Australasian Transport Research Forum 2019 Proceedings
30 September – 2 October, Canberra, Australia
Publication website: http://www.atrf.info

Review of bus rapid transit and branded bus service performance in Australia: From workhorse to thoroughbred

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Abstract

Bus rapid transit on dedicated right-of-way and branded bus services with a distinct visual identity have been implemented in various forms around Australia over the past three decades. A major public policy debate has surrounded the relative success of these bus priority and branding measures as compared with generic route services in attracting patronage. In this paper, we devise a metric known as a (gross) performance ratio to quantify the success for each of 7 bus rapid transit systems and 20 branded bus services as compared with regular route buses across six Australian capitals. A regression analysis is conducted to determine the statistical significance of various bus priority and brand identity initiatives which are used as inputs into a normalisation procedure to determine the net performance ratio of each service offering. This allows an informed comparison between systems and cities, controlling for operating environment and other service characteristics. The results reinforce the merits of upgraded bus services both as standalone initiatives and also as an alternative to expensive, rail-based infrastructure investment. Measures like network legibility and brand identity all help upgrade the image of the bus from workhorse to thoroughbred.

1 The BRT debate: What happened?

The humble bus is often criticised. The underappreciated workhorse carries more people than trains even in cities with extensive rail systems (e.g., London), yet the age-old adage that buses are boring and trains are sexy holds stronger than ever. This belief resonates in Australian capitals despite buses accounting for the bulk of the passenger transport task from their sheer spatial availability, especially for shorter journeys in the inner city and as first/last mile services to rail in middle and outer suburbs (Wong and Hensher, 2019). As a result, the importance of bus dominates rail in passenger trip terms, but this is rarely appreciated by the community nor public policy makers. Without exception, rail is always the preferred mode, and bus seen as the 'compromise' solution—sentiments which have held true for decades. The well-documented saga that is **choice versus blind commitment** (Hensher, 1999, Hensher and Waters, 1994) continues to manifest itself around Australia, most recently in Canberra (Capital Metro), the Gold Coast (G:Link) and Sydney (CBD and South East

Light Rail, and the proposed Parramatta LRT). It is often the case that politicians pick their preferred mode as their platform (sometimes even without a corridor in mind!) which is taken to election, then are left to justify ex-post (LRT as compared with bus-based alternatives), often using questionable wider economic benefit calculations (Stanley and Wong, 2016, Hensher et al., 2019b). In many cases LRT has been, in effect, a solution in search of a problem.

In an ideal world, we as a community ought to consider a transport problem objectively and then select the most appropriate transport mode to meet that challenge. This is a rational but unpopular approach given that bus rapid transit (BRT often being most cost effective) simply does not typically resonate with the community nor carry the same political benefits as rail. This is often the result of the public's existing experiences and biases on buses and trains (Hensher et al., 2019a). Indeed, bus services are conventionally perceived to be slow, polluting and unreliable (with poor service frequencies and ride quality) as there has been a constant failure to argue that service quality is a result of right-of-way (i.e., linked to congestion-induced travel time delay) and not traction technology (rubber versus steel wheels). It is therefore difficult for the public to imagine a bus-based service offering (BRT) which carries over many of the characteristics intrinsic to rail (although the recent interest in 'trackless trams' is encouraging). As we look around Australia on the BRT/LRT debate, it is an unfortunate reality that this battle might already be lost. Brisbane has traditionally been the sole exception, but time will tell if Perth joins this bandwagon. In the meantime, what are our alternatives?

Over the past two decades, BRT-lite or branded bus services (BBS) have emerged as a cost-effective reform to improve the bus network. There is growing interest around Australia in these schemes with a dedicated brand identity (fleet, stops, marketing, etc.), coupled with some level of bus priority and operating on headway regularity (at least from the customer perspective) as opposed to traditional timetables and schedules. Often, they are developed and implemented together with wider network rationalisation, simplifying route structures and stopping patterns and consolidating services onto high frequency trunk corridors. Interestingly, BBS is not usually delivered in the context of a bus versus rail debate and a number of systems were 'last minute' bids of political desperation (Sydney's Metrobus and Canberra's Rapids expansion being recent examples). Regardless, we believe there to be much potential for BBS in the present political and economic climate.

In presenting the case for BBS, we are not condoning BRT creep[1]. Many other studies have confounded the BRT/BBS distinction which we find problematic—e.g., Currie and Delbosc (2010) which includes Melbourne's BBS SmartBus amongst BRT initiatives, itself accounting for 174% of the 200% quantified increase in Australasian BRT route length (2006-10) to which the study refers. It is therefore important to note our use of terminology: **BBS is not BRT.** Whilst a distinct brand identity is an important element of quality BRT systems (ITDP, 2014), the essential characteristic of BRT remains its dedicated right-of-way and off-vehicle fare collection which delivers travel time benefits and operational efficiencies. The few BRT schemes in Australia (Brisbane being the

[1] BRT creep describes how the right-of-way requirements for strict BRT has gradually been disregarded (often with the intention to mislead), and results in misunderstanding within the community of what constitutes BRT.

sole system recognised by ITDP[2] and ranked silver—see Li and Hensher (2019)) rate poorly on brand identity, which together with service simplification constitute two of the most cost effective ways to grow bus patronage (Currie and Wallis, 2008). BBS (which by contrast usually enjoys more limited bus priority in Australia) enters the fray as a package of measures to change perceptions and the image of the bus (Devney, 2011). The rationale for BBS is that its distinct brand identity attracts patronage by making the bus network more legible and easier to navigate. Further, reforms usually follow best practices in network design, including a more appropriate mix of patronage versus coverage-oriented services (Walker, 2008, Nielsen et al., 2005), refined stop spacing and positioning, and adding cross-town orbitals to create a more 'gridded' network (thereby enhancing connectivity) as opposed to the traditional focus on radial routes in and out of the CBD. Our evaluation of BBS within this BRT/BBS review will encompass this broad suite of policy initiatives, whilst continuing to treat BBS separately to BRT.

Within the setting of multimodality, the boundaries between modes are getting ever more blurred. What BRT/BBS and optically-guided bus (or 'trackless trams') do is bring rail characteristics onto bus. In this paper we show that there is a value proposition for hybridity, in bringing together or 'integrating' the very best characteristics of both bus and rail modes. As technological developments bring new system characteristic possibilities into fray, it is no longer useful to consider modes as mutually exclusive. BRT/BBS exemplify the very essence of the ideals of modal integration, and we establish their value as part of the urban public transport modal mix in this paper.

Section 2 introduces the range of BRT and BBS schemes to be evaluated in this paper. Section 3 describes the (gross) performance measure used to capture productivity, whilst Section 4 explains the rationale for normalising this metric to ensure comparability between systems and cities. Section 5 presents this net performance comparison and offers policy-relevant interpretations. Section 6 concludes with broader commentary and reflects on the continuing challenges of bus and the role of new technologies in transforming urban public transport in Australia.

2 An overview of BRT and BBS in Australia[3]

The aim of this paper is to evaluate the performance of BRT and BBS schemes in Australia, relative to generic route services in their respective six capital cities. Studied systems are summarised in Table 1[4], and scored according to their BBS (fleet deployed and brand identity) and BRT bus priority characteristics. We have excluded services operating outside the standard contractual framework like airport shuttles and tourist products. The first characteristic refers to whether a system is operated using a **dedicated fleet**. This allows for more specialised fleet characteristics including dedicated liveries and vehicle type (e.g., double-decker buses), but also reduces operational flexibility, resulting in increased vehicle and driver requirements. **Brand identity** refers to the prominence of a service against the broader network structure—*none*, where the service is unnamed (in contrast to the *infrastructure* name which often still exists); *weak* means that whilst the brand exists, it is not applied prominently nor

[2] The Institute for Transportation and Development Policy (ITDP) is a non-profit which has developed *The BRT Standard* to score systems around the world.
[3] For full details on each system, we refer readers to our companion report prepared for the Bus Industry Confederation Hensher et al. (2019c).
[4] Included routes for each service cluster are detailed in an Appendix to this paper.

consistently across customer-facing material; for *medium*, the brand is recognised consistently in timetables, network maps, bus stops and on the bus destination; and finally, *strong* signals a prominent branding applied across all mediums plus a fleet operated in dedicated livery. **Bus priority** can refer to a dedicated carriageway separated by a physical median or a dedicated lane with the potential for traffic conflicts (usually kerbside). The three levels refer to the proportion of the service granted each quality of bus priority. Signal priority in the form of induction-loop queue jumps and transponder-activated signals is captured within this characteristic.

Table 1: BRT (green) and BBS (blue) schemes evaluated, scored according to their service characteristics

City	Service	Fleet deployed	Brand identity	Bus priority
Sydney	T-way (Liver-Parra)	Mixed	None	Medium
	T-way (North-West)	Mixed	None	High
	M2 Busway	Mixed	None	Medium
	Metrobus (Phase 1)	Mixed/Dedicated	Medium	Low
	Metrobus (Phase 2)	Mixed/Dedicated	Medium	None
	B-Line	Dedicated	Strong	Low
Melbourne	SmartBus (Original)	Mixed/Dedicated	Strong	Low
	SmartBus (DART)	Mixed/Dedicated	Strong	Low
Brisbane	Bus Upgrade Zone (BUZ)[5]	Mixed	Weak	High
	CityGlider	Dedicated	Strong	None
	Great Circle Line	Mixed	Weak	None
Perth	Central Area Transit (CAT)	Dedicated	Strong	None
	CircleRoute	Mixed	Weak	None
	Transperth 950	Mixed	Weak	Low
Adelaide	O-Bahn	Mixed[6]	Weak	High
Canberra	Rapid	Mixed	Weak	Low

As noted, premium bus services in Australia score highly either on brand identity *or* bus priority—but never both! This is peculiar and very much unlike implementation in other parts of the world, and certainly contravenes the BRT best practices espoused by ITDP (2014). However, we do note the tendency for branding elements not to accompany developed-world BRT implementation (especially in the US)—an example of BRT creep, but also the different institutional contexts at play.[7] As such, all upgraded bus services in Australia can be categorised as either BRT or BBS—and can be considered mutually exclusive.

[5] There is no system name for Brisbane's busway infrastructure (apart from distinct station architecture), but the high-frequency BUZ network is closely aligned. All BUZ services use at least the CBD component of the busway (Cultural Centre to Roma St), and most use the majority of the entire busway corridor. TransLink routes 66 and 111 are dedicated busway-only trunk services which will be analysed separately as part of this research.

[6] There is a dedicated O-Bahn fleet for maintenance and operational purposes, but no customer-facing brand elements.

[7] In developing economies (Africa and South America), BRT often results from the formalisation of the informal minibus taxi sector, and hence is almost always set up as an independent company (and brand) from the outset. There are accompanying advantages and disadvantages to this model.

3 Gross performance comparison

The main focus of the paper is on system-specific challenges and constraints, we now evaluate their relative success according to our devised index of performance (see below). We have selected the following number of characteristics segmented by individual BRT, BBS and generic route services as inputs into our criteria for comparing and assessing the performance of each system:[8]

- Total vehicle service kilometres
- Average service headway (every *x* min) in weekday AM and PM peak (directional), weekday inter-peak, and weekends. The weekday time of day segments are: AM peak (7:00-9:00AM; 2 hours), inter-peak (9:00AM-4:00PM; 7 hours), and PM peak (4:00-6:30PM; 2.5 hours)
- Percentage of route distance that is in priority lanes or carriageway in each of the weekday AM and PM peak (directional), weekday inter-peak, and weekend periods[9]
- Average speed (km/h) in weekday AM and PM peak (directional), weekday inter-peak, and weekend periods
- Total passenger boardings per annum
- Average number of passenger boardings per vehicle service kilometre

Whilst more detail has been provided for Sydney, to be able to compare the six cities in Australia (Sydney, Melbourne, Brisbane, Perth, Adelaide and Canberra) where there exists varying quantum of BRT and BBS, the data set is limited to the items summarised above. In addition, it must be recognised that some comparisons make more sense within the one metropolitan area given differences in the scale of services and the characteristics of the service delivery areas with respect to population density, road quality and the overall supply of public transport (including the presence of competing modes). For example, the overall vehicle service kilometres in Sydney are ten times greater than Canberra and cover a much greater catchment area and population with much greater traffic congestion in peak periods. We do, however, define a number of features of the various systems that represent either a service-specific feature or a context-specific setting potential influence to capture these effects as summarised in Table 2.

We have developed a performance indicator to capture the relationship between patronage, service kilometres and service frequency. This indicator, which we call the **gross performance ratio (GPR)**, is defined as the ratio of passenger boardings per service kilometre to the frequency of provided services. This measure enables us to comment on the success of each service offering in attracting passengers, consequent on the amount of service kilometres delivered and its embedded service frequency. This aligns well with two important drivers of patronage growth—connectivity (correlated with service kilometres) and frequency.

It is important to add some clarity on why headway is included to adjust the patronage per service kilometres in the GPR index. In arriving at an average headway (the inverse of service frequency), we accounted for headways during three times of day;

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[8] We thank state and territory agencies for the provision of data.
[9] This accounts for time-limited priority like peak-only bus lanes.

namely (i) peak period peak direction (as the peak), (ii) inter-peak (measured at 12PM as the trough), and (iii) weekend (usually flat). We then defined average headway as (peak + trough + flat)/3. This approach allows us to capture peaks and troughs and overcomes concerns such as the performance metric being heavily impacted by the span of hours of service. A service with shorter span of hours (e.g., Perth CAT buses) will score highly because the average headway is higher. If we had defined headway as a straight up average, this would have been conflated with service kilometres. Under our formula, headway has a partial correlation of -0.32 with passengers per service kilometre.

In assessing each BRT and BBS system, it is necessary to define a suitable level or scale of analysis. Importantly, there exists an inverse relationship between greater aggregation and the inherent level of variance in each characteristic which is essential for explaining the causes of variability in performance. For this reason, some of the studied BRT and BBS systems of interest are considered in totality (as one unit), whilst for others particular routes (or series of routes) are assessed and compared independently. We explain our rationale below:

- Sydney's Metrobus Phase 1 and 2 serve different functions ('top-up' versus cross-town orbital) so are segmented for analysis. Metrobus M61 is also assessed separately since it is unique in running express (and at high speed) along the M2 Hills Motorway unlike other frequent stopping trunk services which ply major arterials.
- Melbourne's SmartBus is segmented into Original (Routes 901, 902 and 903), Doncaster Area Rapid Transit (DART), and Routes 703/900. These are (respectively) cross-town orbitals, radial express routes via the M3 Eastern Freeway, and shorter connections in the middle suburbs.
- Brisbane's TransLink routes 66 and 111 operate on the busway trunk only and are assessed separately to Bus Upgrade Zone (BUZ) services which capture all busway services including through-routes into residential suburbs in mixed traffic. This tests for differences between closed and open BRT operations and how it might impact on performance statistics.
- Brisbane's CityGliders are assessed independently (Blue and Maroon) since they face different operating environments (and by extension, traffic levels). The Maroon CityGlider operates on significant parts of the South East busway.
- Perth's Central Area Transit or CAT (Red, Blue, Yellow and Green routes) are separated for analysis to capture greater detail in their relative performance.
- Canberra's four Rapid services (Blue, Red, Black and Green) are analysed independently given different operating environments and serving different patronage functions.

What interests us is the relationship between patronage, service kilometres and service frequency. Figure 1[10] compares the patronage per service kilometre against the service frequency over a seven-day period (weekdays and weekend), which we refer to as the gross performance ratio index. It shows the relationship between the

[10] Column colours correspond with the (primary) bus livery colour in each city.

number of bus passengers, the amount of provided service kilometres and service frequency (average headway). We would want to see growing patronage when we increase vehicle service kilometres and introduce more frequent services (shorter headways). A high patronage per service kilometre (a larger value) and a higher service frequency (a lower value) will increase the performance ratio. Conversely, a smaller number for the ratio suggests a lower relative level of performance. As examples, the M2 busway in Sydney (rank 4) has a relatively high patronage per service kilometre and a relatively high service frequency, resulting in a higher performance ratio. In contrast, the Liverpool-Parramatta T-way (rank 18) has a relatively lower service frequency and passengers per service kilometre, resulting in a lower performance ratio. Another way of viewing this is to consider how effective the provided service kilometres and associated service frequency are in attracting patronage.

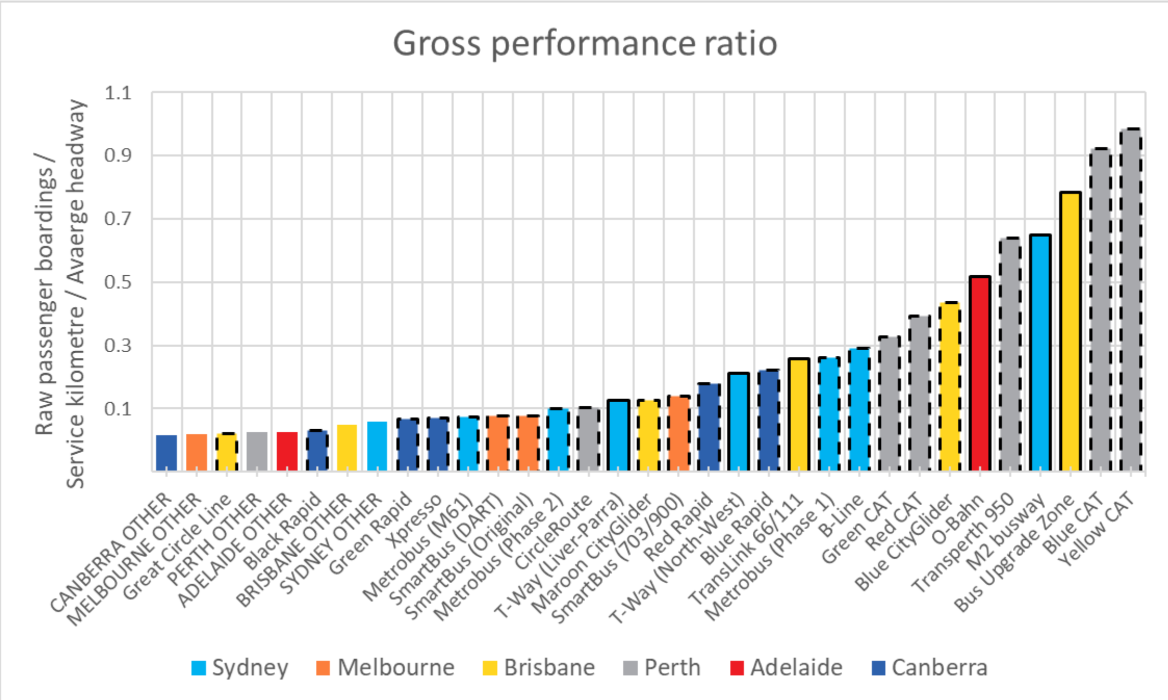

Figure 1: Rank of gross performance ratio defined as raw passenger boardings per service kilometre divided by average headway. Column outlines represent service type: BRT in solid outline, BBS in perforated outline, and generic services without outline

It is important to clarify how the assessment of the performance of each of the services being compared within and between the six capital cities is justified. Specifically, we fully understand that the locations in which specific services are operating vary greatly between geographical jurisdictions. Influences such as alternative public transport on offer (notably rail), levels of traffic congestion on the roads, population density and other land use factors, can all influence the success of a specific bus-based service.

In this study, we acknowledge all of these potential influences (see Table 2). We propose a normalisation process (to be introduced) to obtain what we call a **net performance ratio (NPR)** (in contrast to a gross or unadjusted performance ratio), enabling us to make comparative assessments of what is actually provided by focussing on how well bus services appear to be performing at present, controlling for the role of other effects. At a very broad strategic level, this provides encouraging evidence on the performance of particular services, and is very useful in messaging the value of BRT and BBS. The focus is on the demand side and not on the cost of providing the service where additional costs are required when there is investment in bus priority infrastructure and dedicated branding of vehicles and stops.

4 Rationale for normalisation

Whenever any form of transport service is compared there is always the risk that we end up making comments that amount to comparing ‘apples and oranges’ and hence relative performance assessment is questionable and of limited value. When there is an interest in comparing the performance of bus systems, it is essential that this is undertaken in such a way that clear and valid statements can be made about how one system performs relative to one or more other services. It is often the case that individuals make comments on how efficient one system is compared to another. We are often asked how such individuals can make such comments! A common concern is that “surely they are not comparing like with like?”

While one can never be sure what a specific study actually does to form a view (factual or otherwise) as to how well one system compares with another (or indeed an entire sector), there are nevertheless some good practical and meaningful principles to adhere to so that sensible debate can occur. The great majority of commentary appears to be based on a simple comparison of key performance indicators (KPIs) measured in terms of what we call the gross level (e.g., passengers per service kilometre as observed). The failure to recognise sources of influence on such KPIs that are not under the control of the system (such as location) and which vary by contextual setting is very poor analysis, resulting in nothing more than a comparison of ‘apples with oranges’.

So what should we do? As a start we need to identify those features of service provision that incur a disproportionate performance impact across the systems being compared—that the system has effectively no control over—and are a recognition of the reality of operating in a specific jurisdiction. To make a valid comparison, these differences must be recognised and accounted for. We call this **‘normalisation’**, although some people often talk of ‘standardisation’.

In the context of metropolitan bus operations in Australia, with a focus on performance related to passengers accommodated by the provision of service kilometres and service frequency, the main influences that are outside the control of most systems are likely to be associated with the location of the services. If there are circumstances that give a particular service an advantage over another simply because of external contextual influences, then they must be controlled for. Examples would include location such as city and intra-city geographical service areas (e.g., the CBD or inner suburbs). Such spatial contextual influences are proxies for population density, the availability of competing modes and other considerations.

How does normalisation work? The most popular method involves replacing the impact of a specific influence not under the control of the system (but essentially under the control of the operating environment), with an average (or median) level (across all sampled systems) of a factor that may influence performance. The same rule would apply to all selected influences that need to be ‘normalised’ as a way of removing the influence of these factors on the comparison of system performance. However, the story does not stop there. Before we can normalise the KPI of interest, we need to find out what role these normalisation criteria play in explaining differences in the level of the KPI of interest, so that we can then ensure that this role is used as a weight to allow for the replacement of the system-specific level of (as an example) direct competition with other services of the sample of all operations being compared. These weights are obtained using a regression model that assures that all influences on differences in a KPI are accounted for (which includes those influences under the control of the system).

A final comment is a question for all analysts—are you using valid methods to undertake a comparative assessment of performance? You cannot and never should simply take, for example, a gross KPI and use it to make statements about whether one operation is more or less efficient or has a higher level of performance than another operation (in situations that are potentially so different). Our real fear and concern is that this is exactly what is happening in many sectors, including the bus transport sector.

5 Net performance comparison

While the gross performance measure presented in Figure 1 is interesting, it is also potentially misleading and requires appropriate adjustment to obtain a strictly 'apples with apples' comparison. To achieve this, we estimated a series of linear regression models designed to identify contextual characteristics that, together with system descriptors, can explain systematic variations in the gross performance ratio index. Table 2 summarises these service-specific and context-specific effects and identifies those which emerged as statistically significant used in the normalisation of the performance ratio.

Table 2: Service-specific and context-specific effects tested for how they influence passenger boardings. Asterisked (*) attributes are statistically significant and form part of the normalisation model

Category	Attribute (1/0)	Description
Bus priority	Dedicated carriageway*	Substantial section of route (>30%) on dedicated bus-only carriageway separated by a physical median
	Dedicated lane*	Substantial section of route (>30%) on dedicated bus-only lane with the potential for traffic conflicts
	Signal priority	Substantial amount of grade separation or signal priority either as induction loop queue jumps or transponder-activated signals
	Premium stations	Substantial number of premium stations featuring better customer amenities
Brand identity	Soft branding	Distinct service branding in marketing material, stops and bus destination display
	Hard branding	Exclusive use of branded fleet reducing operational flexibility
Service type	Downtown circulator	CBD loop service
	Radial inner	CBD to inner suburbs route
	Radial outer*	CBD to inner plus outer suburbs route
	Cross-town/Orbital*	Route connecting suburban CBD locations
	Feeder/Coverage	All other services connecting to the high frequency network
Other	Direct competition*	En route competition for a significant section of the corridor (>60%)
	Free service	Service is fare-free

	System-specific dummies*	Controls for all other system-specific effects not otherwise captured
	City-specific dummies*	Controls for all other city-specific effects not otherwise captured

The final model identified 17 influences plus a constant. The model included six city-specific dummy (1,0) variables for Sydney (Syd), Brisbane (Brs), Canberra (Can), Melbourne (Mel), and Perth (Per) (Adelaide being the base); and seven system-specific dummy (1,0) variables for Perth's CAT services (PCat), Brisbane's busways (BBWay), Brisbane's CityGlider services (BCGlid), Canberra's Rapid services (CRapid), Melbourne's SmartBus (SMetB), Sydney's B-Line (SBLine), and Sydney's M2 busway (SM2Bw). Three variables represented location effects—radial/outer (Outer), cross-town/orbital (Orbital) and the presence of competition on the corridor (Comp). Finally, we found both dedicated carriageway (PricWay) and dedicated lane (PriLane) to be statistically significant influences on gross performance. Branding attributes (both hard and soft) did not emerge as statistically significant despite evidence from the literature to the contrary (Currie and Wallis, 2008), perhaps because of unique ways in which branding affects travel choice and behaviour. It has been found that 'hard' factors like service span and frequency drive modal shift, but once people become regular users it is the 'soft' factors which retain patronage (Hensher et al., 2010). Therefore, the importance of distinct branding should not be dismissed.

Equation 1 is the final formula used to obtain the NPR, using the normalisation procedure explained in the previous section. First we estimate this model using GPR as the dependent variable in order to obtain the parameter estimates. This is a linear regression model with all parameter estimates having *t* values greater than 1.96 which means that all parameter estimates are significantly different from zero at the 95% confidence level. The overall explanatory power of the model (R-squared) is 0.729 which tells us that 72.9% of the variation in the dependent variable (i.e., GPR) is explained by the variation in the levels of the explanatory variables. To obtain the NPR we use this equation but replace the levels of specific variables (excluding ones that refer to a service dummy variable) by the average of the sample of services. These include PricWay, PriLane, Outer, Orbital and Comp.

Equation 1:

$$\begin{aligned} NPR = {} & 0.1068 - 0.772 * Syd + 0.0199 * Brs - 0.0189 * Can + 0.1396 * Per + 0.0293 \\ & * Mel + 0.3065 * PCat + 0.3678 * BBWay + 0.0509 * BCGlid + 0.0763 \\ & * CRapid + 0.0726 * SMetB + 0.1486 * SBLine + 0.0244 * SM2Bw \\ & + 0.1252 * PricWay + 0.0977 * PriLane - 0.1048 * Average\ Outer \\ & - 0.0879 * Average\ Orbital + 0.1038 * Average\ Comp \end{aligned}$$

Figure 2 summarises the net performance ratio evidence and Figure 3 compares the gross and net performance ratios for the 27 BRT and BBS systems relative to generic route services in the six Australian capitals. As can be seen, there are a number of changes after normalisation that are important to recognise and comment on. The most notable adjustment is the elevation of Brisbane's BRT Routes 66 and 111 (running trunk-only), which exhibited the greatest absolute difference between net and gross performance (moving up from rank 12 to rank 6). However, it does not perform as well as its BUZ cousin despite the latter including suburban running in mixed traffic. This may be attributed to a lower level of service on individual routes relative to a combined service offering. Perth's four CAT services and Route 950 show consistently high performance, despite a slight drop in absolute performance (though its relative rankings remain relatively unchanged) upon normalisation, accounting for the impact of free fares (in the case of CAT) and high service frequency. Adelaide's O-Bahn exhibits the greatest negative adjustment post-normalisation (moving down from rank 6 to rank 13), which means that much of its performance may be linked to system-specific characteristics like its high operating speed and right-of-way. It means that the O-Bahn ought to perform better than it presently does for its given level of infrastructure and geographic setting. The best normalised performance ratio for Sydney is associated with the M2 busway (rank 5)—and this is considering the impact that NorthConnex construction had on service performance during the period of data collection. Melbourne's SmartBus (Original) perform similarly to Sydney's Metrobus (Phase 2), with both being cross-town orbitals serving the metropolitan fringe. Finally, Canberra's Blue and Red Rapids perform well, though they remain mid-range in the context of all Australian systems.

Of special interest is the performance ratio for all services that are not classified as BRT or BBS. The regular services in each city under the gross performance ratio were ranked 26th (Sydney), 27th (Brisbane), 29th (Adelaide), 30th (Perth), 32nd (Melbourne) and 33rd (Canberra). After normalisation, their rankings changed to 21st (Sydney), 23rd (Perth), 25th (Adelaide), 26th (Brisbane), 27th (Melbourne) and 28th (Canberra). The improvement of Perth and Adelaide is noticeable. What we find is that the performance ratio for generic routes is (relatively) low and supports the proposition that the services provided on regular route services have a worse performance ratio than the majority of BRT and BBS. The exceptions are a number of BBS with performance close to generic route level being Brisbane's Great Circle Line, and Canberra's Green Rapid, Black Rapid and Xpresso services. Poor performance in Canberra is consistent with Australia-wide benchmarks of farebox recovery and other performance indicators (MRCagney, 2015).

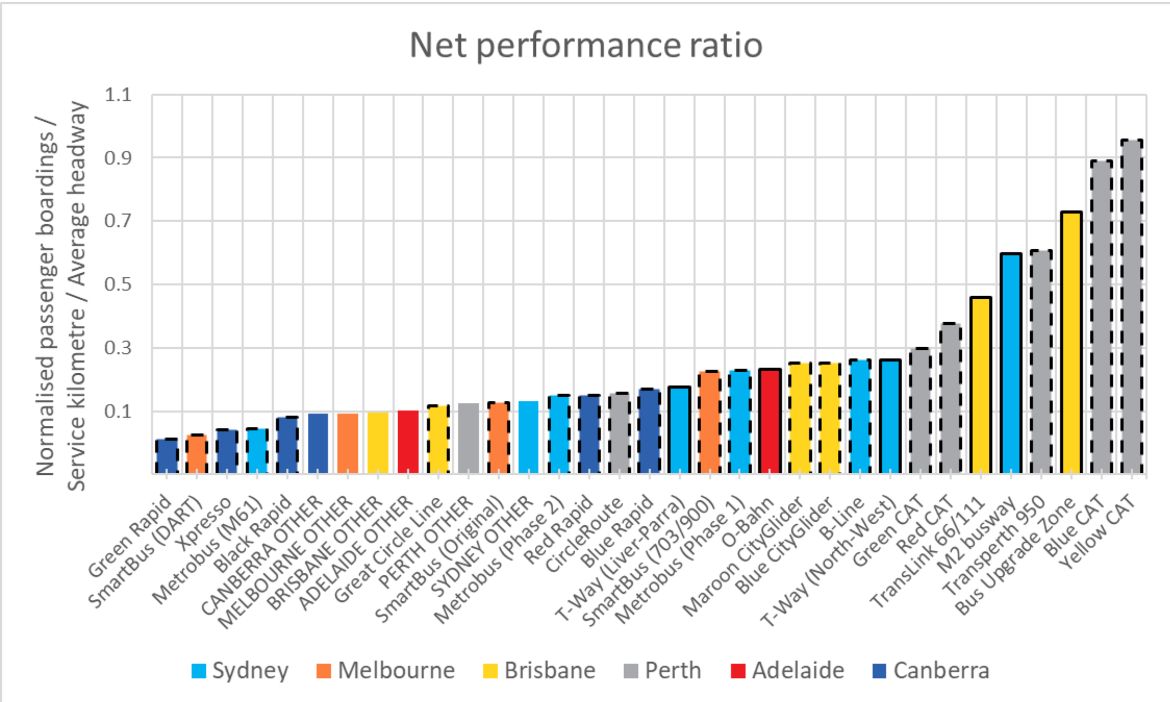

Figure 2: Rank of net performance ratio defined as normalised passenger boardings per service kilometre divided by average headway. Column outlines represent service type: BRT in solid outline, BBS in perforated outline, and generic services without outline

To gain a better appreciation of how normalisation has influenced the ranking of systems, Figure 3 compares the gross and net performance ratios. Reading from left to right, the larger negative values indicate that performance has deteriorated after normalisation, in contrast to the right hand side where performance has improved. Clearly, normalisation has had a noticeable impact on the relative performance of the 33 systems and services, but a large majority have changed only slightly (between -0.5 and +0.5). The top three rankings (Perth's Yellow and Blue CATs, and Brisbane's BUZ) have remained unchanged post-normalisation.

What is very noticeable is the presence of high performing services that are not privileged to have a significant amount of bus priority, and indeed the Perth services stand out as having virtually no bus priority and compete in mixed traffic. One has to be careful in inferring anything about the influence or not of bus priority since the traffic streams in many situations where BBS exists may not justify a dedicated lane given achievable average speeds in mixed traffic (including consideration of stop distances and traffic type—e.g., circulation versus through-traffic). Our regression model of the proportion of a route that is afforded bus priority (either dedicated carriageway or lane) is poorly correlated with average speed, and the reason is largely due to the high incidence of mixed traffic distances in the overall route operation where any gains on a dedicated corridor are dissipated by the performance when off the corridor, resulting in a lower average speed. Sydney's M2 busway and Brisbane's BUZ services (the two top performing BRT) are cases in point where significant sections of route are in mixed traffic off-corridor (both being open BRT systems).

Despite limitations, our robust methodology has identified the important attributes driving the system performance of BRT and BBS in Australia. Through a normalisation process, we have benchmarked and ranked the 27 service offerings in Australia, and found a very strong endorsement of the relative performance benefits associated with both BRT and BBS.

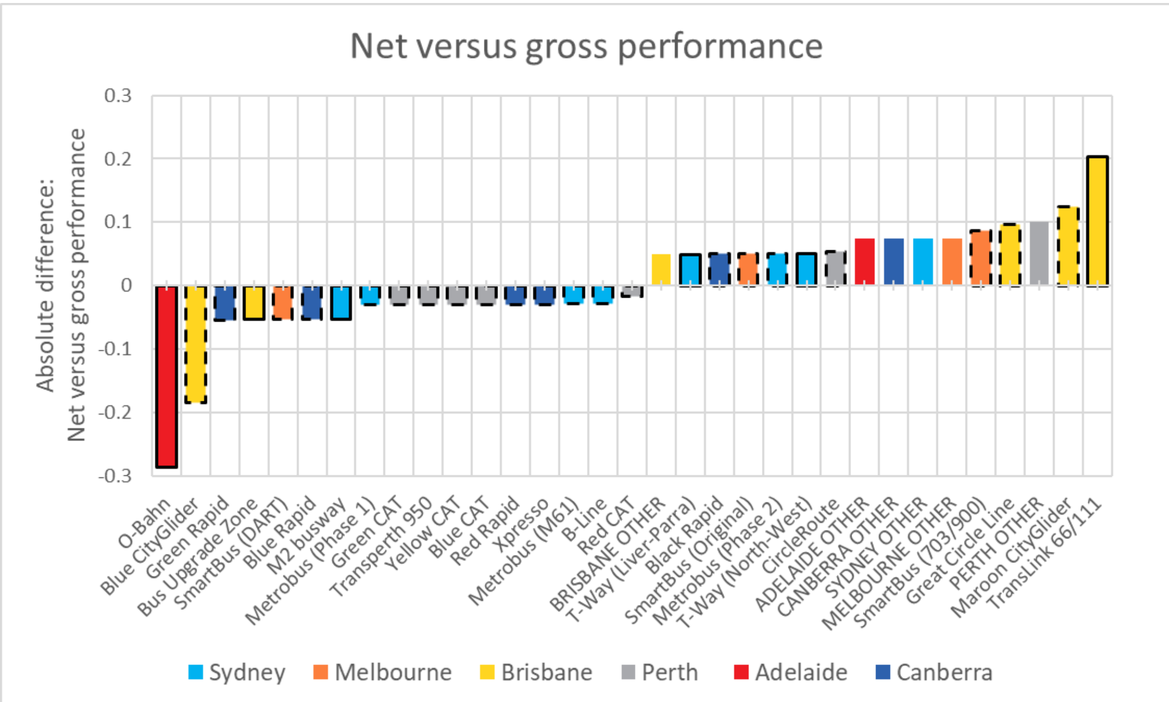

Figure 3: Difference (net minus gross) in the performance ratio of systems under net and gross performance calculations. Column outlines represent service type: BRT in solid outline, BBS in perforated outline, and generic services without outline

6 Discussions and conclusions

It is an unfortunate reality that bus-based investment has at times struggled to gain political traction in Australia. An example is Infrastructure Australia's national priority list (Infrastructure Australia, 2018), which is dominated by road projects and urban rail (Brisbane Metro perhaps being the sole exception). Economic analysis has shown time and time again that BRT investment offers far greater value for money than LRT schemes, yet the notion of 'bus stigma' holds truer than ever. In popular media and culture, the bus is painted as a grimy last resort, not a first choice for the travelling public. It is up to us as academics and as an industry to debunk the myths and advocate for sensible policymaking—to showcase the importance of bus as an underappreciated workhorse of our cities. The purpose of this report is to showcase the many BRT and BBS schemes (27 in total) in Australia and to perform some benchmarking (through a sophisticated normalisation process) so as to demonstrate their productivity as compared with regular route services in Australian capitals. We have established an evidence base with which to prosecute the value of investing to upgrade bus-based services in Australia.

We conclude with a number of critical observations. BRT is not a revolutionary new technology, but a timeless geometric reality. Indeed, the origins of the BRT concept can be traced back to 1939 when the world's first exclusive bus lane was opened in Chicago (Deng and Nelson, 2011). Not being a 'technology', it has struggled to gain the same attention as emerging concepts like autonomous vehicles, on demand buses and even shared electric scooters. NSW's *Future Transport 2056* strategy typifies this issue where there is little recognition of how geometric realities like right-of-way and transport corridors might limit the potential operation of future technologies (Transport for NSW, 2016). The philosophy of allocating public transport priority continues to be problematic. The conversation is always around building additional road space (through land acquisition or otherwise) to accommodate a bus lane rather than reallocating existing road space for the bus. What is important is the travel time relativity between private car and public transport that can attract users onto more sustainable, spatially-efficient modes. Government mentality continues to be on 'growing the pie' (with links to the concept of Pareto efficiency) and improving both roads *and* public transport—and so the **relativity** between modes remains unchanged and thus it is little wonder governments struggle to improve public transport mode share (which is almost a universally stated aim). What it does, however, is buy a few more years of accommodation for growth. Not only must there be a far more optimal allocation of road space (with success breeding success), but also the need to incorporate a road pricing mechanism with inputs by time of day, geography and modal efficiency (including passengers per vehicle and proportion of time on the road network). We believe future developments like mobility as a service (MaaS) offers immense opportunities to bring the entire transport system into equilibrium (Wong et al., 2017).

On the topic of relativity, railways with their usually dedicated alignment performs well because there exists not the same corridor competition. BRT even with dedicated carriageway often parallels an existing roadway and therefore relies solely on congestion to increase this relativity. Adelaide O-Bahn, Brisbane's busway (especially the Eastern busway to the University of Queensland's St Lucia campus) and to a lesser extent Sydney's Liverpool-Parramatta T-way are unique examples of where this is not the case and so perform extremely well in terms of attracting modal shift. Another issue with BRT is the confusion between vehicle capacity and corridor capacity. It is well known that when implemented well BRT routinely offers throughput above 20,000 (and even up to 45,000) passengers per hour per direction—as is the case in many Latin American cities like São Paulo, Porto Alegre, Bogotá and Curitiba (Hensher and Golob, 2008).

In terms of modal ideology, the preference for rail is driven by both cultural and biological factors. Ride quality is invariably better on a guided system where there is less lateral movement, although we have also explained how pavement quality and corridor geometry might also contribute to passenger experience. It remains very much the case that public perception depends very much on their experience of bus and rail systems (Hensher et al., 2019a). Our research has shown that people with greater exposure to quality BRT systems (like residents in BRT-extensive cities) are more likely to support bus-based investment as compared with rail. Their preferences are conditioned based on experiences of vehicle amenity, network legibility and susceptibility to delays (see previous commentary on bus priority). It is also the case that rail networks are marketed better (simpler) whilst buses remain unnecessarily complicated. BBS and initiatives like 'trackless trams' are a deliberate effort to make bus and tram feel as similar as possible, although some commentators argue that 'trackless trams' are not BRT[11]—something we dispute if delivered at the Gold Standard (ITDP, 2014). Despite the additional cost and sacrificing operational flexibility (and this is a trade-off policymakers will have to evaluate), we have shown there to be great benefit to BBS which in many cases even outperforms BRT. This is despite many being marred in controversy from the outset and introduced only as a quick political fix.

Whilst our modelling has shown branding factors to rate marginally in terms of affecting travel choice, we believe there is still value, especially around frequent network branding and network simplification (Currie and Wallis, 2008). It is usually the case that 'hard' factors like service span and frequency drive modal shift but once people become regular users it is the 'soft' factors which add value to retain patronage (Hensher et al., 2010). It remains a curiosity why BRT systems in Australia lack quality branding or BBS elements. The importance of branding cannot be understated given the complexity of many bus networks. In the same way that street directories (and online maps today) show a hierarchy of roads for different purposes (motorway, arterial, collector and local), frequency mapping can help communicate where all-day, turn-up-and-go services may be accessed. Especially in Sydney, there is a severe fragmentation of frequent network brands (and linked to different political persuasions when implemented) and so we call for a coordinated multimodal (bus and rail) approach for showing the spatial availability of frequent services across a metropolitan area. There are also enormous opportunities to extend this frequent network through clever scheduling (especially on corridors at contract boundaries) to improve effective frequency for zero additional cost (Wong, 2014)—easily implementable 'low-hanging fruit'.

Whilst this constitutes a comprehensive review and benchmark of all BRT and BBS systems in Australian capitals in 2018, there remains a number of opportunities for further empirical research. Supply-side constraints like the costs of construction and ex-post cost-benefit analyses have not been considered, but these are difficult to do at scale and as a comparison. It is more readily conducted at the margin and so we

[11] See https://theconversation.com/looking-past-the-hype-about-trackless-trams-107092

suggest two key areas for future focus. The first revolves around understanding the secondary benefits of public transport priority (Currie and Sarvi, 2012). Whilst passenger travel time savings are well known and usually a key metric for road authorities implementing bus lanes and signal priority, what is less researched is its impact on operating costs, fleet resources, modal shift and even changes in land use. A better understanding has practical implications for future project appraisal. Secondly, it is important to understand the value uplift potential of bus-based projects. Rail is often hailed as transformative and there has been work done investigating the impact of BRT (Mulley and Tsai, 2017), but none so far for BBS incorporating the best branding elements of rail. These are important research gaps considering the potential of BBS to upgrade the image of the bus from workhorse to thoroughbred and as an ever more attractive alternative to fully-fledged BRT or rail-based schemes in an increasingly financially-constrained environment.

Acknowledgements

We thank Michael Apps and the Bus Industry Confederation for its support in seeking data from all state and territory transport authorities and in providing funds for this project. This paper contributes to the research program of the Volvo Research and Educational Foundations Bus Rapid Transit (BRT+) Centre of Excellence. We acknowledge the Foundation for partial funding support.

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Appendix: Included routes in each service cluster

<table>
<tr><th>City</th><th>Service cluster (Table 1)</th><th>Service cluster (Figures 1, 2 and 3)</th><th>Included routes</th></tr>
<tr><td rowspan="4">Sydney</td><td colspan="2">T-way (Liverpool-Parramatta)</td><td>T80</td></tr>
<tr><td colspan="2">T-way (North-West)</td><td>S8, T60, T61, T62, T63, T64, T65, T66, T70, T71, T72, T74, T75, 602X, 607X, 613X, 616X, 617X, 619, 705, 706, 708, 711, 715, 740, 744, 745</td></tr>
<tr><td colspan="2">M2 Busway</td><td>M61, 602X, 607X, 610, 610X, 611, 612X, 613X, 614X, 615X, 616X, 617X, 618X, 619, 620N, 620X, 621, 622, 627, 628, 642, 642X, 650, 650X, 652X, 653, 740</td></tr>
<tr><td colspan="2">Metrobus (Phase 1)</td><td>M10, M20, M30, M40, M50</td></tr>
</table>

	Metrobus (Phase 2)	Metrobus (Phase 2)	M41, M52, M54, M60, M61, M90, M91, M92
		Metrobus (M61)	M61
	B-Line		B1
Melbourne	SmartBus (Original)	SmartBus (Original)	901, 902, 903
		SmartBus 703/900	703, 900
	SmartBus (Doncaster Area Rapid Transit)		905, 906, 907, 908
Brisbane	Bus Upgrade Zone (BUZ)	Bus Upgrade Zone (BUZ)	66, 100, 111, 120, 130, 140, 150, 180, 196, 199, 200, 222, 330, 333, 340, 345, 385, 412, 444, 555
		TransLink 66/111	66, 111
	CityGlider	Blue CityGlider	60
		Maroon CityGlider	61
	Great Circle Line		598/599
Perth	Central Area Transit (CAT)	Red CAT	1
		Blue CAT	2
		Yellow CAT	3
		Green CAT	5
	CircleRoute		998/999
	Transperth 950		950
Adelaide	O-Bahn		500, 501, 502, 502X, 503, 506, 507, 528, 530, 540, 541, 541X, 542X, 543X, 544, 544X, 545X, 546X, 548, 556, 557, 559, 578, C1, C1X, C2, C2X, J1, J2, M44, N502, N541, N542
Canberra	Rapid	Blue Rapid	300, 313, 314, 315, 316, 318, 319, 343 (weekend 300 trunk-only)
		Red Rapid	200, 251, 252, 254, 255, 259 (weekend 200 part-only)
		Black Rapid	250 (weekday-only)
		Green Rapid	6 (weekend 938)
		Xpresso	705, 712, 714, 717, 718, 719, 720, 725, 726, 732, 743, 744, 749, 765, 767, 783, 775, 791, 792 (weekday-only, peak-period peak-direction)