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Barriers and facilitators of integration between buses with a higher level of service and rail: An Australian case study

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ABSTRACT: The debate as to whether investment should be made in bus based or rail based rapid transit systems continues within the academic literature with entrenched arguments on both sides. Within Australia, the debate has become increasingly political with questions around the transport benefits, the environmental impacts and the financial costs of the rival technologies being significant issues in recent state and territory elections. However, this tends to be a debate around the appropriate solution for particular corridors. In practice all major Australian cities have made investments in both bus serviced and rail serviced corridors. If public transport services are to operate as a coherent network then successful integration must occur between these bus and rail corridors. This paper adds to the literature on the success factors for network integration by examining the barriers and facilitators of integration between buses with a higher level of service and rail using two case studies from Australia. The paper sets out a taxonomy of the elements of network integration then examines cases from around Australia to show aspects of where service integration has been successful and where it has been less so. The paper includes a detailed study of a new public transport infrastructure project in Sydney to examine the concept of bus and rail integration more holistically and to show how a framework of examining success factors for network integration can inform policy.

KEY WORDS: ***Bus, Buses with a high level of service, Rail, Transfer, Passenger value chain, Travel time, Frequency, Connectivity***

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1. Introduction

The success of a transport corridor is typically considered in terms of the transport benefits to potential users of that corridor relative to the cost of building and operating the service. More holistic evaluations consider the benefits to the transport network as a whole and this is obviously essential when considering integration between bus and rail serviced corridors. However, a transport centred approach to judging the success of a transport corridor is increasingly seen as incomplete as governments are seen to be placing more emphasis on the ability of transport investments to generate ancillary developments, particularly in activating new high density housing developments but also in terms of 'place making' and the creation of employment opportunities. This paper follows this development and looks beyond the generation of transport benefits to the ability of the transport network or corridor to generate transit oriented development around interchanges and around the corridors themselves as an important element of the success of an integrated bus-rail network.

For this paper, buses with a higher level of service have been selected as the unit of analysis to encompass both Bus Rapid Transit and less intensive bus based transit systems as in the Australian context, investments in bus services with a higher level of service exist on a continuum between full BRT and enhanced bus corridor services. Investment in rail has included suburban rail, commuter rail, metro rail and light rail so this paper will consider all types of rail services. The paper covers all Australian implementations of bus services operating on dedicated roads but excludes buses with a higher level of service in cities without passenger rail services (e.g. Hobart, Tasmania). Those cities are covered in depth in Clifton and Mulley 2016.

The rest of the paper is structured as follows, section 2 looks at the literature on integrating modes within urban areas and examines those aspects of interchange that are most relevant to users. Section 3 looks at the current state of integration between rail based and bus based implementations of fast, frequent public transport services and considers the likely impact of future light rail lines in Canberra and the Gold Coast on integration with frequent bus networks. Section 4 examines a case study in more detail looking at the impact on travel times when the network of direct bus services to the Central Business District with a network of frequent feeder buses to the under construction North West metro. Section 5 draws conclusions and recommendations for future research in this area.

2. Literature context

The literature context for this paper concentrates on two issues. First the issue of literature examining the integration of modes within urban areas into coherent networks. Second, those aspects of interchange which appear to be important to users in changing between one mode and another because these are issues that a highly integrated system of urban transport will need to get right.

Within urban areas, there have been a number of studies that have looked at competition between the same mode. For example, the deregulation of bus services in the UK in the mid-1980s provided much data on intra-modal competition with papers looking at more theoretical aspects of a single route or group of routes or aspects of competition such as the introduction of new vehicle sizes or fares (Glaister 1985, 1986). However, much more empirical research centres on the experience post-deregulation with many authors identifying quality (frequency of service, comfort and other 'soft' factors) as being more important than price for passengers (Mackie et al. 1995). However, most of the studies that have considered inter-modal competition have been centred on longer journeys such as those made by air or high speed rail (for example, Behrens and Pels, 2012; Dobruszkes et al., 2014) rather than inter-modal competition within the same urban system as considered in this paper with a notable exception being the paper by Yen et al (2017a) which used revealed preference data in the form of public transport smart card data to investigate competition between the bus and heavy rail systems in Brisbane, Australia. This paper adds to the literature by providing a more in-depth review of the ways in which multi-modal systems can and do interact with suggestions providing an evidence base for good and not so good factors for network integration.

Good integration in multi-modal urban transport systems demands effective interchange between modes. This is supported by Chowdhury and Ceder (2013) whose study of perceptions found that public transport users were more willing to use a route which involved an interchange if there is a good connection. There are however many studies that have looked at the implications of interchange from a travellers' perspective with travel time, waiting time and waiting time being revealed as increasingly important important at interchange (Vande Walle and Steenberghen 2006; Xumei et al. 2011). Indeed, it is commonly understood that there is a transfer penalty at interchange with different modes being associated with different penalties and with commuters appearing to experience lower penalties than the one-off or irregular traveller. Litman (2014) estimates penalties of between five and fifteen minutes of in-vehicle or travel time. This penalty is at the lower end when information is good and where there interchange facilities provide comfort. Travellers clearly dislike interchange (even if it exposes more of the network to them for travel (Hitrans 2005) but more than the time of interchange, travellers dislike interchange that involves a financial penalty (Yen et al 2017b). This brief discussion about interchange identifies that considering the time taken travelling, the time waiting and walking, the provision of information and whether there is a fare penalty are all important considerations in identifying whether a multi-modal urban system is well integrated.

3. Integration between bus based systems and rail based systems in Australia

3.1 Overview of integration

The current levels of integration between bus based systems and rail based systems in Australia are summarised in Tables 1 and 2. Services are evaluated in terms of those network planning factors considered relevant in the academic literature for transfer between services. It is important to note that these tables do not consider all factors of importance to public transport users. The physical infrastructure of the transfer points themselves (e.g. covered walkways, distance between bus stops and railway platforms, etc.) are outside the scope of this paper as are the waiting time for connecting services. Some factors intrinsic to the individual routes (e.g. frequencies) are also outside the scope of this paper but are covered in Clifton and Mulley 2016 for the bus based services.

Despite political debates being framed in terms of competition for investment money between modes, there is actually quite strong integration between bus based and rail based systems in Australia. Outside of Central Business Districts, there is little competition between modes on particular corridors. Furthermore, all cities have single websites and apps covering all modes along with integrated smart card ticketing systems and all cities except Sydney have integrated fares. Australian cities are less consistent in terms of presenting information to the public in terms of maps, which remain important for wayfinding before and during travel (Mulley, et al. 2017) with most cities not presenting frequent bus and rail services on the same map (if a map of frequent services is produced at all).

Tables 1 and 2 track fourteen different implementations of buses with a higher level of service. The majority are simply branded high frequency services operating on surface streets but there are instances of services operating on dedicated bus only roads that meet the standard definition of Bus Rapid Transit (e.g. Brisbane and Sydney's busways and Adelaide's OBahn). Most of these services operate in cities which also have suburban heavy rail systems; the exception being Canberra, which only has a long distance rail service and the Gold Coast which has an interurban heavy rail line. Adelaide, Sydney and the Gold Coast each have a single light rail line, Melbourne has a network of light rail or tram lines and Canberra is constructing its first light rail line. Adelaide is the only city which brands its high frequency (headway of 15 minutes or better) rail services separately from the low frequency services using the Hi Frequency brand on one heavy rail line (Adelaide Metro 2013) and one light rail line (Adelaide Metro 2016).

Table 1: Network structure of enhanced bus services, BRT and rail in Australian cities.

City	Enhanced bus service	Rail	Network structure
Brisbane	Busway, BUZ, glider	Heavy rail	Complementary, Competitive and Cooperative
Gold Coast	Turn up and go	Heavy rail, light rail	Complementary and Cooperative
Sydney	M2 busway, NW Transitway, Liverpool to Parramatta Transitway, Metrobus	Heavy rail, light rail	Complementary and Cooperative
Canberra	Red rapid, blue rapid, Gold Line, Green Line,	Light rail under construction	Complementary and Cooperative
Melbourne	SmartBus network	Heavy rail, light rail	Complementary
Adelaide	OBahn, Go Zone	Heavy rail, light rail	Complementary
Perth	High Frequency Bus Services	Heavy rail	Complementary and Cooperative

Table 2: Integration of ticketing, fare structures and information for enhanced bus services, BRT and rail in Australian cities.

City	Fare payments and fare levels		Integration of information		
	Single smart card system across modes	Integrated fares	Apps	Maps	Website
Brisbane	Yes	Yes	Yes	Busways shown on rail map but frequent rail services not shown on frequent bus map	Yes
Gold Coast	Yes	Yes	Yes	Yes	Yes
Sydney	Yes	Bus and light rail fares are integrated; Transfer discount applies for bus to train transfers	Yes	No	Yes
Canberra	Yes	Fares will be integrated when light rail opens in 2019	n/a	2017-2020 frequent network plan shows both light rail and rapid bus routes	Yes
Melbourne	Yes	Yes	Yes	No	Yes
Adelaide	Yes	Yes	Yes	Frequent services not distinguished on network map	Yes
Perth	Yes	Yes	Yes	Yes	Yes

3.2 Integration of network structures

For the purposes of this paper, the network structure integration between bus and rail based systems has been classified as complementary, competitive or cooperative. A complementary network structure has bus and rail based services on separate corridors, facilitating the extension of frequent services over a greater geographical area. All cities have complementary network structures. The stated rationales for implementing buses with a higher level of service typically emphasise the desire to spread enhanced services to areas not serviced by the existing heavy rail network (Clifton and Mulley 2016).

On the other hand, a competitive network structure would have bus and rail services competing for the same passengers on the same corridors. Geographical constraints mean that some degree of competition is inevitable (e.g. the Sydney Harbour bridge carries Metrobus, M2 busway services and heavy rail) so bus and rail based networks are only classified as competitive if there is a substantial degree of overlap. Brisbane is the only example of a competitive network structure with a seven kilometre corridor[1] through the inner city served by both a railway and a busway (Figure 1). It is perhaps not coincidental that this competitive network has had two 'owners' with the Brisbane City Council taking the lead on implementing buses with a higher level of service in Brisbane (Clifton and Mulley 2016) and until 2004 set separate fares to the state government operated rail network.

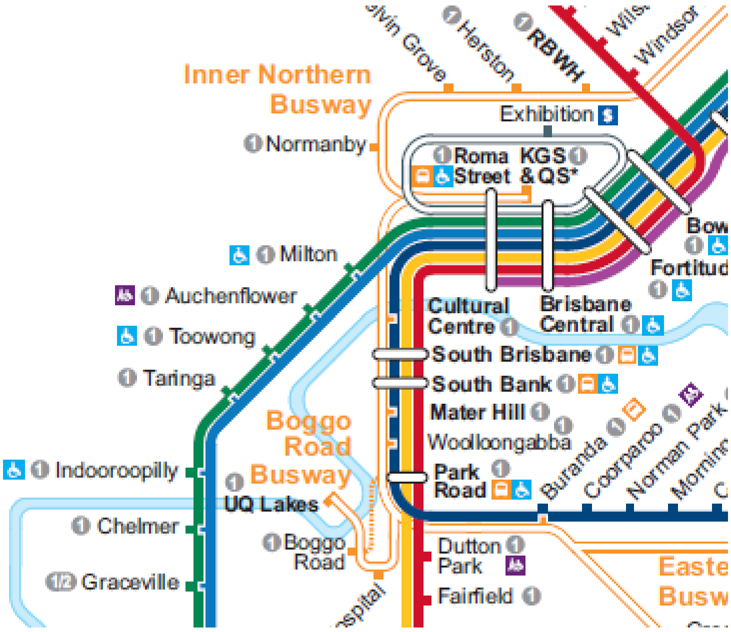

Figure 1. Competing Rail and Bus Rapid Transit corridors in Brisbane, Queensland
Source: https://translink.com.au/sites/default/files/assets/resources/plan-your-journey/maps/161219-train-busway-ferry-tram-network-map.pdf

A cooperative network has tight integration between the two modes allowing for easy transfer between bus and rail modes and maximising the network effects from investing in both rail and bus based networks. Sydney's network is highly cooperative, at least in the structure of the network, with cross-regional Metrobus corridors connecting rail corridors (Ho and Mulley 2014) and the other buses with a higher level of service networks radiating from train stations. Brisbane's shared bus and rail corridor also creates a cooperative network structure, although at the expense of duplicated service. Brisbane's Cross River Rail project (Queensland Government 2017) will redirect rail services onto a new corridor

[1] Buranda station to Windsor station

through the Inner-City. This project will dovetail with the Brisbane City Council's planned Brisbane Metro (Brisbane City Council 2017) which would replace most of the existing busway services with bi-articulated BRT standard buses. The net effect of both developments would be to create a more cooperative, less competitive network structure.

The Gold Coast (Figure 2) and Canberra (Figure 3) are examples of bus networks recast to create a cooperative network structure as part of the development of light rail corridors. The first stage of the Gold Coast Light Rail opened in 2014 and replaced a frequent bus service (Clifton and Mulley 2016). The bus services released by the new light rail line were redirected to strengthen services on other corridors creating a network of high frequency bus services alongside the light rail line. The second stage of the Light Rail between Griffith University and Helensvale is due to open in 2018 releasing more buses to strengthen services elsewhere (Translink 2017a).

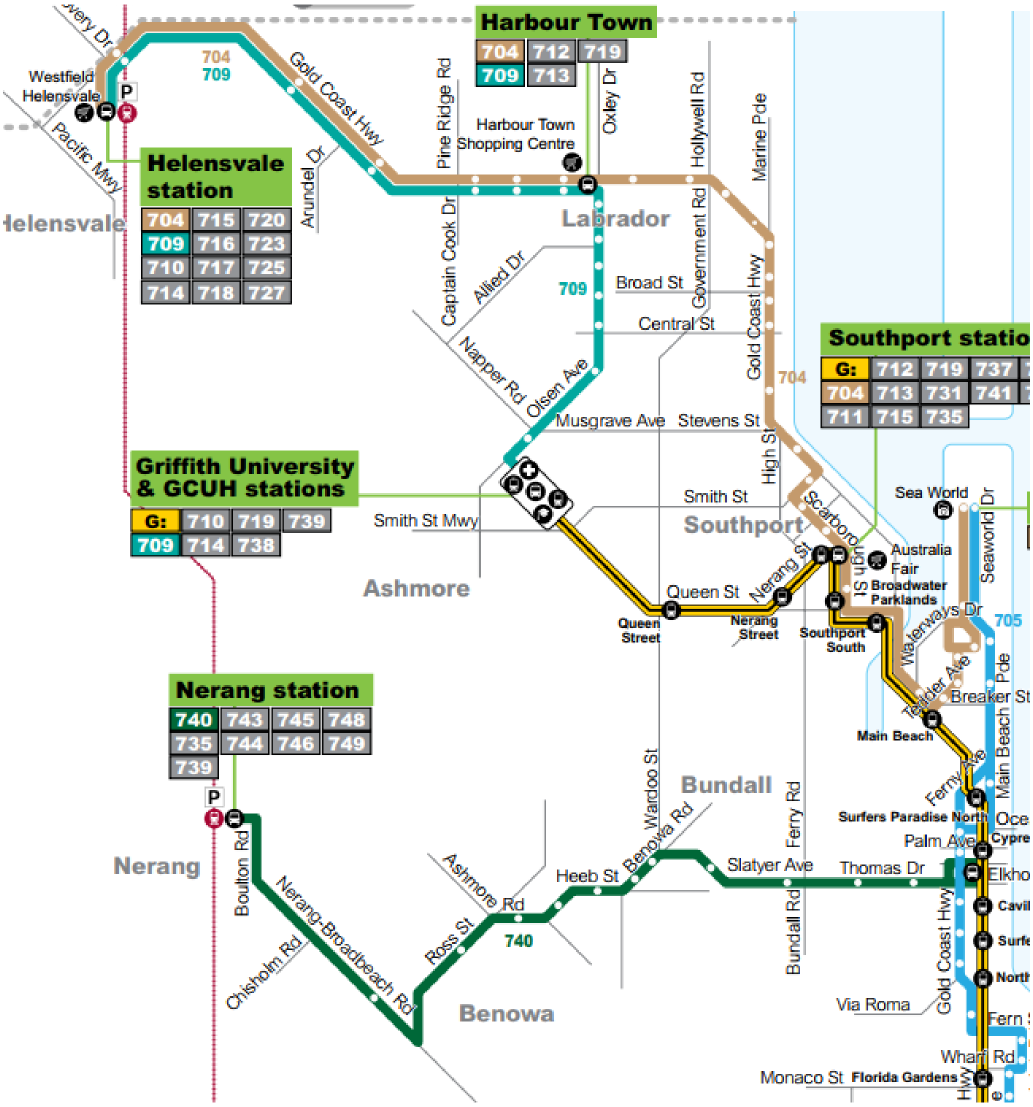

Figure 2. Cooperative Rail and Frequent Bus corridors on the Gold Coast, Queensland
Note: The yellow line with a black centre running East and South from Griffith University is the light rail line; thin red line is the lower frequency interurban rail service and the other lines are frequent bus services.
Source: https://translink.com.au/sites/default/files/assets/resources/plan-your-journey/maps/170123-gold-coast-turn-up-and-go.pdf

A similar recasting of the Canberra bus network is planned for the opening of the first Light Rail line in 2018 (ACT Government 2015) which will replace the Northern half of the Red Rapid frequent bus corridor from the City to Gungahlin and allow for the creation of additional rapid bus routes connecting with the light rail line at three interchanges (Figure 3).

Figure 3. Cooperative Light Rail and Frequent Bus corridors proposed for Canberra, Australian Capital Territory
Source: Transport for Canberra 2016

3.3 Integration of fare structures and payment methods

Canberra only has bus services at present but all other surveyed cities offer smart card ticketing systems that cover all modes within their respective cities. Furthermore all those cities, with the exception of Sydney, offer integrated fares between modes defined as fares that do not differ between modes and no separate flag-fall for transfer between modes. Brisbane and the Gold Coast share the same Go Card system (Translink 2017b). Canberra's current smart card and fare system will be extended to cover the light rail line when it is opened (ACT Government 2015).

Sydney has a complicated fare structure with light rail and bus services sharing one distance based fare structure that offers free transfers between bus and light rail. The rail network employs a different distance based fare structure and the ferry system uses a third distance based system. People transferring between modes using different fare structures pay the sum of the separate fares for each segment. However an AUD2.00 rebate for journeys was introduced in 2016 (NSW Minister for Transport and Infrastructure 2016) and in some cases this more than offsets the additional flag-fall.

3.4 Integration of information provision

A well-integrated public transport network of fast-frequent services will only be effective if the potential users are aware of the services. Mulley, et al. 2017 looked at the importance of information provision for public transport finding that trip planning apps, websites and physical maps are of most importance for trip planning by regular and irregular users. Each of the surveyed cities have both websites and travel planning apps offering transport information across all modes.

Authors such as Walker (2008) have looked at the importance of frequent network maps. Both the Gold Coast (Translink 2017a) and Canberra (Figure 3) have produced maps showing their under construction light rail lines and the frequent bus network that will operate alongside them. The Gold Coast also produced a similar map for the currently operating services during the interim between the 2014 opening of the first stage Light Rail line and the 2018 completion of the second stage. Perth's takes a different approach showing all bus, rail and ferry services on its network maps (Transperth 2017) but using a different colour to highlight the frequent bus services (all rail services operate with headways of 15 minutes or better).

Brisbane has a less consistent approach to the mapping of high frequency services. A map of the high frequency bus services are produced (Translink 2016) but not one of the high frequency rail or ferry services. However, the rail map (Figure 2) does show the busways as well. Melbourne produces a stand alone map of the SmartBus network (PTV 2017). Adelaide did produce a map of its Go Zone network (Adelaide Metro 2009) but no longer does so. Sydney is also lacking here with no overall map of its frequent services and no integrated network map.

3.5 Future developments in integration between bus and rail based systems

This section has looked at the current state of integration between bus and rail based systems and has identified those systems which are generally providing good integration (The Gold Coast and, from 2018, Canberra) and those systems were elements of integration are lacking with Sydney where the network and fare structure are fragmented being the least well integrated. The next section will examine a case study of investment in new transport infrastructure to examine the effect that these will have on integration between bus and rail based systems and travel time for commuters.

4. Case study of investment in new transport infrastructure

New investment in public transport infrastructure (predominantly rail) is taking place in several Australian cities but only four of these projects will have major implications for existing networks of buses with a higher level of service. The developments in Brisbane, Canberra and the Gold Coast have been discussed in Section 3 and this section will provide a more detailed case study of the North West metro project in Sydney. This section will discuss the project and its likely impacts on integration between bus and rail based systems.

4.1 The Current network in North West Sydney

The Hills District of North Western Sydney by a number of ordinary bus routes connecting to employment centres and railway stations outside the Hills District as well a Metrobus service offering a fast and frequent cross regional service through the Hills District. There is also a network of bus only roads. The M2 busway operates for part of the length of the M2 Toll Road connecting the Hills District to Macquarie Park, North Sydney and the Sydney Central Business District whilst the The North West Transitway or NW Tway has branches that connect the Hills District to Blacktown, Westmead and Parramatta which are employment and activity centres in their own rights and also interchanges with the rail network. These are shown on Figure 4. As is typical for Australia (Mulley, et al. 2016) the Tway and M2 busways are operated by both trunk routes and combined trunk and feeder bus services that connect into the surrounding suburban areas, one of these services (the M61 from Castle Hill to the Sydney CBD via the M2 busway) is branded as a Metrobus service. Development of bus services and the busway network area are discussed in Clifton and Mulley 2016.

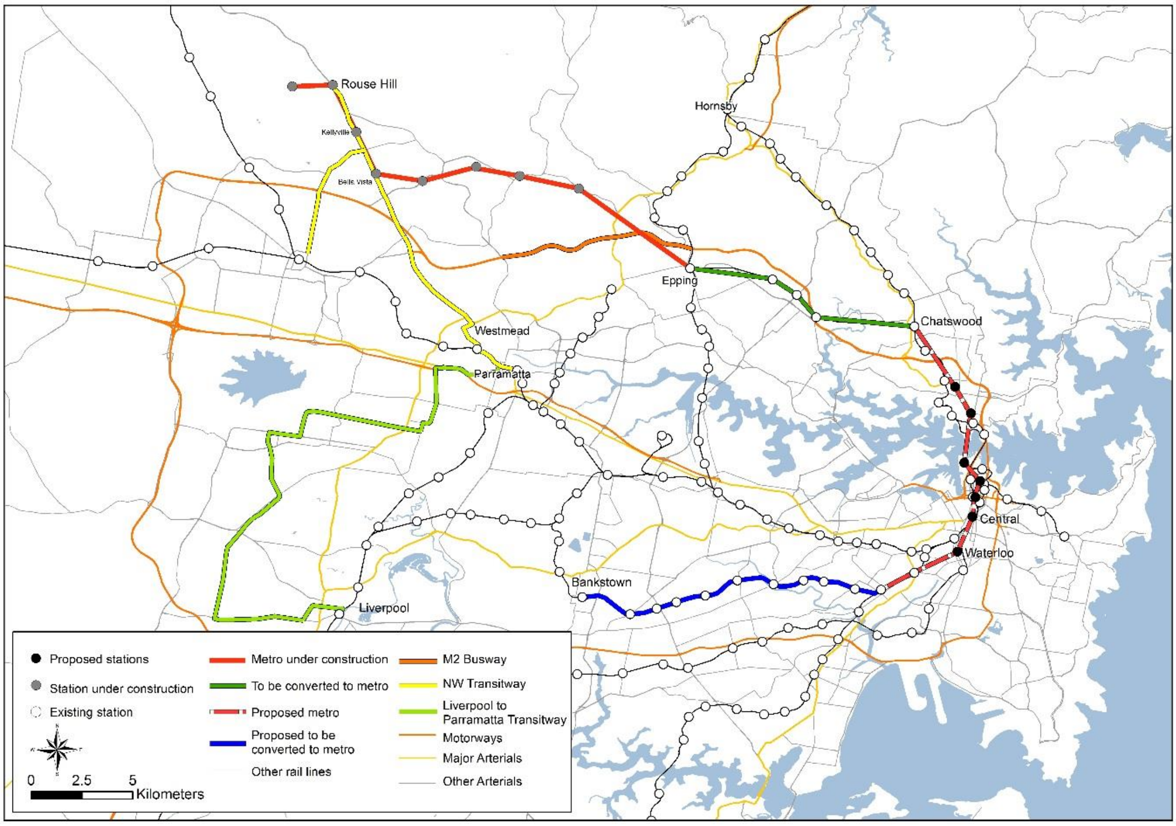

Figure 4. Rail and Bus Rapid Transit corridors in Sydney, New South Wales

The current network is complex having developed over a number of years and the routes which provide a higher level of service in terms of speed and frequency are not clearly separated from the peak hour only commuter routes or the other routes which provide a lower level of service (Figure 5). The North West Metro project is intended to replace the existing network with a revised hierarchy of routes based around feeder services to rail and trunk routes (including the NW Tway) to regional centres not on the North West Metro.

Figure 5. Bus network map of the Hills District of North West Sydney, New South Wales
Source: Hillsbus 2017

4.2 North West Metro

The North West Metro will consist of a 23 kilometre rail line between Cudgegong Road and Epping and (Transport for NSW 2011, p.10). From Epping, the line will take over the existing Epping to Chatswood Rail Link (ECRL) with passengers transferring to the existing Sydney Trains network at Chatswood for onward travel to the lower North Shore and Sydney Central Business District (CBD). Eventually Metro service will be extended through a new tunnel to the Sydney CBD and onwards to South West Sydney (Transport for NSW 2016).

The North West Metro has been considered by other studies. Hensher and Rose 2007 conducted demand modelling for an earlier version of the project and Hensher, et al. 2012 looked at the Wider Economic Benefits (WEBs) and Impacts (WEIs) to develop new methodologies for evaluating transport projects. Clifton, et al. 2014 discussed the history of planning for the proposed rail link and used a similar methodology to this section to look at the potential impacts on users of the successive iterations of the proposed rail link as plans altered over time. More recently, Douglas (2016) found the impact of the long tunnel section on potential users of the North West Metro will be equivalent to a 'penalty' of 1.3 to 1.9 minute of in vehicle travel time.

4.3 Impact on travel times for existing users of enhanced bus services

Clifton et. al 2014 and Clifton and Mulley 2017 sets out the methodology by which travel times can be estimated for the future bus and rail network after completion of the North West Metro from Cudgegong Road to Chatswood based on published information in the Environmental Impact Statement (EIS, Transport for NSW 2012) and assuming that the current bus network will be redirected to operate largely as a feeder service to rail stations in line with the EIS. These can be compared to the travel times as at September 2015 prior to the impacts of construction of the new Metro, Sydney CBD Light Rail and Northconnex Motorway extension on the existing bus network.

Changes in travel times can be estimated on both an unweighted (actual minutes of travel time) or on a weighted basis (see Table 3 for the weights) which recognises that a minute of in vehicle travel time does not have the same effect on passengers as a minute of walking time or waiting time. For this paper, the weights used in the Australian academic literature (Ho and Hensher 2017) with transfer penalties from Booz Allen Hamilton and PCIE 2003 quoted in Douglas and Jones 2013 are used in preference to the weights given in the official Transport for NSW Appraisal Guidelines (TfNSW 2013). The academic weights were chosen as they put less weight on the out of vehicle components of travel time and therefore provide lower weighted travel times for the after construction case than the official guidelines.

Table 3: Relative valuations of the components of travel time for non-business related trips

Component of travel time	TfNSW appraisal guidelines	Australia academic literature
Walking access	1.5	1.5
Waiting	1.2	0.8
In vehicle	1.0	1.0
Transfer penalty	14.8	8.5
Walking transfer	1.5	1.7
Waiting transfer	1.5	1.7
Walking egress	1.5	1.9
Average delay	3.0	n/a
Standard deviation of delay	1.0	5.1

Sources: TfNSW Appraisal Guidelines is Transport for New South Wales 2013; Australia academic literature is Ho and Hensher 2017 with the exception of the transfer values which are taken from Booz Allen Hamilton and PCIE 2003 quoted in Douglas and Jones 2013.

The Methodology was used to estimate the before and after travel times for travel from six Origins within the Hills District (Figure 6). Five destinations were selected as being important destinations on the new North West Metro (Macquarie University and Chatswood) or on the existing heavy rail network

(North Sydney, Wynyard and Central Station) requiring Metro passengers to transfer to the existing rail network at Chatswood. Two additional Origin-Destination (O-D) pairs were selected to provide additional coverage. The first O-D pair covers trips from one of the busway stations (at Winston Hills) outside the main study area to Wynyard in the Central Business District; this route is likely to have its busway services reduced once the new Metro commences. The second O-D pair covers reverse commute trips from the Central Business District into the main employment hub of the Hills District at Norwest. In total there are 32 Origin-Destination pairs selected (Figure 6) and travel times have been calculated for both the peak hour (arrival at 08:30) and the off-peak (arrival at 12:30). All origins and destinations are either busway stations or bus stops on existing busway or enhanced surface bus services routes serving the North West to allow for comparability of existing enhanced bus services to new Metro services.

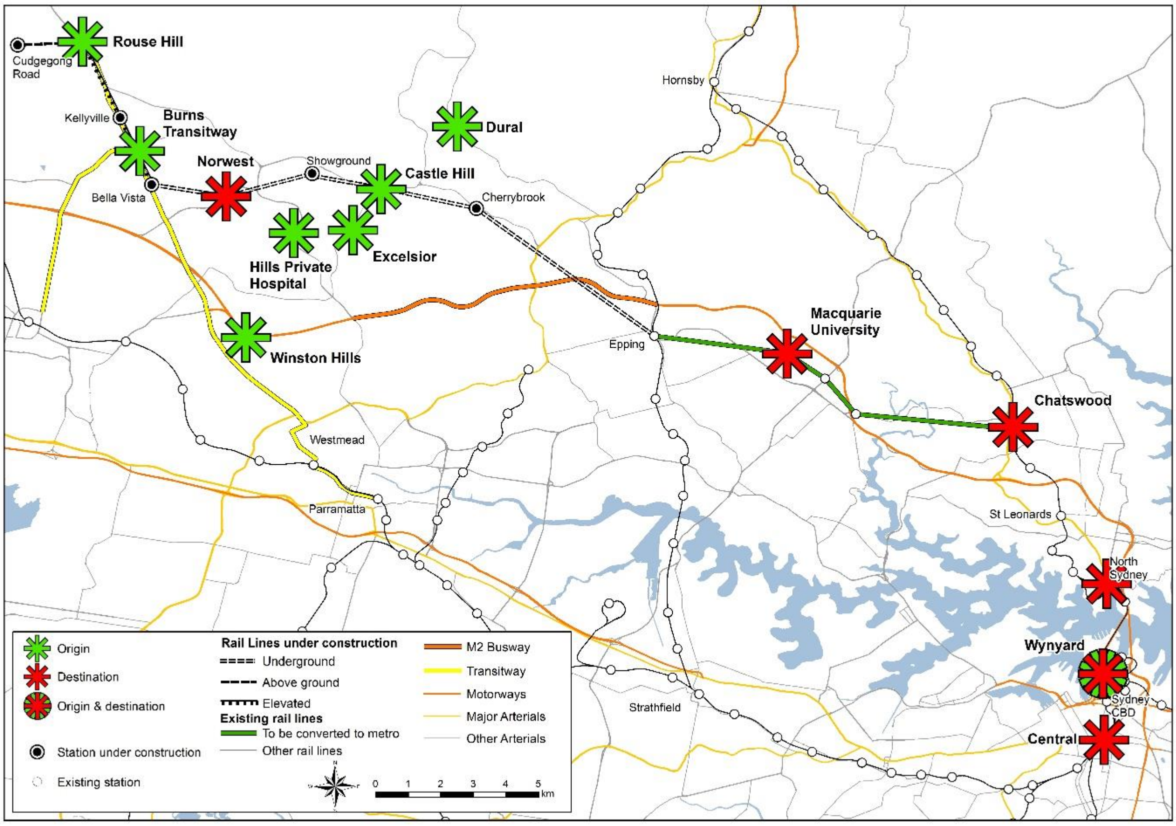

Figure 6: The study area
Note: The coloured stars in Figure 2 represent origins (green stars) and destinations (red stars) for the comparison of travel times and fares.

The impacts on travel times for the 32 Origin-Destination pairs are shown in Tables 4 and 5 below. The tables indicate that there are travel time savings for many Origin-Destination pairs but some journey times will remain consistent or even increase in travel time. Furthermore, travel time savings vary by time of day as well as by location with some locations benefiting in the peak but not the off peak (e.g. Castle Hill to Wynyard).

Looking at specific destinations shows how the travel time benefits are not evenly distributed. Generally services to Macquarie University and Chatswood will be quicker in both the peak and off-peak hours but there will not be as significant gains for areas close to the existing busway (i.e. Excelsior Avenue) as a direct bus service will be replaced by an indirect bus service via Castle Hill.

Travellers to Wynyard, which is the current focus of most M2 busway services and accounts for most of the patronage for these services, will face mixed benefits. Services in the off-peak will be more frequent from some parts of the North West but not others (i.e. Castle Hill and Excelsior). However, most passengers will face longer travel times with travel time savings only from the more distant parts of the study area (e.g. Rouse Hill in the peak and Dural in the off-peak). Travel time benefits to the Southern end of the Central Business District around Central Station will also be mixed, although there are likely to be travel time benefits for more travellers given that buses currently run on-street on congested CBD streets between Wynyard and Central Station.

However, some users are unambiguously better off. No direct service is currently provided in off-peak hours to Chatswood or for reverse commuters from Wynyard to Norwest, by lowering travel times the new rail link will open up new cross regional public transport opportunities and travellers will be benefit from the off-peak fare discount that only applies to rail services.

Travel times from Winston Hills to Winston are higher across the day which is to be expected as Winston Hills is on the M2 busway but not near a new Metro station. Replacing an existing busway service with a new rail corridor will lead to losses in utility for some users unless the new rail line serves exactly the same corridor as the bus service it replaces.

One noticeable benefit is that travel times will be more consistent with differences of only one or two minutes between the expected peak and off-peak travel times once the Sydney Metro opens. Currently travel times can be up to twenty minutes faster in the off-peak (e.g. most services to Central Station) where there is extensive on-street running or up to fifteen minutes slower (e.g. Baulkham Hills Private Hospital to Macquarie University) where no direct services exist in the off-peak. The more consistent travel times after introduction of the rail link reflects the generally lower levels of congestion within the study area and the relatively short feeder bus journeys.

4.4 Other impacts

Apart from the Metrobus, Transitway and some M2 busway services most current bus routes only operate in frequently outside of peak hours. The replacement feeder bus services and new Metro line are being advertised as operating at high frequencies across the day (Transport for NSW 2017) although exact services levels are not yet published. Many travellers will benefit in the off-peak from the higher frequencies that will exist between most Origin-Destination pairs, as the driverless Metro will operate at higher frequencies than most of the existing trunk bus routes.

Given Sydney's fragmented fare structure, there will also be fare impacts from the new network structure with some travellers paying lower fares and some paying higher fares. The level of fare changes will depend on the distances travelled and the weekly travel behaviour of each passenger but there may be savings of up to 35 per cent for some travellers and higher fares of up to 45 per cent for others.

Table 4: Changes in total travel time and weighted travel time for each Origin-Destination pair for the peak

	To Macquarie University					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	00:48	00:36	00:35	00:37	00:29	00:33
Change in total travel time	- 00:21	- 00:20	- 00:10	- 00:08	- 00:05	- 00:04
Change in weighted travel time	- 00:30	- 00:20	- 00:08	- 00:06	+ 00:05	- 00:03

	To Chatswood					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	01:20	01:00	00:54	01:09	00:54	01:02
Change in total travel time	- 00:41	- 00:32	- 00:17	- 00:28	- 00:18	- 00:21
Change in weighted travel time	- 00:50	- 00:32	- 00:22	- 00:27	- 00:07	- 00:23

	To North Sydney					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	01:11	00:59	01:18	01:01	00:52	00:56
Change in total travel time	- 00:17	- 00:15	- 00:26	- 00:05	00:00	+ 00:03
Change in weighted travel time	- 00:06	- 00:04	- 00:04	+ 00:16	+ 00:21	+ 00:13

Table 4: Changes in total travel time and weighted travel time for each Origin-Destination pair for the peak continued

	To Wynyard					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	01:06	00:54	00:49	00:55	00:46	00:47
Change in total travel time	- 00:05	- 00:04	+ 00:10	+ 00:09	+ 00:12	+ 00:19
Change in weighted travel time	+ 00:05	+ 00:06	+ 00:31	+ 00:19	+ 00:33	+ 00:40

	To Central Station					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	01:19	01:12	01:00	00:58	01:04	01:02
Change in total travel time	- 00:11	- 00:15	+ 00:08	00:00	+ 00:01	+ 00:11
Change in weighted travel time	- 00:00	- 00:04	+ 00:10	00:00	+ 00:22	+ 00:32

	To Wynyard	To Norwest
	From Winston Hills	From Wynyard
Current total travel time	00:40	00:52
Change in total travel time	+ 00:16	+ 00:02
Change in weighted travel time	+ 00:26	+ 00:02

Table 5: Changes in total travel time and weighted travel time for each Origin-Destination pair for the off-peak

	To Macquarie University					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	00:46	00:29	00:41	00:36	00:24	00:46
Change in total travel time	- 00:19	- 00:13	- 00:16	- 00:07	00:00	- 00:18
Change in weighted travel time	- 00:28	- 00:13	- 00:05	- 00:05	+ 00:10	- 00:31

	To Chatswood					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	01:12	00:53	00:55	01:02	00:46	00:53
Change in total travel time	- 00:33	- 00:25	- 00:18	- 00:21	- 00:10	- 00:13
Change in weighted travel time	- 00:59	- 00:34	- 00:19	- 00:37	- 00:08	- 00:25

	To North Sydney					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	01:12	00:52	01:08	01:02	00:45	00:44
Change in total travel time	- 00:18	- 00:08	- 00:16	- 00:06	+ 00:07	+ 00:12
Change in weighted travel time	- 00:22	- 00:07	- 00:06	- 00:00	+ 00:18	+ 00:12

Table 5: Changes in total travel time and weighted travel time for each Origin-Destination pair for the off-peak continued

	To Wynyard					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	00:55	00:45	01:05	00:45	00:38	00:40
Change in total travel time	+ 00:06	+ 00:05	- 00:06	+ 00:18	+ 00:20	+ 00:23
Change in weighted travel time	+ 00:16	+ 00:15	+ 00:15	+ 00:39	+ 00:41	+ 00:32

	To Central Station					
	From Rouse Hill	From Castle Hill	From Dural	From Burns Transitway	From Excelsior	From Baulkham Hills Private Hospital
Current total travel time	01:08	00:58	01:22	00:58	00:51	00:53
Change in total travel time	00:00	- 00:01	- 00:16	+ 00:09	+ 00:14	+ 00:17
Change in weighted travel time	+ 00:10	+ 00:09	- 00:06	+ 00:28	+ 00:35	+ 00:26

	To Wynyard	To Norwest
	From Winston Hills	From Wynyard
Current total travel time	00:31	01:04
Change in total travel time	+ 00:06	- 00:10
Change in weighted travel time	+ 00:18	- 00:19

5. Discussion and conclusions

This paper has considered the current performance of Australian cities in terms of integration between bus based and rail based rapid public transport services, services which can be characterised as fast, frequent and direct. It was found that, despite the political discussion being framed around *competition* between modes for the allocation of investment funds, there is actually reasonably strong integration between bus and rail based systems in most Australian cities. What competition that does exist between modes serving the same corridor is either incidental to geographic constraints (e.g. along the Harbour bridge corridor in Sydney) or is planned to be eliminated (Brisbane). Fare structures and levels are largely integrated (with the exception of Sydney) and, in terms of information provision, the systems tend to be presented to the public as part of an integrated network. Sydney is a notable exception here as information provision is more fragmented as is Adelaide which does not fully identify its frequent rail and bus network online.

Currently investment mostly favours rail based solutions for particular corridors. Given the relative expense of rail infrastructure, the number of corridors serviced by rail will necessarily be limited and bus based frequent networks will continue to provide the breadth of coverage. In Canberra and the Gold Coast the frequent bus network is being expanded at the same time as new light rail lines are replacing parts of the existing frequent bus network, expanding opportunities for transit users. However, the case study of North West Sydney showed that replacing bus based with rail based services can also have more ambiguous results with some transit users experiencing improvements in travel times and others experiencing longer trips.

Integration has been defined here as complementary or cooperative network structures and integration of fares and information provision but there are other forms of integration that are outside the scope of this paper. The physical connections between bus stops and railway stations or light rail stops are also important with close proximity, covered walkways and clear directions being important to users (Wardman, et al. 2001). Information provision at bus stops and train stations is also important, irrespective of whether an interchange is taking place (Mulley, et al. 2017).

Consideration of these aspects of integration might improve the standing of Sydney and Adelaide. Adelaide has good information provision at stations and frequent bus stops (Clifton and Mulley 2016) and Sydney has invested heavily in this area with good interchange facilities between bus and heavy rail at many stations (e.g. Parramatta) and good interchange facilities under construction at North West Metro stations. Future work in this area could include stated preference modelling of travellers preferences around interchange between bus based and rail based rapid public transport networks.

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