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Reviewing the last decade of public transport infrastructure projects in Australasia

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Abstract

The decade from 2000-2009 spawned a variety of public transport infrastructure projects in Australia and New Zealand. An extensive survey from a variety of sources developed a list of 33 public transport infrastructure projects that were completed between 2000 and 2009. The projects collectively cost approximately A$10.9 Billion (2010 dollars).

All public transport modes (heavy rail, light rail and buses) were represented and included the construction of major new lines and corridors, line extensions, track amplification, rail electrification, airport rail connections and refurbishments of existing infrastructure.

The data collected in the survey has been scaled up to constant 2010 dollars and further analysed to develop indicative construction cost profiles for certain kinds of projects (such as underground railways, busways and light rail extensions) along with an analysis of some of the political and economic circumstances surrounding the inception and delivery of these projects.

This is the only known survey of its kind undertaken in Australian and New Zealand of public transport infrastructure projects and represents an important piece of research into the costs of public transport infrastructure provision in Australia and New Zealand.

1. Introduction

During the first decade of the 21st Century (2000-2009), over 30 major transport infrastructure projects were completed in Australia and New Zealand. These projects covered an array of heavy rail, light rail (tram) and bus rapid transit projects, with a total cost of approximately A$10.9 Billion (2010 dollars).

While some of these projects (most notably the Sydney and Brisbane airport rail links) were constructed as PPPs (Public-Private Partnerships), the majority of these projects were fully funded by state and regional governments. As such, these projects represent a significant expenditure of public monies and have had significant implications on each jurisdiction's budget. During the time period of this study, Australia's Federal government, which had sporadically involved itself in the funding of urban public transport infrastructure (firstly in the 1970s and again in the 1990s) had resumed its involvement with the announcement of $4.62 billion in funding for urban public transport projects in the 2009-10 Federal Budget (Australian Government, 2009).

This study attempts to rank the 33 identified public transport projects constructed over the last decade in Australasia by project cost and cost per kilometre to develop some indicative per-kilometre costings for the different transport technologies and to better understand the cost structure of these major public transport projects. There is a specific focus on per-kilometre track costs across a variety of transport technologies (heavy rail, light rail, bus rapid transit) in an attempt to develop a reliable set of indicative costs for the:

- Construction of new lines

- Extensions of existing lines
- Amplification and upgrading of existing lines
- Electrification of existing lines

This kind of work is important for decision makers who fund and manage public transport at all levels of government in Australasia to know the recent history of transport projects and the costs of delivering them.

State Governments and their public transport infrastructure delivery agencies have been criticised in the media (Toy 2009), by public transport lobby groups (Gatenby 2009) and State Auditors-General in New South Wales and Victoria (NSW Audit Office 2010; VAGO 2010) over the escalating cost of public transport and particularly rail projects. Better knowledge of public transport infrastructure project costs may allow decision makers to prepare more robust business cases that give treasuries greater confidence in the ability of infrastructure delivery agencies to complete projects on time and on budget.

There is a growing literature addressing the risks, causes and effects associated with cost overruns on major infrastructure projects, particularly transport projects in the 20th Century. Sir Peter Hall was an early entrant to the field, featuring a history of the faulty assumptions and cost overruns in the construction of San Francisco's BART subway system in *Great Planning Disasters* (1980).

From the 1990s onward, a number of studies have been undertaken on risks associated with large-scale infrastructure projects (called 'mega-projects) around the world, most notably the work led by Bent Flyvbjerg (2003). Relevant to this study was work done on determining route kilometre capital costs on urban rail projects in Europe and America (Flyvbjerg et al 2008). From the context of the United States, Altshuler and Luberoff (2003) have added to this body of literature with an overlay of the way the United States' unique political culture has shaped the development and delivery of major projects.

2. Methodology

2.1 Project definition, selection and filtering

In developing this study, a review was undertaken of State and Federal budget papers, mainstream media, the transport industry trade press and other publicly available sources to identify an initial list of public transport projects from Australia and New Zealand for consideration. From this initial list of over 50 projects, a number of filters were applied to remove certain types of projects that were considered by the author to be out of scope. Projects considered out of scope and rejected for further analysis in this study included:

- Grade separations (essentially road rather than rail projects)
- Projects benefiting predominantly rail freight traffic
- Infrastructure projects supporting improved public transport operations (train stabling, bus/tram depots, turnbacks, discrete re-signalling projects)
- 'Station' works (Accessibility programs, park and ride, modal interchanges)
- New stations (such as Melbourne's Southern Cross station) unless part of a larger public transport project

This meant that some high-value public transport infrastructure projects were excluded from the scope of this study. As a result of applying these filters, a core list of key infrastructure projects remained within the scope for consideration in this study. This list consisted of projects involving:

- Construction of new lines

- Extensions of existing lines
- Amplification and upgrading of existing lines
- Electrification of existing lines

The remaining projects were then further investigated to develop fuller profiles of project scope, size and cost. These were then assembled and ranked by total cost and cost per kilometre. The list of all 33 projects selected for this study are shown below in Table 1 below ranked by total cost from most expensive to least expensive in constant 2010 Australian dollars.

2.2 Costings methodology

As these projects were completed across a 10-year time period from 2000 to 2009, a method was sought to approximately equalise each project's cost at the time of completion into constant dollars. There were two methodologies examined, from which from the two below, the first was chosen.

The first method used a simple set of calculations utilising the rate of inflation in the Australian economy to escalate project costs from the time of project completion into constant (2010) dollars. For Australian projects, the amounts were fed into the Reserve Bank of Australia (RBA) inflation calculator[1] to scale them up to 2010 dollars. For New Zealand projects, conversion to Australian dollars was achieved by determining the average $NZ/$A interbank exchange rate for the calendar year of project completion using a currency converter[2]. This $A amount was then scaled up to 2010 Australian dollar values using the RBA calculator as for the Australian projects.

During the data analysis process it was realised that the first methodology gave useful indicative costings, but after referring to the methodology used by Flyvgberg *et al* (2008) in comparatively pricing costs for rail projects in Europe and the USA, a second method, based on movements in Producer Price Indices over time would give more accurate results.

Analysing samples of the data in Tables 1 and 2 using the Australian Bureau of Statistics' (ABS) Producer Price Index (PPI) data for the construction sector of the economy (ABS 2011) showed that this method was able to give more finer-grained results, with variances of around +/- 2-3 per cent from the costs derived using the first methodology. This variance was particularly important in states such as Queensland and Western Australia where the PPIs for construction rose faster than the national average. One caveat in the use of PPI data is that the equivalent data for projects from New Zealand is only available from June 2009, so direct comparison is not available using this methodology. In these cases, Australian PPI data would need to be used once project costs in $NZ had been converted to $A.

As this paper consists of preliminary analysis of transport project costs, it is proposed that future iterations of the project costs database in Tables 1 and 2 be analysed using PPI data.

2.3 Data methodology

The use of publicly-available information to develop project costs was a simple data collection method, but also problematic. As Flyvbjerg et al found in their study of European and American urban rail projects (2008: 20), capital cost data varied in quality and detail. Extensive use of 'open source' information using budget papers, newspapers and the transport trade press was needed to develop 'headline' costs for the 33 projects.

[1] http://www.rba.gov.au/calculator/
[2] http://www.oanda.com/

Table 1: Public transport infrastructure projects 2000-2009 ranked by total cost (2010 dollars)

Rank	Project Name	State / Territory	Technology	Completed	Cost in A$M	Cost in A$M (2010 dollars)	Length (km)	Cost per km $AM (2010 dollars)
1	Epping-Chatswood Railway line	NSW	Suburban heavy rail	2009	$2,350	$2,417	12.5	$193.36
2	Perth-Mandurah Railway line	WA	Suburban heavy rail	2007	$1,103	$1,250	72.0	$17.36
3	Sydney Airport railway	NSW	Suburban heavy rail	2000	$762	$1,024	10.0	$102.40
4	South-East Busway	QLD	Bus Rapid Transit	2001	$660	$950	16.5	$57.58
5	Regional Fast Rail	Victoria	Regional heavy rail	2006	$750	$839	500.0	$1.68
6	North West Transitway	NSW	Bus Rapid Transit	2007	$524	$573	24.0	$23.88
7	Liverpool-Parramatta Transitway	NSW	Bus Rapid Transit	2003	$346	$421	30.0	$14.03
8	Eastern Busway Stage 1 (Boggo Road-Buranda)	QLD	Bus Rapid Transit	2009	$366	$376	2.1	$179.05
9	Inner Northern Busway Stage 2	QLD	Bus Rapid Transit	2008	$333	$349	1.2	$290.83
10	Robina-Varsity Lakes Railway extension	QLD	Suburban heavy rail	2009	$325	$334	4.1	$81.46
11	Caboolture-Beerburrum duplication	QLD	Interurban heavy rail	2009	$298	$306	13.7	$22.34
12	Airtrain	QLD	Suburban heavy rail	2001	$220	$296	15.9	$18.62
13	Salisbury - Kuraby triplication	QLD	Suburban heavy rail	2008	$256	$268	9.5	$28.21
14	Auckland Northern Busway	NZ	Bus Rapid Transit	2008	$240	$251	8.7	$28.85
26	Britomart Transit Centre	NZ	Suburban heavy rail	2000	$160	$215	3.0	$71.67
15	Inner Northern Busway Stage 1	QLD	Bus Rapid Transit	2004	$135	$160	2.8	$57.14
16	Helensvale - Robina duplication	QLD	Interurban heavy rail	2008	$123	$129	16.6	$7.77
17	Craigieburn Rail electrification	Victoria	Suburban heavy rail	2007	$115	$126	10.0	$12.60
18	Turrella-Kingsgrove quadruplication	NSW	Suburban heavy rail	2001	$85	$109	4.0	$27.25
19	Currumbine-Clarkson rail extension	WA	Suburban heavy rail	2004	$58	$96	4.0	$24.00
20	Sydenham rail electrification	Victoria	Suburban heavy rail	2002	$44	$55	6.5	$8.46
21	Clifton Hill rail project	Victoria	Suburban heavy rail	2009	$49	$51	1.0	$51.00
22	Mitchellton-Keperra duplication	QLD	Suburban heavy rail	2008	$46	$48	2.5	$19.20
24	Dapto - Kiama rail electrification	NSW	Regional heavy rail	2001	$42	$54	24.0	$2.25
25	Vermont South tram extension	Victoria	Light rail	2005	$31	$35	2.8	$12.50
26	Box Hill tram extension	Victoria	Light rail	2003	$28	$34	2.2	$15.45
27	Adelaide CBD tram extension	SA	Light rail	2008	$31	$32	2.1	$15.24
28	Sydney Light Rail Extension	NSW	Light rail	2000	$20	$27	3.6	$7.50
29	Ormeau-Coomera duplication	QLD	Suburban heavy rail	2006	$22	$25	6.7	$3.73
30	Returning passenger trains - Bairnsdale	Victoria	Regional heavy rail	2004	$15	$18	68.8	$0.26
31	Returning passenger trains - Ararat	Victoria	Regional heavy rail	2004	$10	$12	92.0	$0.13
32	Returning passenger trains - Echuca	Victoria	Regional heavy rail	2007	$10	$11	87.8	$0.13
33	Docklands Drive tram extension	Victoria	Light rail	2005	$8	$9	1.0	$9.00
				TOTAL in A$M (2010 Dollars)		**$10,900**		

Where information was available, each project was further examined to strip out non-infrastructure capital cost elements (such as operating costs and rolling stock procurement) and the costs of 'enabling' or 'network-wide' infrastructure works (such as train stabling and workshops) if possible to provide construction costs for just the right-of way and stations. It was considered going to a further level down to screen out the cost of stations to develop a 'basic' per-kilometre cost for rights-of-way only. 'The success or otherwise of this methodology and the level to which costs can be isolated depends on the level of financial transparency and project governance provided by each infrastructure building body and their governments through their annual reports, budget papers and other communications.

Two examples of how basic construction costs were determined are shown at both ends of the cost spectrum. The construction of the 2.8km tramway extension from East Burwood to Vermont South (Melbourne) in 2005 is often quoted as costing $42.5M (2005 dollars). However, this amount was an aggregated one that included $12M of operating costs alongside the $30.5M capital costs (Victorian Government 2005). Equally, Perth's New Metro Rail project (which included the construction of the Perth-Mandurah railway line) with its quoted cost of $1.663 Billion (2007) was made up of a number of projects. Stripping out parts that were not directly related to construction of the Perth-Mandurah line (such as the Thornlie spur line and the Clarkson extension) or network-wide elements (Nowergup railcar depot and new rolling stock), the remaining capital spend on infrastructure that could be attributed to the Perth-Mandurah railway is $1.103 Billion (Waldock *et al* 2008: 59).

3. Analysis

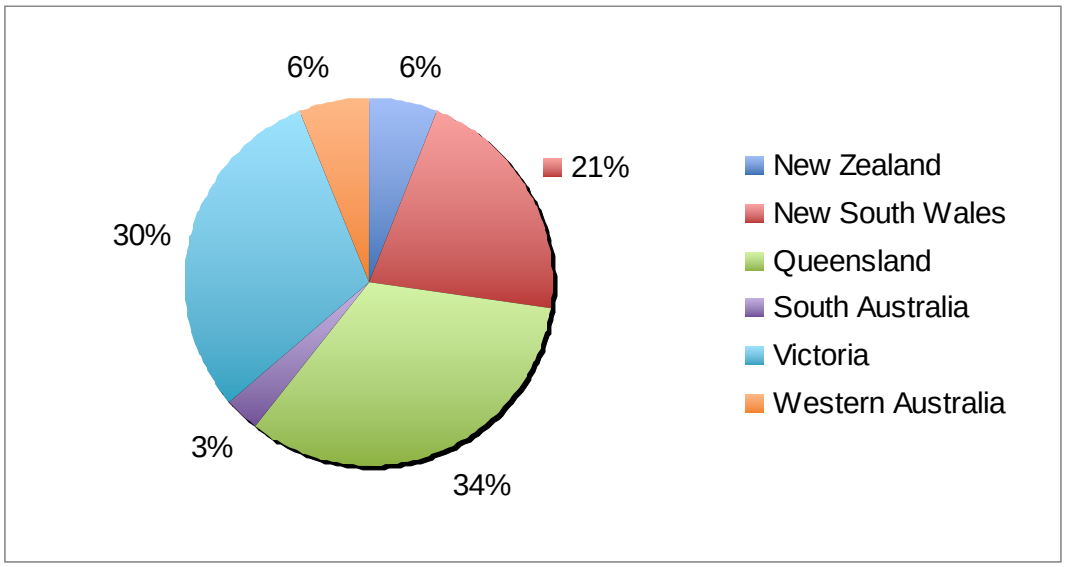
The projects shown in Figure 1 above cover a wide variety of public transport infrastructure, ranging from tramway and light rail extensions, busways for Bus Rapid Transit, extensions or electrification of suburban heavy rail lines and upgrades of regional heavy rail lines. The costs for these projects ranged from a relatively modest $8.684M for the 1km on-street Docklands Drive tram extension in Melbourne to $2.417 billion for the largely tunnelled 12.5 kilometre Epping-Chatswood railway.

Geographical clustering of the projects considered in this study in eastern Australia was observed, with nearly two-thirds of all projects considered in this study being constructed in the three states of New South Wales, Queensland and Victoria. The two largest states of New South Wales and Victoria jointly accounted for half of the projects by number and 53 per cent in value ($5.814 billion in 2010 dollars). Queensland also featured strongly accounting for 34 per cent by number and 29 per cent ($3.2 billion in 2010 dollars) by value of the total listed projects.

Western Australia's creditable performance saw the state's two key public transport projects (the Clarkson extension and the Perth-Mandurah Line) accounting for 12 per cent or $1.3 billion (2010 dollars) of the total spend, while projects in South Australia and New Zealand made up the remainder. It is worth noting that Tasmania, the Northern Territory and the Australian Capital Territory did not construct any public transport infrastructure projects during the last decade that fit the criteria for this study. The geographical breakdown of these projects is displayed at Figure 1 below.

Analysis of the projects selected for examination in this study has seen patterns emerge that are in the author's opinion significant and worthy of undertaking further in-depth research and refinement. The detailed results of this further research could possibly have an impact on more accurately costing public transport projects that would be extremely useful to Australasian infrastructure planning and delivery agencies to develop the next wave of public transport infrastructure projects that will be delivered during the second and third decades of the 21st Century.

Figure 1: Place of origin for the 33 identified public transport infrastructure projects 2000-2009



The preliminary results of this research outline a generalised per-kilometre capital cost profile for constructing rights of way for busways, light rail and heavy rail projects. These profiles also suggested that the decision to put a public transport right-of-way underground commits the proponent to a greatly escalated per-kilometre cost along with attendant engineering and other risks.

3.1 A generalised per-kilometre construction cost for public transport infrastructure projects

As stated previously, journalists in the print media and public transport advocates have claimed in recent years that construction costs for public transport infrastructure projects (particularly heavy rail projects in Sydney and Melbourne) in Australia are much higher than they 'should' be. Some commentators ascribe these escalated costs to the way that infrastructure delivery authorities 'bundle up' operating costs with capital costs, or when construction costs for rights-of-way are aggregated together with project 'enabling works' (such as resignalling or train stabling).

While there may be many reasons behind escalating costs of infrastructure projects, there is a perception that indicative per-kilometre costs for public transport infrastructure projects in Australia are not well known by governments. Better knowledge of these costs and indicative values of how much a kilometre of (for example) busway should cost would benefit decision makers and arguably provide better value for money in public transport infrastructure projects across Australasia. This is important in our present decade as a number of major projects to build and improve public transport infrastructure in Australasian cities are either planned or underway.

The research undertaken in this paper to identify eligible public transport infrastructure projects has provided some preliminary cost indications for construction of light rail extensions, heavy rail (electrification of existing lines, track amplification, new lines) and busway projects. These preliminary values still need further refinement and testing, however they enable some initial analysis as outlined in the remainder of this paper. The basis of the observations made here is Table 2, which ranks the projects listed in Table 1 in terms of average cost per-kilometre from most expensive to least expensive.

Table 2 - Public transport infrastructure projects ranked by cost per km (2010 dollars)

Rank	Project Name	State / Territory	Technology	Completed	Cost in A$M	Cost in A$M (2010 dollars)	Length (km)	Cost per km $AM (2010 dollars)
1	Inner Northern Busway Stage 2	QLD	Bus Rapid Transit	2008	$333	$349	1.2	$290.83
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				TOTAL in A$M (2010 Dollars)		**$10,900**		

3.1.1 Methodology

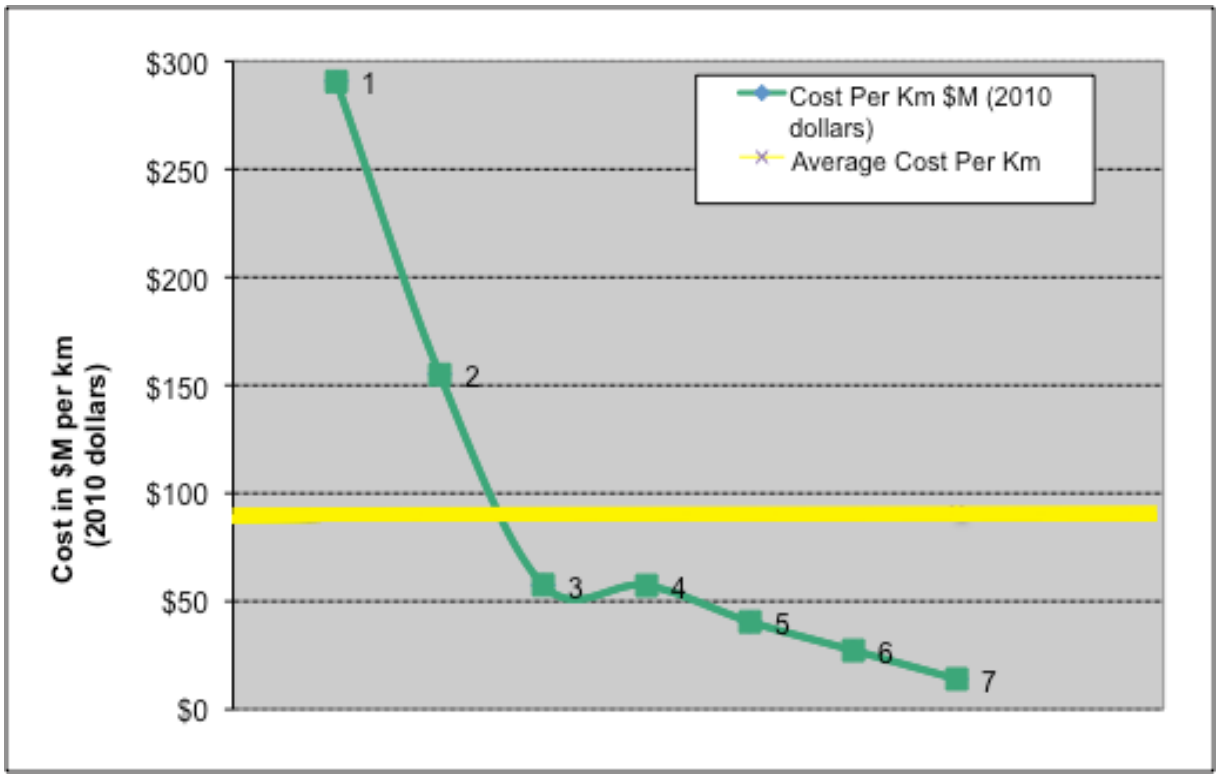
The methodology chosen to derive construction costs is relatively straightforward, in that the costs for each transport technology type (busway, light rail, heavy rail) in the sample list of projects (in Table 1) have been aggregated together and averaged out to provide the mean cost of construction for a kilometre of each technology type.

Further analysis of the mean cost for each transport technology type has shown that there is stratification of mean costs per kilometre that is dependent on the 'level of difficulty' for each project. For example, it is not surprising that a busway constructed with extensive tunnelling under buildings and grade separation over existing road and rail lines will cost more to construct than a busway constructed beside an existing freeway or on arterial roads in middle or outer suburbs.

3.1.2 Bus Rapid Transit (Busways)

Some Australasian cities (Brisbane in particular) have invested heavily in the transport technology of Bus Rapid Transit (BRT) or more commonly, Busways. Within this catch-all term are a variety of sub categories of busways that are more or less defined as BRT.

Figure 2 – Australasian Busway per-kilometre construction costs 2000-2009



Key: 1: Brisbane Inner Northern Busway (BINB) Stage 2, 2 : Boggo Road Busway, 3: South East Busway, 4: BINB Stage 1, 5: Auckland Northern Busway, 6: Northwest T-Way, 7: Liverpool-Parramatta T-Way.

In a recent survey of Australasian BRT projects (Currie and Delbosc 2010) the diversity of types of BRT operating in the cities of Adelaide, Auckland, Brisbane, Melbourne and Sydney was observed, ranging from guided buses using mostly segregated rights of way (Adelaide) to unguided buses on mostly segregated rights of way (Auckland, Brisbane, Sydney) unguided buses on arterial roads in mixed traffic (Melbourne). There is also a further geographical diversity in BRT routes between radial routes focused on the CBD (Adelaide,

Auckland, Brisbane) and routes in middle suburbs serving major suburban activity centres (Sydney, Melbourne).

This diversity is reflected in the per-kilometre cost profiles for busway construction in Australasia. Figure 2 above shows the costs for the seven busway projects in the sample group. Costs ranged from a high of $290.5M per km (Brisbane Inner Northern Busway [BINB] Stage 2) to just over $14M per km (Liverpool-Parramatta T-Way). The average per km construction cost came to $91.7M.

Skewing the average cost higher were the BINB Stage 2 and Boggo Road Busway projects (both of which involved expensive tunnelling beneath the Brisbane CBD). Removing these two projects drove the average busway construction cost down to just under $40M per km. This lower average cost reflected construction of the remaining busways on mostly segregated alignments in the suburbs of Auckland, Brisbane and Sydney, with lower land acquisition costs, lesser need for expensive tunnelling and grade separations and use of existing alignments (freeway, pipeline corridors) for rights of way.

3.1.3 Light Rail (Tramways)

During the last decade, light rail in Australia underwent somewhat of a renaissance with five projects taking place in three cities. Adelaide's single tram route was upgraded and extended through the CBD to the western end of North Terrace; Sydney's sole light rail route was extended from Wentworth Park to Lilyfield and three extensions of Melbourne's tram network in the middle suburbs and on the newly-developed CBD fringe.

Figure 3– Australian Light Rail per-kilometre construction costs 2000-2009

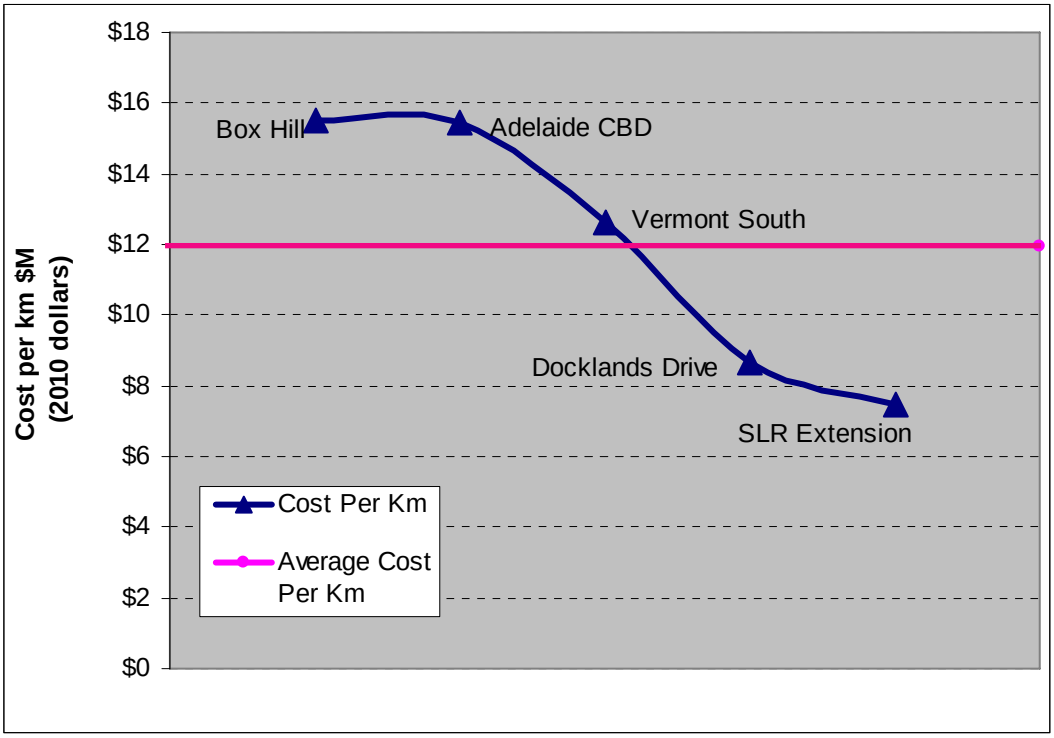


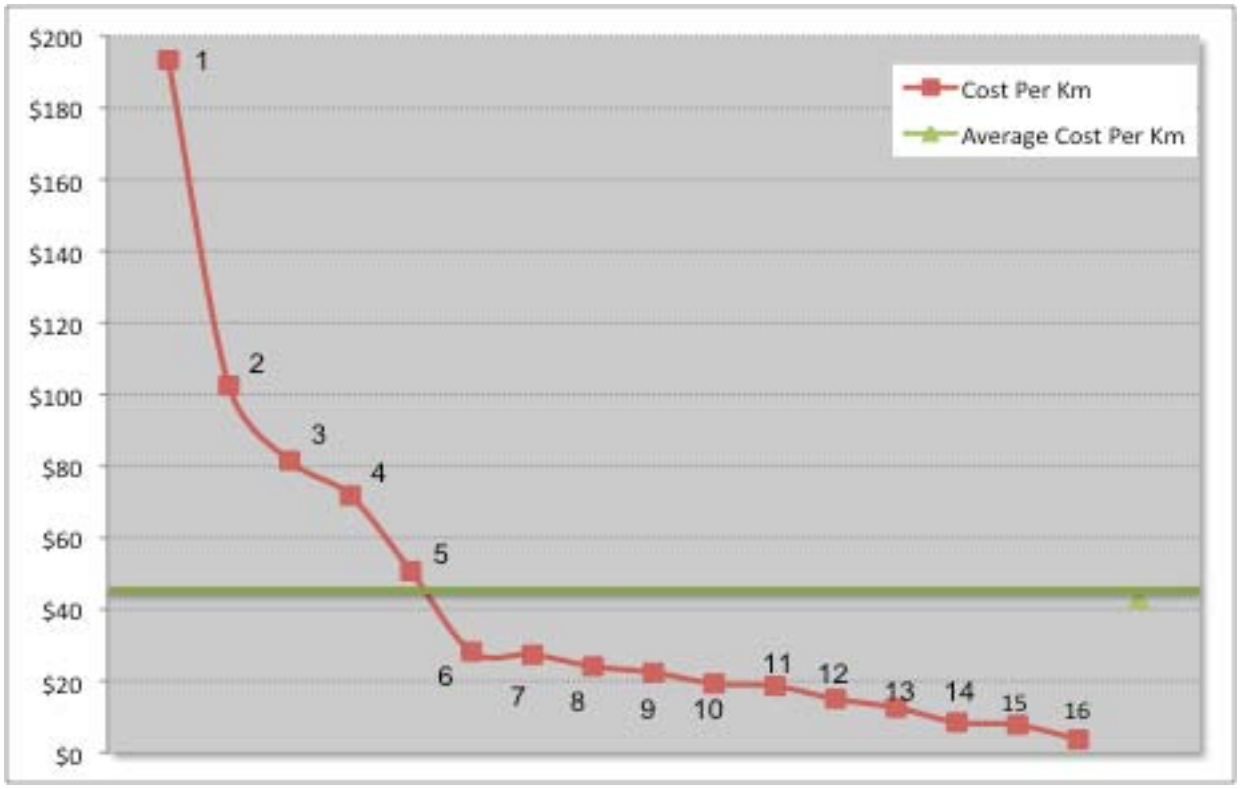
Figure 3 above shows the per-kilometre construction cost profiles that were developed using the sample group of five light rail extension projects. The costs ranged from an upper value of $15.48M (2010 dollars) for the Mont Albert-Box Hill tram extension in Melbourne to a lower bound of $7.467M for the Sydney Light Rail extension to Lilyfield. Based on the sample of projects, the average per-km construction cost for a light rail project in Australia based on actual costs from the previous decade is $11.9M.

The range of costs reflects the different environments that extensions to light rail lines encounter. The above average cost values ($12.5M - $15.5M) reflect construction taking place in the medians of arterial roads in Melbourne (Box Hill and Vermont South extensions) or through the Adelaide CBD. The below average cost values ($7.5M - $8.7M) reflect the easier construction in an inner-urban renewal area (Docklands Drive) or through the re-use of an existing, segregated heavy rail alignment (Sydney Light Rail extension).

3.1.4 Suburban Heavy Rail

In this sample group, 16 suburban heavy rail projects were confirmed as completed between 2000-2009. These covered a gamut of project types including electrification and track amplifications (duplication, triplication, quadruplication) of existing lines, construction of rail extensions on existing lines and the construction of new lines. These projects often prove the most contentious, as the risk of cost escalation due to environmental factors and subsequent scope creep (mitigation of noise, reduced amenity of nearby residents and environmental degradation) is both more likely to occur and their effects more apparent in heavily populated areas of our major cities. The cost profile of these 16 projects is given in Figure 4 below.

Figure 4 - Australian Heavy Rail per-kilometre construction costs 2000-2009



Key: 1: Epping-Chatswood line, 2: Sydney Airport line, 3: Varsity Lakes extension, 4: Britomart Transit Centre, 5: Clifton Hill duplication, 6: Salisbury-Kuraby triplication 7: Turella-Kingsgrove quadruplication, 8: Currambine-Clarkson extension, 9: Caboolture-Beerburrum duplication, 10: Mitchellton-Keperra duplication, 11: Perth-Mandurah railway, 12: Craigieburn electrification, 13: Brisbane Airtrain, 14: Sydenham electrification, 15: Helensvale-Robina duplication, 16: Ormeau-Coomera duplication.

The per-kilometre costs for rail projects in this sample range from an upper bound of $193.5M for the mostly bored tunnel right of way of the Epping-Chatswood Rail Link to the lower bound of $3.67M for the Ormeau-Coomera Duplication. The average per-kilometre cost for these projects was $42.94M (2010 dollars).

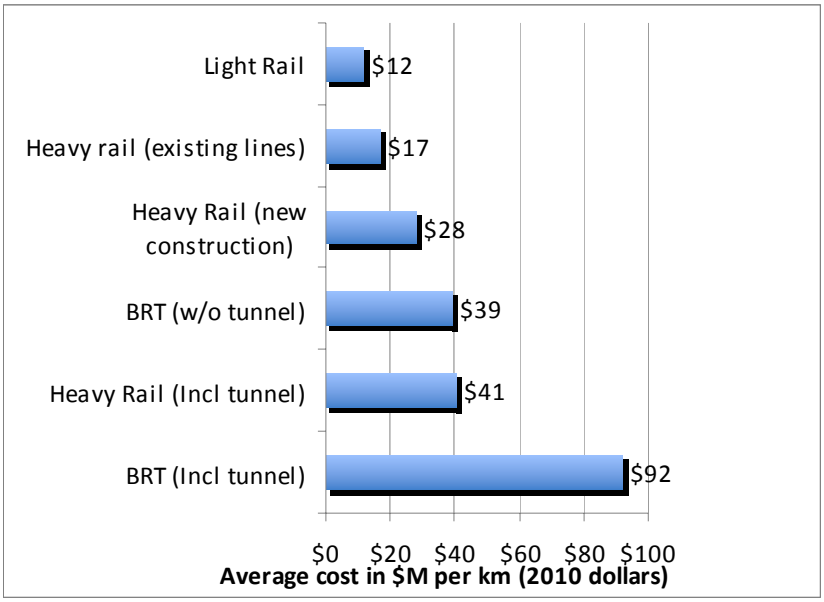
The greatest escalator of per-kilometre costs for heavy rail projects is the decision to pursue tunnelled rights of way. The technical and geological complexity and risk of these projects greatly increases this cost. The decision to choose a tunnelled right-of-way occurs for a variety of reasons. These most typically include the high cost of land acquisition and disruption to the inner core and CBD area of cities of construction and environmental and visual amenity issues. Weighing up these factors tends to preclude the consideration of surface and elevated rights-of-way.

Removing the two most expensive projects with tunnelled rights-of-way (Epping-Chatswood and Sydney Airport Railway) from the equation, average construction cost drops by around one-third to $27.95M per-kilometre. Removing the top five most expensive projects (involving either extensive tunnelled rights-of-way, cut-and-cover tunnelling and grade separations (Varsity Lakes extension), tunnelling and rail construction in the inner core for a new CBD station [Britomart Transit Centre] or erecting a new bridge over a waterway [Clifton Hill duplication]) reduces the average construction cost by 60 per cent to $17M per-kilometre. This average cost effectively deals with the range of rail projects (such as electrification, track amplifications and extensions) taking place in existing rail corridors. This average figure is also very close to the average construction cost for the mostly 'greenfields' Perth-Mandurah line ($18.6M per-kilometre).

3.1.5 Cross-Modal Comparison

Average per-kilometre cost profiles for heavy rail (new and existing lines) and BRT (with and without tunnelling) as well as those for Light Rail based on the sample of 33 projects are given in Figure 5 below.

Figure 5 – Indicative average per-kilometre construction cost profiles for Australasian public transport projects 2000-2009 by mode



3.1.6 Regional Heavy Rail

Finally, four Victorian projects and one project from New South Wales during the decade involved investment in regional heavy rail. These projects were all relatively low cost projects that improved or restored heavy rail access to regional towns and cities.

The main Victorian project was Regional Fast Rail (RFR) that consisted of a large-scale upgrading of track and signalling system between Melbourne and four key Victorian regional centres (Ballarat, Bendigo, Geelong, Latrobe Valley) that were completed in 2006. The

remaining three Victorian projects all involved the restoration of passenger rail services to Ararat, Bairnsdale and Echuca, all of which had lost regular rail services during the 1990s.

All four Victorian projects were relatively low cost as the scope of works effectively involved remediation of existing railway lines (reballasting, resleepering) and upgrading of level crossings and stations to support passenger train operations. No new stations were constructed On the four RFR corridors, additional costs to upgrade approximately 500 kilometres of regional railway lines to support train speeds of up to 160km/h and the installation of new signalling and safeworking systems were incurred that pushed the per-kilometre project costs out to $1.6M. On the three other routes, indicative costs were much lower, with a range of costs between $0.265M and $0.124M per-kilometre of track, reflecting the minimised scope of works to support lower passenger train service frequencies (2-3 return trips a day) and lower passenger maximum train speeds (up to 130km/h) on routes that saw relatively little freight traffic.

The sole project from New South Wales was the 24 kilometre-long extension of the electrified CityRail interurban rail network from Dapto to Kiama which was completed in 2001. In this project, a higher per-kilometre cost of $2.25M (2010 dollars) was incurred as a result of the provision of overhead wiring infrastructure and extension of the electrical power distribution system, alongside resignalling of the line and other substantial infrastructure works. These included the lowering of the track in the 470 metre-long Bombo tunnel and opening out structure clearances in the Croom Tunnel as well as building new or lengthened platforms at eight stations on the line (Gullick, 2002).

3.2 High per-kilometre cost for tunnelled rights-of-way

Table 2 showed the 30 projects assessed here ranked by their average (per-kilometre) cost from most expensive to least expensive. What becomes apparent when viewing the project list sorted in this way is that the four most expensive projects in Table 2 (each costing over $100 million per kilometre) are those that feature significant length of rights of way in tunnels.

These four projects (and one honourable mention) are all examples of not only the high cost of tunnelled rights of way, but also contextualise the use of tunnelling as the most feasible option for constructing a transport corridor in a complex inner urban environment.

3.2.1 Inner Northern Busway Stage 2 (Brisbane)

Most expensive at just over $290 million per-kilometre was the Queen Street-Upper Roma Street section of Brisbane's Inner Northern Busway. This project featured a 500 metre excavated tunnel under the Brisbane CBD and the retrofitting of two major busway stations into existing structures and significant underground road works in order to connect the three existing busway routes and maintain a corridor for a fourth future busway route (Rawlings *et al* 2009).

Additional challenges included the need to undertake 'top-down' piling from the surface supporting construction by sections in sequence to minimise traffic disruptions, relocating existing public utilities (electricity, water, gas, sewerage, telecommunications, road and rail) while maintaining uninterrupted service and minimising disruptions to affected civic and commercial properties in the Brisbane CBD. Construction started in March 2005 and the project was completed 8 months ahead of schedule in May 2008.

3.2.2 Epping – Chatswood railway (Sydney)

The next most expensive was the Epping-Chatswood railway in the northern suburbs of Sydney, with a per-kilometre cost of approximately $193 million. When the line was first proposed in 1998 as one section of the *Parramatta Rail Link* (PRL) as part of the NSW Government's *Action for Transport 2010* document it was scheduled for completion in 2006 (NSW Ministry of Transport 1998). The entire route of the PRL was costed at $1.4 billion for the construction of a 28km-long (21km in tunnels) electrified, double track railway, with a

bridge crossing the Lane Cove River and a connection into Parramatta along the Carlingford branch line.

In 2001, resistance by resident's groups and conservationists saw the Lane Cove River bridge replaced with an underground tunnel. In November 2002, construction commenced on the Epping-Chatswood section of the PRL. In the 2003-04 NSW Budget papers, costs for the PRL had escalated to $1.6 billion (2000 dollars), which led to cutting back of scope to an Epping-Chatswood route in August 2003 (Kerr 2003). Further cost escalations of $447 million tipped the cost over the $2 billion dollar mark. After the opening of the line in February 2009, the NSW Audit Office's final forecast cost for the project was $2.3 billion (NSW Audit Office 2010, p. 204).

How did the cost climb so high? Clearly, the extensive tunnelling across almost the entire route impacted upon costs, based on the decision to tunnel under the Lane Cove River and the consequent depth of caverning required at the three new stations along the route. Specifying that each track should have its own tunnel rather than a twin bore tunnel for both tracks may have also contributed to cost escalation. Without more detailed information, it is difficult to know the exact reason and to determine the decision making process that led to these outcomes remains a topic for further investigation.

3.2.3 Eastern Busway Stage 1: Boggo Road-Buranda (Brisbane)

This project saw the construction of 2.1km of busway in two stages: A 1.5 km section from the Eleanor Schonell Bridge at Dutton Park (near the University of Queensland), to the Queen Alexandra Hospital and another 600m section from Princess Alexandra (PA) Hospital to connect with the South East Busway to the north of the Buranda busway station (Thiess Australia n.d). The project cost $179.4 million per kilometre to construct and was opened in August 2009.

Both sections required significant tunnelling in a complex inner city environment that is close to the Brisbane River. The first section involved a cut-and-cover tunnel to get the busway under the QR suburban railway lines, a 480 metre-long driven tunnel under the historic Boggo Road Gaol site and a change of levels to a high-level busway station at PA Hospital. The second section involved changing levels again to bring the busway down over Ipswich Road, an underpass to get below the QR railway lines and cut-and-cover tunnel to pass under the Pacific Motorway before joining the South East Busway.

As with the Inner Northern Busway Stage 2 above, the complexity of the urban environment and the density of utilities along the alignment added one level of cost, while the changes of level and the requirements to build cut-and-cover tunnels under railway lines and motorways and a more sophisticated driven tunnel (using an imported roadheader) under Boggo Road Gaol added another level of cost and complexity to the project.

3.2.4 Sydney Airport railway (Sydney)

Construction of the Sydney Airport railway began in 1995 and was opened in May 2000, three months ahead of the 2000 Summer Olympic Games. The 10 kilometre-long double-tracked route runs almost completely underground with the exception of short sections at both ends of the line (at Central and Wolli Creek).

The line was built as a public-private partnership with the NSW Government building the railway infrastructure (tracks, overhead traction supply, signalling) and the new interchange station at Wolli Creek. The Airport Link consortium would build the four new stations (Green Square, Mascot, Domestic and International) in return for a 30-year franchise to operate the stations and levy a surcharge on passengers to use them. The government-funded component of the Sydney Airport railway cost $1.024 million (2010 dollars) or $102.4 million per kilometre.

To deal with the railway alignment being mostly below the water table and the 10km of tunnelling taking place through a combination of rock (4km) and soft ground (6km), the construction of the Airport railway employed a single bore tunnel dug with a Tunnel Boring Machine (Australasian Tunnelling Society n.d.). Like the other tunnelling projects mentioned above, there was a complicated inner-urban environment with a high density of utilities that needed to be accounted and a requirement to ensure that tunnelling would cause minimal disruption to activities taking place on the surface, such as the Domestic and International terminals at Sydney Airport.

With the absence of all but one of the stations (Wolli Creek) in the cost of this project, the Sydney Airport railway is one of the best examples of a public transport infrastructure project where the costs of building the basic rail infrastructure in a tunnel environment are able to be determined. The costings are sufficiently robust to be comparable to international tunnelled heavy rail projects (Ecotransit 2011). This alone makes the Sydney Airport railway an important yardstick for validating local construction costs for rail projects in heavily tunnelled inner-urban environments such as Melbourne's proposed Metro One or Brisbane's Cross River Rail project.

3.2.5. Perth-Mandurah railway Package F (Perth)

The cost for the Perth-Mandurah railway project shown in Figures 1 and 3 are for the full length of the project. While the vast majority of the 70km-long Perth-Mandurah railway line was constructed along freeway medians and sandy scrubland south of Perth, the last few kilometres of the line into Perth represented complex engineering challenges. Firstly, the crossing of the Swan River at the Narrows and secondly the tunnelled approach to Perth station and connection through to the Joondalup line. This latter portion of the project ('Package F') provides another example of the increased costs of tunnelling in an inner urban environment. The final cost of the works for Package F was $398.1M or approximately 36 per cent of the project's construction costs (Waldock *et al* 2008, p. 59) and consisted of:

- 350m of cut and cover tunnels
- 600m of open dive tunnels
- 700m of twin bored tunnels
- two underground stations
- railway track, overhead power, signalling and communications
- associated roadworks, drainage and landscaping.

This 1.3km package of works cost $249.6 million per kilometre.

Again, a complex urban environment was encountered between the north bank of the Swan River and Perth station. Geologically, tunnelling took place in 'soft ground' of sand, clay and fine gravel and below the water table. As in the other projects, customised tunnelling machines were used to bore the tunnels, while extensive utilities relocation took place along the route. The two new stations (Esplanade and Perth Underground) were constructed underneath the Perth CBD and extensive efforts were made to minimise disruption and damage to buildings above including a number of heritage buildings/facades. Another complicating factor was a 2-week industrial dispute affecting Package F worksite that purportedly added a further $1.28M to project costs (Perpitch 2007).

4. Conclusion

In conclusion, the information and figures provided above are the first results of what is an extensive research project into the cost of constructing public transport projects in Australasia. All data on projects and their costs used in this paper have been gathered using open source information that is publically available.

While the author feels that some of the initial research questions have been answered in terms of developing a per-kilometre cost for different transport technologies in Australia and New Zealand, there are still other questions that require further investigation. In particular, there is still work to be done on further splitting out costs for stations and other infrastructure to develop unit costs for these elements also.

Other questions arising from this study are more qualitative than quantitative in nature, dealing more with the making of key decisions that defined project scope and the management of risk. Obtaining more qualitative information on these projects will involve interviews with past and current project managers involved with these and other projects, along with other key decision makers alongside more intrusive data gathering processes (such as Freedom of Information requests).

While this paper has covered what the likely range of per-kilometre costs are for a range of public transport infrastructure projects, there are also limits to what information can be found through open source data collection. This means there is further quantitative research work required to further isolate costs around different project components (such as stations and supporting civil works) to develop a true cost for constructing a kilometre of heavy rail line (electrified and non-electrified), busway and light rail in Australasia.

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