be very interesting to compare the performance of bus and BRT routes with light railway systems using a comparative approach.

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