Australasian Transport Research Forum 2013 Proceedings
2 - 4 October 2013, Brisbane, Australia
Publication website: http://www.patrec.org/atrf.aspx

Bus Rapid Transit: An examination of changes of travel patterns for journey to work and socio-demographic characteristics

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Abstract

Over the past two decades, four Australian capital cities (Adelaide, Brisbane, Melbourne and Sydney) have implemented Bus Rapid Transit (BRT) within their Urban Public Transport (UPT) networks. This has resulted in extensive BRT networks and high patronage. From 2006 to 2010, the total length of BRT networks in Australia increased 194% to 318 kilometres backed by an increase of 130% (36.6 million to 84 million) in annual number of passengers carried. However, despite the increasingly important role of BRT as a component of the UPT networks, the extent to which BRT has modified travel patterns in Australian cities has scarcely been investigated. As such this paper examines this question in order to better understand the impacts of BRT implementation on travel patterns. Drawing on journey-to-work (JTW) census data from 1996, 2001, 2006 and 2011 in Brisbane, we first examine changes in the dynamics of JTW patterns over a decade period (1996 to 2006) before modelling the relationships between mode shares of BRT adjacent catchment and socio-demographic characteristics in 2011. Results reveal some localised changes in JTW patterns associated with the expansion of the BRT network and linked to socio-demographic characteristics. The findings provide a first step in developing an evidence base with the capacity to inform future expansions of the BRT.

1. Introduction

The future sustainability of Australian cities is threatened by the significant rise in private car use coupled with limited urban public transport (UPT) share. Recent data shows that the overall mode share of UPT (i.e. the total of train, bus, tram and ferry trips) across Australia's major cities equates to approximately 10% of all trips while the mode share of private car is around 86% (Cosgrove, 2011). Given this imbalance in the modal share, there is a pressing need to address people's travel needs, whereby smart UPT design and implementation is one opportunity to progress towards sustainable urban transport (Newman and Kenworthy, 1999, Wright and Fjellstrom, 2003).

While rail-based transit has been traditionally appraised for its high capacity and speed, more cities opted for Bus Rapid Transit (BRT) as an alternative (Wright and Hook, 2007). BRT's rail-like service pattern including high service frequency and fewer stops guarantees the capacity to carry relatively large numbers of passengers, typically 8,000 to 20,000 passengers per hour per direction during peak hours (Hensher and Golob, 2008). In comparison to rail-based transit, BRT is between 4 to 20 times cheaper to construct and maintain (Wright and Hook, 2007), and offers increased flexibility, in that it can be operated off the dedicated busway (Levinson et al., 2002). These features collectively have made BRT a more attractive UPT option to address the issues of sustainable transport.

Over the past two decades, BRT has played an increasingly important role in the UPT networks of Australian cities. Four Australian capital cities (Adelaide, Brisbane, Melbourne and Sydney) have implemented BRT within their UPT networks to enhance service quality and progress towards sustainable urban transport (Currie, 2006, Currie and Delbosc, 2010). Substantial money (in total over $1 billion) has been invested to fund the construction of BRT networks. From 2006 to 2010, the total length of BRT networks in Australia increased 194% to 318 kilometres backed by an increase of 130% (36.6 million to 84 million) in annual number of passengers carried. In addition, further expansions of BRT networks are planned over the next 4 to 5 years, which will result in an additional 100 kilometres of BRT network across Australia.

However, despite the increasingly important role of BRT as a component of the Australian UPT networks, the extent to which BRT has impacted upon our travel patterns has scarcely been investigated. A limited number of studies have shed light on the efficiency of BRT performance in Australian cities, see for example, Currie (2006), Currie and Delbosc (2010), Bitzios et al (2009). However, detailed information concerning the impacts of BRT on the adjacent catchment areas and its links with the socio-demographic characteristics of commuters remains unexplored. Addressing these questions is of practical value in informing future implementation of BRT with regards to the evaluation of its impacts and profiling the characteristics of its adjacent catchments.

Among the four BRT systems in Australia, Brisbane’s BRT has been highlighted as best practice in terms of its infrastructure and service quality. Comprised of exclusive busway, well-equipped stations and intelligent information system, it has been deemed as an exemplar for the BRT design in other cities (Levinson et al., 2003). Moreover, the 187 bus routes are fully or partially operated on the dedicated busway (Currie and Delbosc, 2010). This is a high number, approximately 47% of the 400 bus routes in Brisbane (Translink, 2012). The service frequency of Brisbane’s BRT also represents the highest level in Australia, with 259 buses per hour during peak hours on the South East Busway (SEB), compared to 55 on Sydney’s Parramatta-Rouse Hill Busway and 78 on Adelaide’s busway. By 2010, the annual ridership of Brisbane’s BRT accounted for over half of the total ridership of all BRT systems in Australia (Currie and Delbosc, 2010). Considerable expansions of Brisbane’s BRT system are imminent at the time of writing, which will result in approximately 30 kilometres of new busway network. As such, the need to investigate the impacts of BRT on travel patterns and associated socio-demographic characteristics in Brisbane is timely.

Drawing on Journey-to-work (JTW) data drawn from the ABS Census, this study addresses two key questions: (1) to what extent BRT implementation has modified travel patterns on its adjacent locales over time; and (2) what relationships exist between travel patterns and socio-demographic characteristics for BRT’s catchments. In order to address these two questions, we first must define the BRT catchment areas following which we then examine the mode share patterns for work trips over the decade to 2006. While JTW trips constitute a small proportion of all trips in Australian cities, they are of primary interest to transport practitioners because of the traffic burdens generated during peak hours (Mees et al., 2008). Moreover, JTW data from the Census is representative of population and available at different spatial levels (for example, city-wide and suburb levels). As such this permits us to examine travel patterns at a micro geographic scale (e.g., the Census Collection District (CD) or Statistical Area 1 (SA1) level) and avoid the issue of small samples typically associated with travel survey data (Rickwood and Glazebrook, 2009, Stone and Mees, 2011). Then, two regression models of mode shares and socio-demographic characteristics are developed to enhance our understanding of their relationships in relation to Brisbane's BRT.

The remainder of the study is structured as follows: the next section provides a background to the previous BRT research with a specific focus on their role in changing travel patterns before introducing the study area, Brisbane's BRT network. Section 3 then describes the method used to determine the catchment areas for the BRT and subsequent extraction of ABS Census data. Section 4 reports the methods and the results. Section 5 offers a tentative conclusion, and discusses their implications in relation to future BRT expansion policies as well as a series of avenues for future research.

2. Previous BRT research on travel patterns and study context

Here we provide a brief review of existing international BRT research to identify its impacts on travel patterns and highlight the lack of a detailed investigation in an Australian metropolitan context. Finally, we introduce the case study, Brisbane's BRT network by briefly describing its history and spatial layout.

2.1 Previous BRT research on travel patterns

Given the increasingly important role of BRT as a cost effective UPT option, more studies in recent years have examined the impacts of BRT on travel patterns in both developed and developing cities. Lleras (2002) confirmed that Transmilenio BRT in Bogota, Columbia, offered an enhanced service compared to traditional on-road bus by considerably shortening travel time and enhancing travel experience for passengers. He also found that Transmilenio BRT benefited more on its vicinity and lower income population than outer area and high income population in terms of travel time-saving. Callaghan and Vincent (2007) compared the influence of the Orange Line BRT system in Los Angeles, US, to a local Light Rail Transit service and a bus service with similar network length. Their results demonstrated that the Orange Line outperformed the other two systems in attracting new passengers, which was attributed to its exclusive right-of-way. In developing cities, Deng and Nelson (2013) revealed that shortly after the implementation of Beijing Southern Axis BRT Line, China, 7.2% new trips were generated along the BRT corridor. In the first month of BRT operation in Jakarta, Indonesia, it has been revealed that 14% of its new passengers previously used private cars for the same trips (Ernst, 2005).

In the Australian context, only a limited number of studies have investigated the impacts of BRT on travel behaviour. Currie (2006) and Currie and Delbosc (2010) reviewed the development history of BRT systems in Australasia from 2001 to 2010, coupled with the overviews concerning the enhanced efficiency of BRT carrying passengers in cities of Australia (i.e., Adelaide, Sydney, Brisbane and Melbourne) and New Zealand (i.e., Auckland). They found strong and steady growth of BRT ridership across Australia between 2001 and 2010, and reinforced the notion of BRT being an attractive alternative to rail transit. Opportunities to enhance BRT service such as off-board fare payment were suggested as well. In addition, Bitzios et al. (2009) examined the benefits from the operation of South East Busway (SEB) in Brisbane between 2002 and 2006. They contended that while traditional cost-benefits evaluation of BRT implementation did not render convincing results of viable economic benefits, it was limited in considering other aspects such as public attitudes towards BRT, promoting public transport use and environmental impacts. Their study revealed positive feedbacks on these aspects.

Apart from the aforementioned studies, the information regarding the impacts of BRT in Australian cities is still limited. First, it is not known the extent to which BRT has modified travel patterns on its adjacent locales over time, specifically the use of sustainable transport modes such as UPT as a replacement of the private cars. Second, to our knowledge, there have been no studies that have explored the dynamics between travel patterns and socio-demographic characteristics for BRT's adjacent catchment areas. More specifically, does BRT only attract commuters with lower income and no access to private vehicles?

Addressing these two questions will advance our understanding in terms of the impacts of BRT on travel behaviour and their relationships to the socio-demographic characteristics of its catchments. As such it will add to the evidence base of the impacts of BRT in Australian cities, as well as identify challenges and set expectations for future BRT expansions.

2.2 Brisbane's BRT network as study context

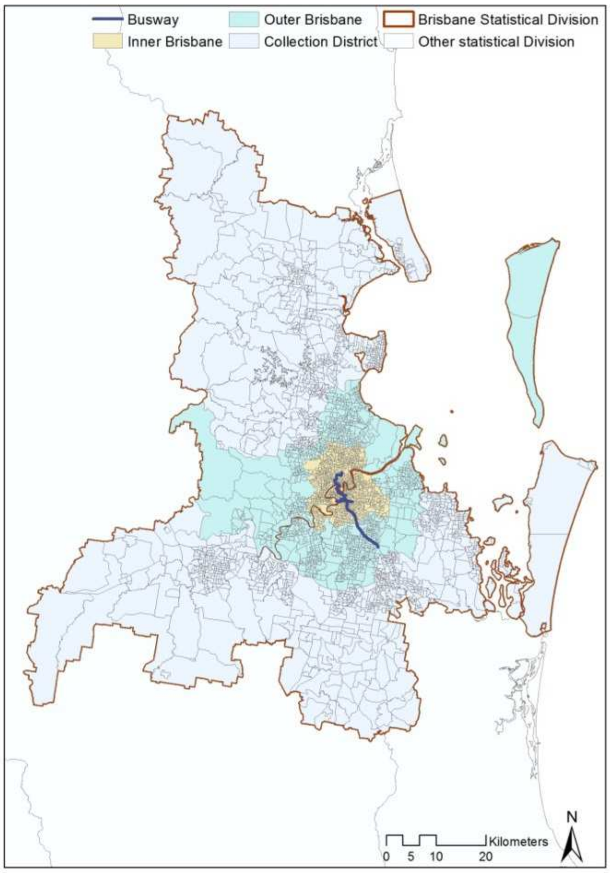

Figure 1a Study context of Brisbane

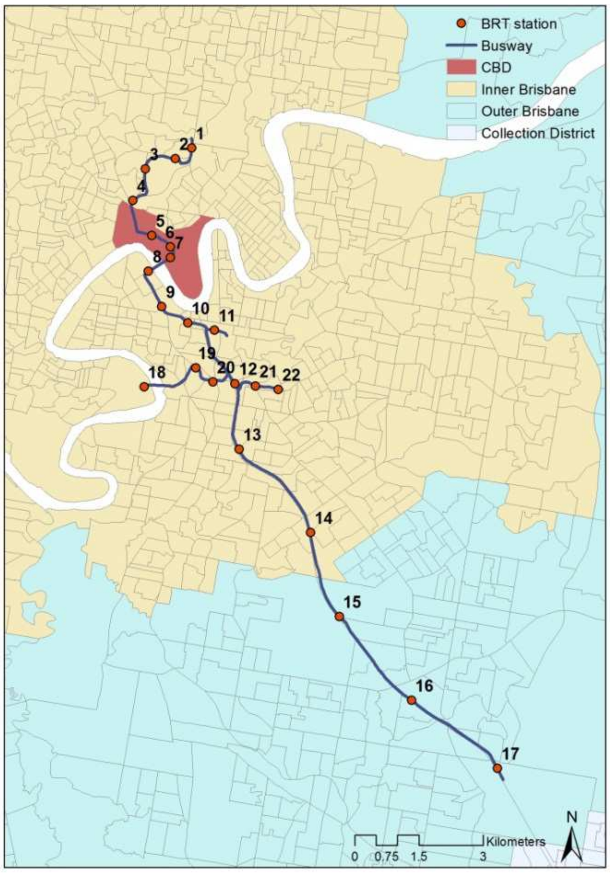

Figure 1b Brisbane's BRT network

Brisbane's BRT network is located across the inner northern and outer southern areas of the city, linking adjacent suburbs to the CBD (Figure 1a). The effect of this spatial structure is to act as feeders from suburban areas to the CBD. Four busway sections, the South East Busway (SEB), the Inner Northern Busway (INB), the Northern Busway (NB) and the Eastern Busway (EB) constitute the current Brisbane's BRT system (Figure 1b). Table 1 summarises the times at which the BRT stations were opened for each of the busway sections between 2000 and 2011. The SEB was opened in 2000, catering for the commuting demand of south eastern suburbs to the inner city (Bitzios et al., 2009). The INB was opened in 2004 with 2.7 kilometres of busway. The remaining 1.9 kilometres of the INB was completed in 2008. The EB and the NB are the latest busway sections both opened in 2009.

The NB extends the INB to a wider catchment in the northern suburbs, while the EB links a major university with the eastern suburbs, intersecting with the SEB at the Buranda station. Until 2011, 3.7 kilometres of the EB and 1.2 kilometres of the NB were put into operation. The expansion of three busway sections (i.e., the SEB, the NB and the EB) is still on-going at the time of writing. This will result in further 30 kilometres of busway in the following 5 years. The existing 26 kilometres of dedicated busway and 22 BRT stations that were opened before 2011 constitute the context for this study.

Table 1 Busway sections and stations, source: Department of Transport and Main roads (2013)

Busway Sections	Length (km)	No.	Stations	Open year
Northern Busway (NB)	1.2	1	RBWH	2009
Inner Northern Busway (INB)	4.7	2	RCH Herston	2004
		3	Kelvin Grove	2004
		4	Normanby	2004
		5	Roma Street	2004
		6	King George Square	2008
		7	Queen Street	2000
South East Busway (SEB)	16.5	8	Cultural Centre	2000
		9	South Bank	2000
		10	Mater Hill	2000
		11	Wolloongabba	2000
		12	Buranda	2001
		13	Greenslopes	2001
		14	Holland Park West	2001
		15	Griffith University	2001
		16	Upper Mount Gravatt	2001
		17	Eight Mile Plains	2001
Eastern Busway (EB)	3.7	18	UQ Lakes	2009
		19	Boggo Road	2009
		20	PA Hospital	2009
		21	Stones Corner	2011
		22	Langlands Park	2011
Total	26.1			

3. Defining BRT's adjacent catchment areas and compilation of the Census data

Before we can conduct both time-series and regression analyses, it is necessary to define the BRT's adjacent catchment areas (e.g., the catchment areas surrounding the BRT stations within a certain distance) and the method for compiling the Census data. Common to many transport studies, an 800-metre radial distance from an identified UPT station is considered as the primary catchment area for a UPT service. The logic behind is that for most people an 800-metre distance is the walkable distance to a transit station (Stringham, 1982, Guerra et al., 2012). Empirical evidence has been found to support this notion, that a large proportion of UPT passengers walk to their transit stations within an 800-metre distance (Stringham, 1982, O'Sullivan and Morrall, 1996, Cervero, 2007), however it is noted that there has been some exceptions to this distance (Zhao et al., 2003). In this study, we adopt the 800-metre catchment in addition to two additional distances (i.e., 1,600-metre and 3-kilometre) to investigate the change of travel patterns for work trips under the impacts of BRT (Figure 3). The 1,600-metre distance represents the maximum walking distance to transit service following previous studies, e.g., Zhao et al (2003), while the 3-kilometre distance is found to be a limit for drive-in/bus-in distance to transit service (Norley, 2010). By comparing the travel patterns on the above three bands, we believe that the 800-metre catchment area can be justified and a clearer picture of the impacts of BRT on the adjacent area can be rendered as well.

Next, the changes in the smallest spatial unit (e.g., CD) between each of the censuses presented a series of issues pertaining to the compilation of census data. First, there have been some minor changes on the CD boundaries between 1996, 2001 and 2006 censuses. Second, for the 2011 census, there was a major shift from CD to Statistical Area 1 (SA1) as the smallest spatial unit. Considering these issues, concorded census data in the same spatial base is needed so as to have comparable data. Unfortunately, given the major shift in 2011 census, its concordance with 1996, 2001 and 2006 census data (at the smallest spatial unit) is not possible. As such, concorded Method for Travel to Work of JTW data by place of enumeration of 1996, 2001 and 2006 on 2006 CD boundaries was required from the ABS. This constitutes the basis for time-series analysis to reveal the BRT impact on travel behaviour. The 2011 census data was drawn separately from the Table Builder of the ABS. A regression analysis on 2011 census data was conducted to examine the relationships between current travel patterns (specifically, bus share and car share) and socio-demographic characteristics (e.g., age, gender, income) of the adjacent catchments of Brisbane’s BRT.

4. Methods and results

This section first explores the change of travel patterns for work trips within the determined adjacent catchment areas of BRT. Based on the identified dynamics of travel patterns, we then model the associations between socio-demographic characteristics and travel patterns to understand their dynamics.

4.1 The change of mode share patterns for work trips from 1996 to 2006

The time-series analysis focuses on the busway sections and stations that were opened prior to 2006, and the associated JTW patterns of the defined catchment areas. The concordance process of census data resulted in a small proportion of CDs from 1996 and 2001 censuses without any data, due to the change of CD boundaries. To further validate the basis of comparison, we only used the CDs with census data for all three censuses. CDs within the three catchment areas were extracted separately by using ArcGIS (Figure 2). For the 800-metre area, 152 CDs were extracted; 150 CDs were extracted at the 1,600-metre area; and 294 CDs were extracted at the 3-kilometre area. Mode share for work trips at each of the catchment areas were calculated from the CD level data.

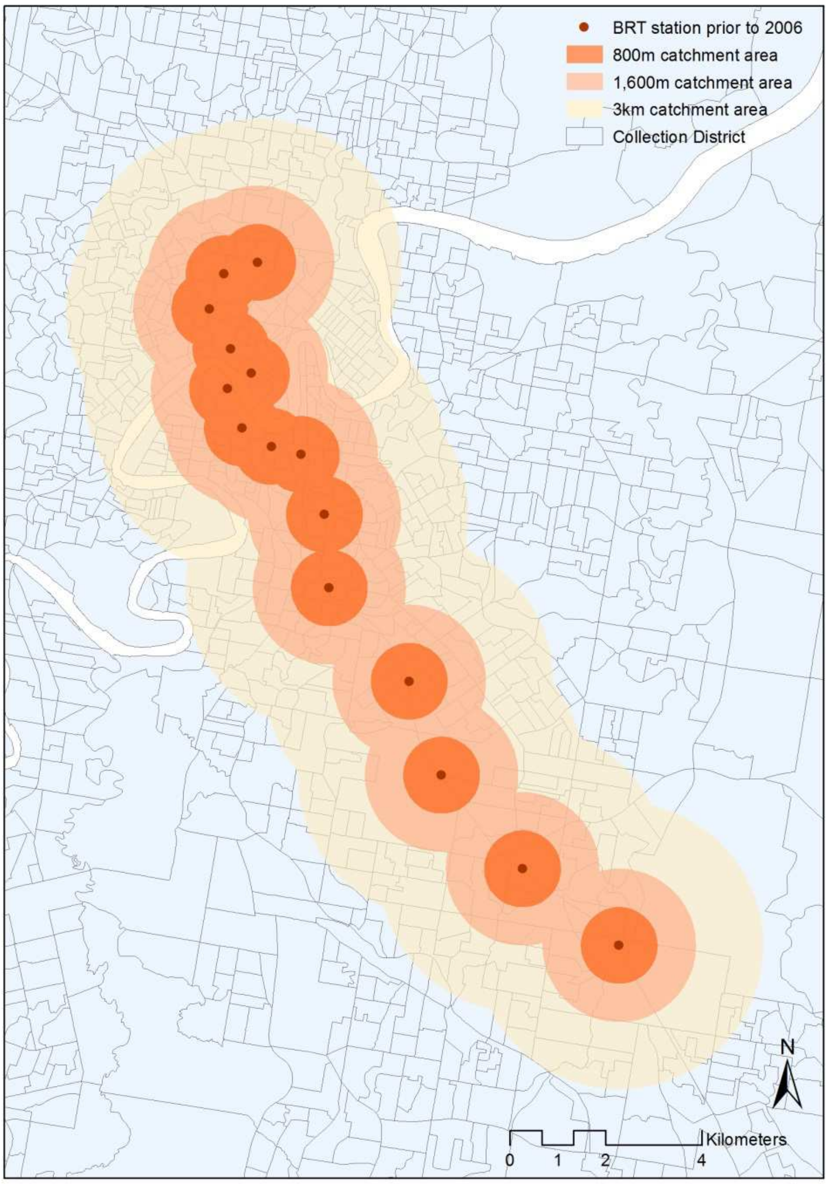

Figure 1 The three catchment areas of Brisbane's BRT

The reported JTW patterns mainly concentrate on the mode shares of train, bus, car (car driver, car passengers and total), walk and bicycle for work trips. Given that the mode shares of other methods including ferry, taxi, motorcycle and mixed methods were low individually at both CD and city-wide levels, they were added together as the 'Other' group. Total number of people who made work trips excludes people who did not go to work, worked at home, or did not state their travel methods. Table 2 summarises the mode share changes at four scales of areas, i.e., the Brisbane Statistical Division (BSD) level, the 800-metre, 1,600-metre and 3-kilometre catchment areas.

Table 2 Mode share patterns at the four scales of areas

Year	1996		2001		2006	
Mode	**Number**	**%**	**Number**	**%**	**Number**	**%**
Mode share at BSD level						
Bus	25648	4.7	28353	4.7	39282	5.5
Train	25834	4.8	27217	4.5	33702	4.7
Car, as driver	382507	70.5	425048	70.2	499644	69.6
Car, as passenger	47820	8.8	48530	8.0	52658	7.3
Car (total)	430327	79.2	473578	78.2	552302	76.9
Walk	17212	3.2	18352	3.0	26257	3.7
Bicycle	5675	1.0	6705	1.1	7946	1.1
Other	38686	7.1	51669	8.5	58792	8.1
Overall	543382	100.0	605874	100.0	718281	100.0
Mode share at the 800-metre area						
Bus	2815	11.0	3026	11.0	4552	13.7
Train	662	2.6	785	2.8	921	2.8
Car, as driver	14527	56.6	15182	55.1	17185	51.8
Car, as passenger	2215	8.6	2175	7.9	2089	6.3
Car (total)	16742	65.2	17357	63.0	19274	58.1
Walk	2772	10.8	3328	12.1	4905	14.8
Bicycle	397	1.5	565	2.1	808	2.4
Other	2296	8.9	2471	9.0	2701	8.2
Overall	25684	100.0	27532	100.0	33161	100.0
Mode share at the 1,600-metre area						
Bus	2931	11.0	3219	11.4	4285	13.1
Train	1001	3.8	1088	3.8	1382	4.2
Car, as driver	16599	62.3	16876	59.6	18859	57.7
Car, as passenger	2305	8.7	2175	7.7	2106	6.4
Car (total)	18904	70.9	19051	67.3	20965	64.1
Walk	1491	5.6	1807	6.4	2611	8.0
Bicycle	373	1.4	627	2.2	828	2.5
Other	1948	7.3	2507	8.9	2636	10.3
Overall	26648	100.0	28299	100.0	32707	100.0
Mode share at the 3-kilometre area						
Bus	5586	10.1	5840	10.1	7560	11.7
Train	2604	4.7	3019	5.2	3438	5.3
Car, as driver	35653	64.6	36531	63.0	39836	61.5
Car, as passenger	4657	8.4	4514	7.8	4290	6.6
Car (total)	40310	73.0	41045	70.8	44126	68.1
Walk	2346	4.3	2521	4.4	3354	5.2
Bicycle	862	1.6	1087	1.9	1244	1.9
Other	3484	6.3	4440	7.6	5076	7.8
Overall	55192	100.0	57952	100.0	64798	100.0

First of all, the travel pattern at the BSD level was examined as the baseline for the time-series analysis. At this level, ‘car’ (total) as expected dominated the share for work trips between 1996 and 2006 (79.2% to 76.9%). Small yet significant decline for share of ‘car as driver (as passenger)’ can be identified over the decade, from 70.5% (8.8%) to 69.6% (7.3%). Two major public transport modes, i.e., ‘bus’ and ‘train’, had similar mode shares for work trips. However, whereas train share was maintained at the same level (4.5% to 4.8%), there has been a more pronounced increase of bus share (4.7% to 5.5%). Last, bicycle share was maintained at a low level of around 1%, whereas walk share experienced an increase from 3% to 3.7%. The BSD level pattern identified here complies with the previous studies investigating travel patterns of Australian metropolitans, e.g., Cosgrove (2011).

At the three adjacent catchment areas of BRT, car was the primary yet declining mode for work trips. However, compared to the BSD level, the car shares ('car as driver or passenger') were significantly lower over the decade. Meanwhile, the bus shares at the three areas (all above 10%) were considerably higher than at the BSD level (around 5%). Moreover, significant rise of walk share can be observed for the three catchment areas. However, there was no notable enhancement of train share at any levels. This might be attributed to a lack of investment in rail transit expansion and improvement in Brisbane (Mees et al., 2008).

Overall, prior to the opening of the BRT system, an environment that encouraged the use of sustainable transport modes has already existed at the focused areas. Based on the current data, it appears that the BRT system has reinforced as well as enhanced this trend.

Comparing the travel patterns at the three catchment areas further highlighted some localised patterns. Between 1996 and 2001, the bus shares at the 800-metre and 1,600-metre areas were maintained at the same level (around 11%), with a slightly lower bus share (around 10%) at the 3-kilometre area. Between 2001 and 2006, there was a considerable jump of bus share at the 800-metre area from 11% to 13.7%. Significant yet lower growths of bus share at the 1,600-metre and 3-kilometre areas were also achieved, from 11.4% to 13.1% and from 10.1% to 11.7% respectively.

There has been a strongly declining trend for car share at all three catchment areas over the decade. Between 1996 and 2001, the biggest decrease of car share occurred at the 1,600-metre area, from 62.3% (8.7%) to 59.6% (7.7%) for 'car as driver (as passengers)', compared to 56.6% (8.6%) to 55.1% (7.9%) at the 800-metre area and 64.6% (8.4%) to 63% (7.8%) at the 3-kilometre area. Between 2001 and 2006, the car shares at the 800-metre area declined to the largest extent, from 55.1% (7.9%) to 51.8% (6.3%) for car as driver (as passengers), significantly higher than the declines in the other two catchment areas, i.e., 59.6% (7.7%) to 57.7% (6.4%) at the 1,600-metre area and 63% (7.8%) to 61.5% (6.6%) at the 3-kilometre area. Last, the share of walking to work also had the biggest increase at the 800-metre area between 2001 and 2006, from 12.1% to 14.8%, compared to 6.4% to 8% at the 1,600-metre area and 4.4% to 5.2% at the 3-kilometre area.

Figures 3a to 3f depict the change in bus and car shares (the total of 'car as driver' and 'car as passenger') within the three catchment areas. The findings point towards a process of increasing concentration of CDs with higher bus share for work trips (over 15%) along the BRT network between 1996 and 2006. In contrast, a reverse trend is observable for car share. However, it should be noted that the locales of the BRT stations within the inner city areas, particularly King George Square, Queen Street and the Cultural Centre, did not experience pronounced changes in bus and car shares. This might be attributed to the fact that active transport modes such as walking and cycling were the main means for work trips within these areas.

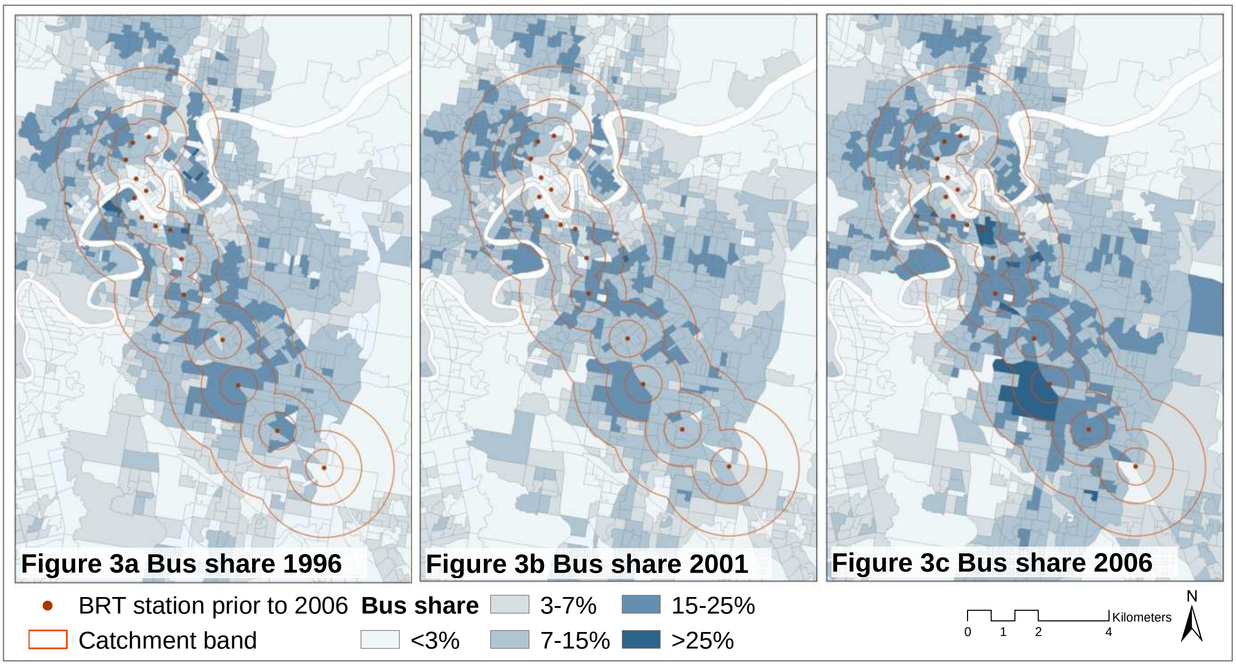

Figure 3a Bus share 1996
Figure 3b Bus share 2001
Figure 3c Bus share 2006

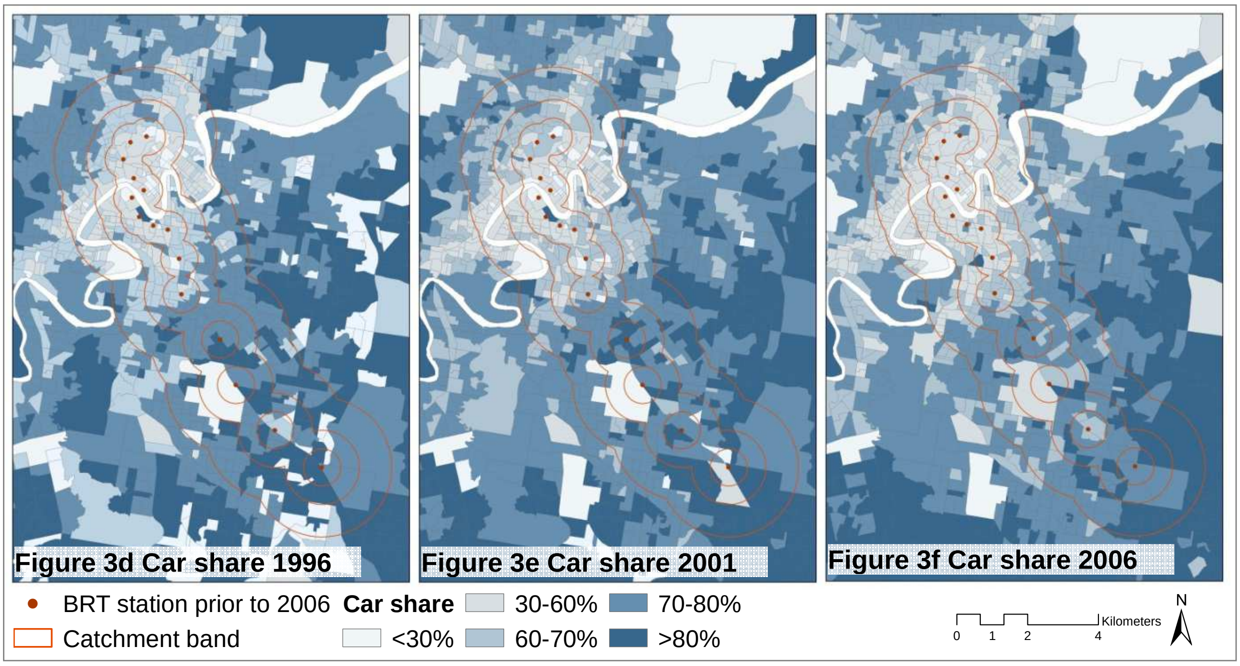

Figure 3d Car share 1996
Figure 3e Car share 2001
Figure 3f Car share 2006

In line with previous studies, e.g., O'Sullivan and Morrall (1996), Cervero (2007), in this study, the 800-metre area was revealed to be the primary catchment area under the impacts of BRT, backed up with the highest level of increase in bus share compared to farther catchment areas. Although to a lesser extent, important increase for bus shares at the 1,600-metre and the 3-kilometre areas over the decade suggests that the implementation of BRT also significantly influenced catchment areas beyond the 800-metre distance. In addition, the declining role of car for work trips suggests that the BRT has importantly incurred the mode shift from car to more sustainable modes of public transport for work trips. Furthermore, considerable growth of walk share for work trips at the three catchment areas is highlighted. Previous studies found that transit-oriented locales such as transit stations coupled with pedestrian-friendly design significantly encouraged pedestrian activity, e.g., Rodríguez et al (2009). However, further investigation regarding urban form and travel behaviour at the focused areas is needed to have more conclusive explanations on this finding.

With the identification of the 800-metre area as the primary BRT catchment area in Brisbane, we move on to analyse the associations between socio-demographic characteristics and travel patterns using 2011 census data and regression method. This provides an initial basis for profiling the current commuters (specifically bus users and car users) at the 800-metre catchment area.

4.2 The mode share patterns and socio-demographic characteristics

As discussed in Section 3, we applied a regression approach to the 2011 Census data to better understand the characteristics of commuters at the 800-metre area. Except for other data being extracted from 'Table Builder' of the ABS, equivalised household income that takes household members' relationships into account was required as part of customised data. This allows more accurate socio-economic indicators to be acquired.

SA1 instead of CD was used as the unit for the regression analysis. All 22 BRT stations in Table 1 were used to identify the 800-metre catchment areas. 221 SA1s that were within or intercepting with the 800-metre circles were initially selected. After excluding 8 SA1s with low population, i.e., less than 20 persons, 213 SA1s remained as the final sample.

Before the regression analysis, the travel patterns at the three catchment areas were examined. The 800-metre area still had the highest bus share (17% compared to 14.8% at the 1600-metre area and 13% at the 3-kilometre area), highest walk share (17% compared to 9.3% and 5.1%) and the lowest car share (overall 52.8% compared to 60.7% and 66%). The travel patterns of 2011 generally continued the trends identified in the time-series analysis.

4.2.1 Overview of variables

Table 3 provides the means and standard deviations of the variables. Two variables, 'mode share by bus' and 'mode share by car' (total of 'car as driver' and 'car as passengers') were constructed as dependent variables in the same way as in the time-series analysis. Through reviewing previous literature (Boarnet and Crane, 2001, Kitamura et al., 1997, Stead, 2001, Bagley and Mokhtarian, 2002), 20 variables were further constructed from census data to reflect the key socio-demographic dimensions of commuters at SA1 level (i.e., gender, age, income, education, household composition, education, motor vehicle ownership and population density).

Close scrutiny of each table and frequency plot showed that most variables did not have highly skewed distributions or problematic kurtosis. Yet, two variables, i.e., 'population density' and 'proportion of persons 15-24 years old', raised some concerns. Examination highlighted that these two variables were strongly skewed (both positively) and had overly concentrated distributions. As such transformation of these two variables was conducted before the modelling exercise. However, this did not improve the overall modelling results. Thus we still chose to use the original variables.

Table 3 Description of dependent and independent variables

	Mean	Standard Deviation
Dependent variables		
Mode share of bus (%)	16.91	6.63
Mode share of car (%)	54.02	15.74
Independent variables		
Proportion of female (%)	49.16	4.25
Population density (persons/ha)	38.98	38.03
Proportion of persons 15-24 years old (%)	19.91	10.13
Proportion of persons 25-34 years old (%)	24.89	9.49
Proportion of persons 35-44 years old (%)	14.28	3.61
Proportion of persons 45-54 years old (%)	10.93	3.48
Proportion of persons 55-69 years old (%)	11.18	4.3
Proportion of households with equivalised weekly income \$0-\$399 (%)	14.36	7.32
Proportion of households with equivalised weekly income \$400-\$999 (%)	29.69	7.84
Proportion of households with equivalised weekly income \$1000 or above (%)	42.32	12.5
Proportion of couple family with no children (%)	47.2	13.03
Proportion of couple family with dependent children (%)	23.71	9.48
Proportion of couple family with no dependent children (%)	9.43	6.46
Proportion of one parent family (%)	12.94	6.15
Proportion of lone person household (%)	26.79	10.55
Proportion of persons with bachelor degree or above (%)	50.73	9.8
Proportion of persons with advanced diploma (%)	12.7	3.26
Proportion of persons with certificate level of degree (%)	18.45	6.36
Proportion of persons finishing school year 11 or less (%)	22.23	8.22
Proportion of dwellings with motor vehicle(s) (%)	73.39	16.8

4.2.2 Modelling results

Two stepwise regression models were computed to investigate the socio-demographic characteristics associated with bus share and car share. The inclusion standard was set at a significance threshold of 95% and removal standard was set at a significance level of 90%. The same modelling procedure was also applied to the 1,600-metre and the 3-kilometre areas. However, considerably lower model fit and explanation power was achieved particularly for the bus share model. This suggests that BRT might have attracted a certain transit-preferred population to the 800-metre area. At farther catchment areas, the use of bus appeared less related to socio-demographic aspects at the SA1 level.

Since we use geographic units (i.e. Statistical Area 1s) instead of actual commuters to conduct the regression analysis, we highlight that the regression results are tentative and that there is a need to now further explore the nature of the relationships using additional data sources such as the household travel survey data.

Table 4 Regression results of bus share model

Model Fit				
Adjusted R^2	0.381			
F	27.15	P<0.0001		
Durbin-Watson value	1.6			
Variables	**B**	**Standard error**	**β**	**t**
Proportion of persons 45-54 years old	-0.746	0.111	-0.392	-6.74
Proportion of female	0.324	0.101	0.208	3.209
Proportion of households with equivalised weekly income $1,000 or above	-0.164	0.03	-0.31	-5.437
Proportion of lone person households	0.152	0.037	0.242	4.069
Proportion of dwellings with motor vehicle(s)	0.124	0.028	0.315	4.435

All variables are significant at 5% level.

Table 4 summarises the results of the bus share model. A statistically significant model was achieved, with adjusted R^2 = 0.381, F (5, 207) = 27.15, P<0.0001. The P-P plot of standardised residuals showed a straight diagonal line. The relatively low Durbin-Watson value of 1.6 raised some concerns. Examining the residual plot however did not reveal highly serious problems such as residual autocorrelation. We assume that the omission of certain important variables such as service features (including speed, service frequency) as found in previous studies, e.g., Currie and Delbosc (2011) might be the major reason in this case. Overall, we consider that the model result is acceptable for preliminary investigation.

A total of five independent variables remained in the final model, explaining 38.1% of variance of bus share at the SA1 level. There was no Variance Inflation Factor (VIF) value over the cut-off value of 10, indicating no collinearity issue. 'Proportion of persons between 45-54 years old' and 'proportion of household with equivalised weekly income $1,000 or above' were negatively associated with bus share (β = -0.392 and -0.31 respectively). 'Proportion of female', 'proportion of lone person households' and 'proportion of dwellings with motor vehicles', were positively related to bus share (β = 0.208, 0.242 and 0.315 respectively).

Table 5 Regression results of car share model

Model Fit				
Adjusted R^2	0.786			
F	98.04	p<0.0001		
Durbin-Watson value	1.93			
Variables	**B**	**Standard error**	**β**	**t**
Proportion of dwellings with motor vehicles	0.373	0.051	0.398	7.31
Proportion of couple family with no children	-0.258	0.056	-0.214	-4.58
Proportion of persons with bachelor degree or above	-0.285	0.075	-0.177	-3.79
Proportion of persons 15-24 years old	-0.47	0.06	-0.303	-7.81
Proportion of female	0.477	0.144	0.129	3.31
Proportion of persons with certificate level degree	0.488	0.126	0.197	3.87
Proportion of household with equivalised weekly income $1,000 or above	-0.222	0.06	-0.177	-3.73
Proportion of lone person households	-0.186	0.062	-0.124	-2.99

All variables are significant at 5% level.

Table 5 summarises the results of car share model. A fairly well model fit was achieved, with adjusted R^2 = 0.786, F (8,205) = 98.04, P<0.0001, Durbin-Watson value = 1.93. The examination of the P-P plot did not incur any serious concerns either.

Eight important independent variables were identified, accounting for 78.6% of car share variance. Again, none of the VIF values indicated collinearity issues. There were strong to moderate associations between car share and ‘proportion of dwellings with motor vehicles’ (β = 0.398), ‘proportion of persons 15-24 years old’ (β = -3.03) and ‘proportion of couple family with no children’ (β = -0.214). The remaining variables had relatively weak relationships with car share.

Based on the modelling results, it appears that within the 800-metre area, female commuters and lone-person (persons who live alone) commuters might rely more on the BRT service for work trips, while commuters in the middle age group between 45 and 54 years old and higher income commuters (proportion of household with equivalised weekly income $1,000 or above) are less likely to use the BRT service. Positive Pearson Correlation between ‘proportion of persons 45-54 years old’ and car share (r = 0.33) was found, suggesting the likelihood of preference of car over BRT for work trips. However, there is no evidence of higher income commuters related to high car use (β = -0.177). Vehicle ownership (‘proportion of dwellings with motor vehicle(s)’) not surprisingly, was revealed to be the strongest contributor to car share. Young commuters between 15 to 24 years old and commuters from couple families without dependent children are less likely to use car to drive to work, given their negative relationships with car share.

What appears interesting is that in addition to car share, vehicle ownership was also positively related to bus share (β = 0.315) in this study, whereas the reverse relationships were often found in previous studies, e.g., Kitamura et al (1997), Bagley and Mokhtarian (2002), Simma and Axhausen (2001). Given this, BRT might have attracted passengers who have access to private vehicles (such as car) but still choose to ride BRT service. In previous studies, in comparison to captive passengers, passengers with access to private vehicles have been deemed as choice passengers, e.g., Foote et al (2001), Figler et al (2011). In addition, vehicle ownership has been often found to be linked with other socio-demographic aspects such as income, household composition (Stead and Marshall, 2001). As such we also examined the Pearson Correlations between vehicle ownership and the important independent variables in the models to further reveal the characteristics of possible captive and choice passengers of BRT as well as non-BRT passengers.

Vehicle ownership was found to be strongly related to a number of independent variables, most notably with ‘proportion of couple family with dependent children’ (r = 0.628) and ‘proportion of female’ (r = 0.483). The positive relationship between vehicle ownership and the presence of children in couple families is quite interpretable, that it might be more convenient for them to use car rather than bus to drop off (or pick up) their child/children at school before driving to (or from) work. The positive relationships found among ‘proportion of female’, vehicle ownership and bus share suggest that some female commuters could be choice BRT passengers. However, it is noted that for couples with cars, females usually have less access to cars than their male partners. Vehicle ownership was found to be negatively related to ‘proportion of persons 15- 24 years old’ (r = -0.395) and ‘proportion of lone person household’ (r = -0.399). As such BRT riders from these two groups are more likely to be captive passengers than other groups.

Although not identified as important independent variables, ‘proportion of household with equivalised income $400-999’ and ‘proportion of persons with advanced diploma’ were positively related to vehicle ownership (r = 0.33 and 0.325 respectively) as well as bus share (r = 0.261 and 0.249 respectively). This indicates the possibility of choice passengers among these groups as well.

Considering the less statistically sound results of the bus share model compared to the car share model, we conducted three commonly applied tests, i.e., Mahalanobis Distance, Cook’s Distance and Leverage (Chatterjee and Hadi, 2006) to detect outlier cases with undue effects. None of the cases had a Cook’s Distance over the cut-off value of 1. However, eight cases were found with fairly large Mahalanobis Distance (over the cut-off value of 15) and Leverage value (over the three times of the average Leverage value of bus share model (0.282)). Re-running the bus share model without the outlier cases resulted in a slightly improved model, with adjusted R^2 = 0.402, F (5, 199) = 28.477 ($p < 0.0001$), and Durbin-Watson Value = 1.666.

5. Discussion and conclusions

This study examined the change of travel patterns for work trips associated with Brisbane’s BRT over the period 1996 to 2006 before modelling the associations between socio-demographic characteristics and bus and car shares in 2011. A number of localised changes in travel patterns and characteristics of commuters in the BRT context were revealed.

The key findings include:

- A radial distance of 800 metres from the BRT network was highlighted as the primary catchment area. At this distance, the greatest impacts of BRT on travel behaviour were identified, with the most notable increase of bus share and decrease in car share following the BRT implementation.
- BRT had important yet smaller impacts on adjacent areas beyond the 800-metre distance (up to 3 kilometres in distance in this study), in encouraging mode shift from car to UPT service.
- The introduction of the BRT encouraged pedestrian walking behaviour (an increase in walk to work in this study) in its adjacent areas (up to 3 kilometres in this study).
- The BRT has attracted more female and lone-person commuters, while car use was more related to the presence of children in a couple family.
- BRT has offered an attractive alternative to certain commuters with access to private car(s), as such generating choice passengers who have preference towards BRT service.
- Commuters from middle aged group and couple families with dependent children were more likely to prefer car to BRT than other groups.

The findings of this study have important implications for future BRT expansion in Brisbane and have the potential to be transferred to other Australian cities. First, given the travel change patterns identified here in addition to previous studies (O'Sullivan and Morrall, 1996, Guerra et al., 2012), the 800-metre catchment can be used to predict direct BRT demand on where BRT expansions might be located. Second, this study reinforces in government policy in investing in BRT to progress towards sustainable urban transport. The results highlight the modal shift from car to bus in addition to higher level of pedestrian walking behaviour within the vicinity of BRT stations. BRT also appears to importantly attract choice passengers who have access to private vehicles. Previous studies found that choice passengers are inclined to be more loyal to a UPT service, which is crucial for the financial well-being of a transit agent, e.g., Foote et al (2001), Figler et al (2011). Finally, there appears to be challenges that remain in association with enhancing BRT's appeal to commuters from middle aged group and couple families with dependent children. Future studies should investigate this issue in greater depth to better understand their travel needs as well as attitudes towards BRT in order to uncover possible ways of promoting higher BRT use for these groups.

This study is the first step in developing a comprehensive evidence base describing the impacts of BRT on travel behaviour in an Australian metropolitan context. Future research endeavours are now required to offer further insight on this issue, particularly:

- The investigation of travel behavioural change in the BRT context of other Australian cities are needed to test and extend our evidence base of BRT impacts, and as such to provide more localised implications for BRT expansion in Australia.
- The census data used in this study does not distinguish BRT use from the use of conventional on-road bus. As such, more precise data such as smart card data should be gathered and analysed (Pelletier et al., 2011) to gain more detailed knowledge in terms of the spatial (e.g., the distributions of origins and destinations) and temporal patterns (e.g., the daily or monthly patterns) of trip making by BRT.
- It would be of interest to investigate BRT passengers' attitudinal aspects such as satisfaction and loyalty in future studies, which will generate valuable knowledge regarding the decision making process underpinning travel behaviour of BRT passengers that cannot be captured by the Census or smartcard data. This will result in more targeted policies for promoting higher level of BRT use.
- An updated cost-benefit study is needed to further quantify the impacts of BRT implementation. In addition to travel pattern change, other related aspects such as service performance, passenger attitude and environmental impacts should be considered as well (Bitzios et al., 2009).

Acknowledgments

The authors would like to thank the Australian Bureau of Statistics for compiling concorded census data.

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