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Of Skyrails and Skytrains - Elevated rail in the Australasian urban transport environment

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Abstract

In recent years, elevated rail corridors have regained favour as a way to retrofit public transport infrastructure into mature urban environments. Elevated rights-of-way are viewed as particularly cost-effective solutions to high capital costs inherent in trenched and tunnelled rail alignments. While elevated rights-of-way are extensively utilised for urban freeway corridors in Australia and New Zealand, they are less utilised for urban rail.

Recent urban rail proposals by Australian state governments using elevated alignments have met with public hostility from concerns about visual and audible impacts upon the adjacent urban environments. The authors argue that elevated rail provides cost-effective urban public transport corridors capable of delivering high-quality built environments, especially around stations. Furthermore, elevated rail corridors, if done well can preserve and enhance overall urban amenity for the public in comparison to trenched or tunnelled alternatives.

This paper investigates claims of elevated rail's lower capital costs compared to trenched and tunnelled alternatives using evidence from benchmarked costings from over 20 years of Australian and international transport projects. Beyond construction costs, a range of other costs and benefits associated with the physical outcomes that may be linked to each corridor type are also considered, including: construction disruption, ground level severance and connectivity, future modal interchange opportunities, creation of new public open space, transit-oriented development opportunities and value capture.

Rail infrastructure investment by governments and the private sector at the corridor-level scale has the potential to be city-shaping and any assessment of such projects must include the broader costs and benefits in terms of urban planning and design. A major conclusion is that many factors beyond physical construction costs alone must be assessed in order to provide a genuine analysis of the value of corridor scale rail infrastructure investment.

1. Introduction

After over a decade of relative dormancy, elevated railways are returning to the railway constructor's toolbox. The 8.5 kilometre-long elevated section of Brisbane's 'AirTrain' has served the airport's two terminals since 2001, meanwhile Sydney's 4-kilometre-long elevated 'SkyTrain' section of the North West Metro is nearing completion. In January 2016, Melbourne added 'Sky Rail' to the Australian lexicon for elevated railways, bestowed upon the Caulfield to Dandenong Level Crossing Removal Project by a journalist (Johnston 2016).

Almost a month elapsed between the initial media frenzy and the formal government announcement, accompanied by high-quality images of the proposed concept designs. The proposal involved 8.2 kilometres of elevated rail in three sections to remove nine level crossings on Melbourne's busiest rail corridor. In short order, 'Sky Rail' became increasingly controversial, with much debate on the merits of elevated rail in Melbourne's established middle suburbs. In this paper, the authors seek to contribute to more informed discussion on the value of elevated rail corridors in the Australasian urban environment through examination of Melbourne's use of elevated rail in its grade separation program.

This paper is divided into three main sections. Firstly, the Victorian Government's methodology for assessing and analysing the costs and benefits of grade separations will be explored. Secondly, the benefits of elevated rail construction compared to alternatives will be examined. Thirdly, indicative construction cost profiles will be developed to provide a cost framework for different types of grade separations and railway to benchmark capital costs of elevated rail against alternative alignment options.

2. Literature review: institutional biases in benefit assessment and analysis in Melbourne

Much of Melbourne's elevated rail debate has concerned the decision-making process driving methods of grade separation. Many international cities have developed transit networks involving substantial elevated rail corridors from whose experience much can be learned. Applying such learning is a fast-evolving area of practice and research in Australia (see De Gruyter & Currie 2016; Currie 2016; Macdonald 2016; Woodcock & Stone 2016 & 2015; Woodcock 2016; Woodcock & Wollan 2013). The literature is important because of the role it has played in setting policy and the evidence it provides about institutional thinking and decision-making.

Towards the end of the 2000s, the removal of level crossings became an increasingly pressing issue and the Victorian Department of Transport and VicRoads collaborated on developing a methodology for prioritising grade separation of the 177 level crossings on Melbourne's passenger rail system (Taylor & Crawford 2009, Crawford 2010). The Multi-Criteria Assessment process focused on four main areas: project costs, social aspects, environmental factors and alignment with strategic objectives for the road network. Project costs and strategic 'fit' were calculated numerically, along with estimates of greenhouse gas emissions to cover many environmental parameters.

A benefit cost analysis was conducted to weigh up costs of project implementation against benefits calculated in terms of travel time savings and accident reduction (Taylor & Crawford 2009, Crawford 2010, VicRoads 2014). Social impacts were assessed qualitatively for a range of criteria, including community severance, visual and noise amenity, development opportunities, transport connectivity / access, and places of social significance. Impacts on the local natural environment were generally seen to apply outside urban areas.

Several weightings were trialled to ascertain the effect of different factors across all four domains, but these could produce contrary results. For example, a weighting towards environmental factors could lead to local roads being prioritised over arterial roads (VicRoads 2014:14). Other aspects, such as local accessibility for pedestrians and cyclists within an area or to public transport were seen as of little importance and not part of the assessment of 'transport' benefits:

> Other factors included in the multi-criteria analysis such as amenity impact were largely matters to satisfy in devising schemes rather than in prioritising. Similarly, factors such as reducing community severance had only marginal impact – there needs to be a major transport benefit for a crossing to be a priority. (Crawford 2010:722)

Ultimately, weightings had to suit strategic road network objectives, with the aim being to find which level crossings needed to be removed to "maximise the efficiency of the road network" (VicRoads 2014: 13). This ultimately meant qualitative aspects, even those which clearly can have hard quantitative measures made of them such as community severance, development opportunities, or public transport access and connectivity parameters were disregarded in the prioritisation process.

Another major framing constraint was seeing each level crossing in isolation. As VicRoads explained, the assessment was:

> ...predominantly focused on individual sites and wholly from a road and rail operations perspective. It did not consider broader network approaches and wider productivity and economic benefits from a corridor or strategic perspective. The initial prioritisation was also influenced by initial costs and benefit cost ratios, which biases the results. While the multi-criteria assessment was a useful tool, it is not the sole input into prioritising level crossings for grade separation. (VicRoads 2014: 13)

The problematic nature of the exercise becomes even more apparent when it is realised the benefit cost calculations were based on cost estimates for grade separation approaches that lacked an evidence base for their assumptions. For example, under the social criteria of ‘community severance’, assessments incorporated presumptions of the most likely type of grade separation and its assumed effects on ‘severance’. In this, rail-under-road grade separations were ranked highest because local road accessibility was improved after removal of the level crossing; whereas rail-over-road was treated the same as road-over-rail based on the negative effects at many places where 1960s and ‘70s-vintage road overpasses resulted in increased severance for pedestrians and cyclists and loss of economic activity. Despite these documents drawing on evidence from places in Melbourne where road overpasses have had these effects, there was a failure to also observe the success of the many extant examples of elevated rail in Melbourne (Woodcock & Stone 2015, 2016; Woodcock 2016). As a result, elevated rail was ranked poorly alongside road overpasses.

In the 2014 VicRoads report there was an awareness that level crossings were a major impediment to achievement of the 30-year goals of the Public Transport Victoria *Network Development Plan* for passenger rail by “increasing services and capacity of the rail network” (VicRoads 2014: 6). Indeed, while PTV’s plan indicated dramatic increases in service frequencies, with some lines tripling or even quadrupling the number of services per hour in the peak (PTV 2012), VicRoads stated that “if no action is taken to remove the level crossings, the capacity to be able to run additional train services and provide a higher level of services to commuters in the future is limited.” (VicRoads 2014: 16).

If a network perspective is taken, the aim of freeing up capacity to allow as many rail services to run as possible should fit with maximising efficiency of the road network so that more buses and trams can also be run to feed the enhanced rail network. Taking a genuinely integrated public transport network focus for Melbourne would make the 116 crossings used by buses and the 3 used by trams priorities for removal (Woodcock & Stone 2015). In their synthesis of the international literature on rail-road crossings, De Gruyter and Currie (2016) identified the effect of level crossing removals on improved train service frequencies as one of the major research gaps.

Further implicated in the assessment methodology informing policy in Melbourne (until mid-2014 at least) is the limited understanding of a connection between transport, especially rail-based public transport and urban renewal and intensification. Again, the preference for rail-under-road grade separations is based on an assumption that development opportunities will exist on top of or adjacent to railway stations. The problem that arises with this is that because building over the top of railway stations is complex and expensive, VicRoads finds “there is a limited opportunity to realise positive financial return on the development of rail land made available by level crossing projects” (VicRoads 2014:12).

This view becomes significant when the potential for integrating land use and public transport through massive public investment in grade separations are disconnected from value capture opportunities. As a result, VicRoads reported that “Value capture and development opportunities have not been considered in the prioritisation of level crossings as the benefits are generally related to sites that have a very high land value" (VicRoads 2014: 12). As a result of the assumptions in the framework for grade separation assessment, there is a disconnect between large numbers of level crossings prioritised for removal and the areas identified for urban renewal in the 2013 *Plan Melbourne* metropolitan strategy and for transit-oriented intensification in its predecessor *Melbourne 2030*. This disconnect would appear to arise from this assessment framework, or one based on similar assumptions. Research, and international experience shows, two important benefits of elevated rail run counter to these assumptions: firstly, elevated rail releases land below the railway that can be used for a very wide variety of land uses (Woodcock & Stone 2016, 2015; Dovey & Woodcock 2015; Woodcock 2016; Woodcock & Wollan 2013); and secondly, freeing up this land can create many kilometres of new frontage, adding significant value to what would otherwise be large quantities of real estate with back boundaries onto rail corridors.

3. The benefits of elevated rail

At this point, the question raised is: 'what difference would be made to multi-criteria assessment analyses by greater understanding of the benefits of elevated rail?' Part of our interest is inevitably in the claimed cost differences between types of grade separation, since these are the major cost component being assessed against the range of benefits that may accrue from a grade separation project. The cost analysis is dealt with later section 4. In this section, we will briefly outline the benefits of elevated rail using the same set of criteria as were used above for social and environmental impacts by VicRoads.

3.1 Safety

The standard numerical assessment of crash statistics and the savings related to traffic and pedestrian accidents assume they are completely removed by grade separations. At this level of analysis, elevated rail should perform as well as any other type of right-of-way.

3.2 Community Severance

In addition to freeing up movement of vehicular and pedestrian traffic on roads where level crossings have been removed, elevated rail releases land in the rail reserve formerly occupied by the railway tracks. Apart from those parts at either end of the railway ramps where the structural headroom is too low, the corridor land beneath the viaduct allows free movement across the former surface railway corridor. Compared to all other grade separation options except tunnelling (either deep tunnelling or cut-and-cover), elevated rail maximises reduction of community severance. Where viaducts run for extended lengths, connectivity gains are maximised, directly reconnecting previously separated communities. If transport benefits are extended to include accessibility gains for active transport modes (pedestrians and cyclists) within a local area and to public transport nodes, reduction in severance needs to viewed with much greater significance than previously. Many local journeys that may have used cars due to severance could potentially be replaced with active transport. The other main types of grade separation used in suburban settings will not allow this to occur.

3.3 Visual Amenity

Visual amenity has been a major issue in Melbourne since January 2016 with the unveiling of the so-called 'SkyRail' project between Caulfield and Dandenong. This has been a primary issue for resident protesters on parts of the corridor who have actively fought to change the design to trenched rail. Amenity is a vague term and encompasses a range of meanings. The primary cluster of issues for residents have related to the visual appearance of the viaduct, graffiti, and property values. Alongside these concerns, we discuss visual amenity for the tens of thousands of rail passengers using the line every weekday.

Lowering rail lines into trenches that pass beneath roads makes the railway disappear from many angles of view. This is seen as improving visual amenity for those who dislike looking at rail infrastructure. However, trenches generally do not improve the view for rail passengers. Contemporary construction standards require trenches to be lined with concrete retaining walls obviating vegetated cuttings. As has occurred with recently completed trenches in Melbourne, graffiti artists are quick to add their touch to these extensive blank canvasses, where their work will mainly be seen by rail passengers. At the same time, the extensive graffiti on back fences lining the rail reserves remains, along with the mostly constrained space for landscaping. Protesters have suggested that vandals will find ways to graffiti viaducts seven to twelve metres above ground and have fed a sensation-hungry media with ‘mashups’ depicting this. Yet, evidence from elevated roads in Melbourne and viaducts around the world would suggest it is very difficult to paint graffiti on viaducts.

Contemporary safety standards require trees to be planted sufficiently far away to obviate them falling across the railway line. Mature trees close to the line must be removed for construction and replacements are unlikely with average width reserves. On the other hand, while trees may need to be removed to build rail viaducts, because of the elevation, much more planting closer to the line is possible to enable screening effects.

Elevated rail dramatically improves visual amenity for railway passengers and the general travel experience through access to natural light and views. The profile of public transport is raised within the landscape, enhancing wayfinding and access both to and from stations, and the bike paths that run beneath the viaducts.

The issue of visual amenity has also been claimed by protesters to result in loss of value for property directly facing a rail reserve with elevated rail above it. There appears to be no definitive data about this other than the opinions of real estate agents reported in the media (Zhou 2015, 2016; Zhou & Robb 2016). Real estate values for properties abutting rail corridors as they exist can sometimes be lower, but the impacts of reclaiming the rail reserve may have the opposite effect. Direct access to linear parks, cycling and walking paths more closely connected to stations and shopping precincts could make these properties more attractive, especially to developers of medium density housing. Some of the land use zoning along the Caulfield to Dandenong corridor anticipates intensification and there are already smatterings of apartment developments that would benefit from more public open space. Finally, there are a number of properties that will be overshadowed by viaducts and the Victorian government has offered compensation for these.

3.4 Noise Amenity

In Melbourne at least, at-grade railways are fairly noisy much of the time because of a lack of maintenance, while level crossings have bells and produce wheel noise from road traffic, along with requiring train horns to be sounded for safety. New elevated track will produce far less noise from train wheels, and the noise associated with level crossings is removed. Sound attenuating barriers can reduce noise transmission further. Whether elevated rail is quieter than trenched rail may be a moot point, there is evidence that both can produce unwanted noise effects, however it will be less noisy than rail at-grade.

3.5 Development Opportunities

Decking over railway trenches to provide development opportunities is expensive and economically viable only when the surrounding land value is the same or greater than the cost of decking. Developers would find it more profitable to purchase nearby land to maximise the proximity benefits to the railway and evidence suggests that while property values are generally higher close to railway stations (LUTI & Mecone 2016), for the residential market in Melbourne at least, the ‘sweet spot’ may be a block or two back (Zhou 2015, 2016; Zhou & Robb 2016). Furthermore, to make development over a railway trench viable, greater building height would likely be necessary than adjacent areas, producing resistance from existing residents. Given enormous costs of grade separation projects, this explains why these kind of 'air rights' developments are viable only in very high land value areas such as Melbourne's CBD or certain inner city corridors. To date, most development on railway land in Melbourne (where it has occurred at all) has been adjacent to stations, not on top of them. As a case in point, an 'up to' 13-storey development has been proposed by the Victorian government on top of a deck built as part of the recent trenched grade separation at Ormond on the Frankston Line. However, there has so far been no visual information or any detail about how this proposal will proceed through the planning process.

By contrast, elevated rail releases land in the rail reserve beneath the tracks and on either side of the station. This enables a wide variety of land uses to incrementally develop over time, at a scale in keeping with the area's pace of development more generally. This allows for integration of complementary land uses (such as retail, commercial, community and recreation) within stations and enables them to be better integrated socially with their urban precincts. This also allows for creation of new public open spaces, whether as station forecourts or linear parks extending along the railway corridor. In the long run, if activity centres around elevated stations develop such that high levels of development become warranted, then elevated rail is no barrier. There are many examples that could be cited internationally, but Chatswood in Sydney is a good example of how development intensity is not constrained by elevated rail.

By contrast, the risk is that the new public spaces created beneath viaducts may not be adequately activated or subject to passive surveillance and so could acquire negative perceptions. To ensure an actively used and positively viewed public realm requires a mixture of pro-active place making, a sense of ownership by local community groups, appropriate planning controls on adjacent land, high quality urban and landscape design, night-time lighting and good connections to local pedestrian and cycling networks: in short, good integration of transport and land use planning with high quality spatial thinking. In the case of the Caulfield to Dandenong 'SkyRail' project, a $15 million budget for the undercroft public realm is being overseen by a trust comprising eminent landscape and other design and planning professionals.

3.6 Transport connectivity and access

The issue of transport connectivity and access warrants close consideration as it has significant implications for grade separations. If public transport network efficiency is seen as a priority to the same extent as the road network, grade separations play a key role in both. Many transport planners argue the most cost-effective way to improve access to public transport in dispersed cities like Melbourne is to rationalise bus routes so they form a more effective network, running them more frequently to form seamless connections with the heavy rail system. Doing this requires road network efficiency to be maximised and buses moving freely upon it without being delayed by congestion or level crossings. Level crossing removal is necessary to make bus (and tram) priority workable. To make the most of free flowing and frequent buses serving increased capacity passenger rail, grade separation types should be used that maximise opportunities for inter-modal transfers (Woodcock & Stone 2016, 2015). Elevated rail provides the greatest flexibility in terms of planning for current and future interchange arrangements. The degree to which this potential can be realised depends on maximising access to railway stations by providing as many entrances as possible to connect them to buses, trams and local pedestrian networks, rather than single points of entry. To enable this, a culture change is needed here in Melbourne away from revenue protection-based controlled access, to a European style access culture with ticket validation technology dispersed among many entry points.

However, the issue of connectivity needs to strategically prioritise grade separations so that not only is road network efficiency maximised, but the ability of the rail system to run as many train services as required for a 'turn up and go' service is also maximised. Typically, railways operate as corridors and the spatial distribution of bus routes and railway lines means that grade separations need to be planned to enable entire rail corridors to operate as efficiently as possible, not just the roads that cross them. The benefits of elevated rail are such that as more of a corridor is elevated, the more overall ground level connectivity can be achieved.

3.7 Places of social significance

So far, this criterion has been intended to refer to protecting and retaining places that are valued, such as heritage listed structures like stations, signal boxes and local reserves etc. Trenched rail projects tend to mean extensive demolition to make way for new structures and tend to take up more of the rail reserve while exacerbating severance either side of where level crossings were removed. If carefully planned, elevated rail can minimise this kind of damage to valued local places. Viaducts can be built over live rail following existing alignments, and heritage structures may be more likely to be retained. However, beyond protecting existing places of social significance, we should ask to what extent grade separations can create new places the community will actively use and value? Here, elevated rail has significant advantages because space created below the viaduct that acts to connect previously disconnected paths, streets, and public open spaces along the corridor. This opens possibilities for creation of many new local places of social significance.

A number of projects internationally propose retrofitting elevated railways to enhance the potential of ground level connectivity for active transport, such as the Radbahn proposal to create a continuous 9-kilometre bike path beneath Berlin’s oldest metro, the U1 line (AllesGerman 2015), and the 16-kilometre Underline project in Miami (The Underline 2016). Other cities with elevated rail, such as Vancouver, Toronto, New York and Singapore have used design competitions to create proposals for retrofitting undercroft spaces below railway viaducts that not only create walking and cycling connections, but add other land uses such as business and arts incubators, markets, various recreational uses as well as potential to act as ecological corridors for urban flora and fauna. We see here a shift in attitudes towards the value of space created as a by-product of major transit infrastructure built at a time when cities functioned very differently. As local demographics change and economies shift from manufacturing to services, neighbourhoods with elevated rail can change to serve the needs and aspirations of the people who live there and pass through them. In a city like Melbourne, new elevated rail can be designed with such uses in mind to ensure that not only does capital investment free up transport movements, but is also a catalyst for place-making.

3.8 Local Natural Environment

In a similar vein to above, the impact in local natural environments was assessed primarily in terms of damage minimisation, hence why it was felt to apply mainly to grade separations outside urban areas. Again, we ask to what extent can rail infrastructure projects create new local natural environments that provide extensions to local public open spaces, wildlife habitats and connected ecological corridors? Here elevated rail clearly can make a potentially radical and transformative contribution. An analysis elsewhere by one of the authors (Woodcock 2016) indicates that if grade separations in Melbourne where prioritised on the basis of enhancing public transport network effects, then at least 146 kilometres of railway corridors, involving the redevelopment of 96 stations would be required. If this were implemented as elevated rail (wherever appropriate from a rail operations viewpoint), then this would create a significant transformation in the public open space network, with over 400 hectares of new linear parks. In the case of the Caulfield to Dandenong ‘SkyRail’ project, 22 hectares of new public open space will be reclaimed from the rail reserve, allowing the re-connection of a series of local public open spaces, improving ecological connectivity. These impacts on local natural environments within urbanised areas are much in need of further research.

4. Recent grade separations in Australia and New Zealand

Much recent debate over elevated railways in Australia has stemmed from a major program of grade separations on the metropolitan rail network of Melbourne, Australia that has taken place in recent years. The program largely aims to improve efficiency of the metropolitan road network and manage increased congestion, with increased rail network capacity as a secondary, but still important priority (VicRoads, 2014: 6). The size and scope of the Victorian Government's target to remove 50 level crossings by 2022 has necessitated thinking on engineering and urban design for level crossing removals to shift from 'spot' treatments of particular level crossings to 'corridor' level treatments of multiple level crossings along a suburban railway line.

While Sydney largely grade separated its rail network from upgrading its arterial road network from the 1950s to the 1990s, grade separations on Melbourne's rail network were much more sporadic and not prioritised by the road and rail agencies to the same extent (Martin, 2012b). While not faced with the same levels of road congestion as Sydney and Melbourne, other Australian capital cities, particularly Brisbane and Perth are investing in grade separations on their rail networks in response to growing populations and road network congestion, particularly for freight transport (Infrastructure Australia, 2015: 2).

Not all grade separations in Australian and New Zealand cities have been undertaken purely for transport network efficiency reasons. Urban renewal in either CBD fringe or suburban town centre sites have been cited as important factors in some grade separations, particularly in Auckland (New Lynn) and Perth (Citylink).

Another important factor driving grade separations is the need to improve rail network efficiency by development of 'flying junctions' on rail networks to increase capacity and reduce conflict between trains on 'at grade' junctions. Development of flying junctions has been particularly important in cities with significant interaction between passenger and freight trains such as Adelaide, Newcastle and Sydney and increasing capacity on busy rail corridors where 'at grade' junctions exist.

The development of a dataset of grade separations was deemed as an important research outcome of this project to better guide decision makers on potential costs and benefits of different types of grade separations undertaken on Australia's urban rail networks.

4.1. Developing a capital cost dataset for grade separation

As part of this paper's data collection process, a capital cost dataset on recent grade separations on Australia and New Zealand rail networks was developed.

This builds upon previous work on capital costs for public transport infrastructure projects in Australia and New Zealand by the secondary author (Martin, 2011 & 2012a). Using the methodology outlined in these works, capital costs in dollars of the day were escalated into 2016 dollars using Producer Price Index data (ABS, 2016 & Statistics NZ, 2016), while conversion from $NZ to $A was achieved using the Reserve Bank of Australia's long-term currency conversion tables (RBA, 2016).

Alongside the three typologies of grade separations previously identified by Woodcock & Stone (2016: 24) of 'rail over road', 'rail under road' and 'road over rail', a fourth of 'rail over rail' is used in this study to capture five significant 'flying junction' grade separation projects.

From this investigation, a dataset of 26 grade separation projects were identified on Australian and New Zealand urban rail networks between 1996 and 2016 and are ranked in chronological order in Table 1. This table outlines locations, types of grade separation, project costs, number of grade separations undertaken, the length of new road or rail constructed in each project and whether a new station was constructed.

Not all grade separations were able to be identified in the dataset, as either many grade separations were built as part of larger road or rail upgrading projects, or where costs for grade separation works could not be disaggregated from overall project costs. Based on this dataset, the quantum of spending on identifiable grade separations over the past 20 years is approximately $2.9 billion in 2016 Australian dollars.

4.2. What the dataset tells us

As indicated in Table 1, a broad range of project costs were observed for grade separations in Australian and New Zealand cities. Generally, ‘Road over Rail’ grade separations were the lowest cost projects, with nine projects identified in a capital cost range between $23 million and $99 million, depending on the complexity of the grade separation and supporting works such as utilities relocation, road duplication or intersection upgrading. It is likely that the low costs for this type of grade separation project is based on the way these projects interface with the railway (often at intermediate locations between stations), the location of road/rail overpasses (middle and outer suburbs) and the lack of new or rebuilt railway stations kept costs low compared to alternative options.

‘Rail under Road’ grade separations tend to be more expensive, based on a sample size of 10 projects, ranging in capital cost between $51 million and $169 million and an outlier project (Perth Citylink) costing $364 million. The three rail-under-road grade separations built in the decade 1998-2007 offered significantly lower costs (from $43 to $86 million) compared to the seven post-2009 projects (from $131 to $364 million). While more research needs to be undertaken into the escalation in costs from pre-2007 and post-2009 rail-under-road grade separations, some preliminary thoughts on the causes could involve: complexity of the project, constraints of the worksite, the need to construct new stations and intermodal transfer facilities in the project scope and the construction of long trenches and approach ramps to transition the vertical alignments of the rail corridor in and out of trenches.

Increasingly, Rail under Road projects also demand construction of new railway stations, modal interchanges and park and ride facilities, particularly in Melbourne where level crossing removal sites are often adjacent to railway stations. Such new public transport facilities trigger extensive additional redevelopment works to build new public transport infrastructure compliant with modern accessibility requirements and provide urban design outcomes that meet community expectations on accessibility and placemaking, particularly those stations in suburban town centres. The Victorian Government has recently acknowledged the ‘additional works’ required to improve public transport nodal infrastructure (stations, interchanges) along with enhanced urban design and amenity as part of grade separation projects has added approximately $1 billion dollars to the overall cost of its level crossing removal program (Willingham, 2016).

The ‘outlier’ Perth Citylink project was an exceptional project, taking place on the edge of the Perth CBD and involved sinking the Fremantle rail line, extending the Joondalup line tunnel, rebuilding the interfaces between the Fremantle and Joondalup lines and extensive upgrading, platform rearrangement and access improvements to Perth railway station. The $364 million cost of this project was a small component of a wider $1.3 billion urban renewal project to sink the railway below the surface, construct a deck over the top of the railway and redevelop 13.5 hectares of land on the western edge of Perth’s city centre (MRA, n.d.).

The five Rail-under-Rail grade separations ranged between $46 million and $265 million, with three being relatively high cost projects (at over $100 million each). All of these projects were built within the rail corridor and fall into three essential categories: improving separation between passenger from freight traffic on rail networks on suburban rail networks (at Flemington Junction, Goodwood Junction and North Strathfield Junction), the separation of the high capacity bulk coal railway from the interstate rail network (Sandgate Flyover) or provide a new, suburban rail route with a grade separated junction (Y-Link). The outlier project (North Strathfield Rail Underpass) cost over $265 million and involved ramping of the

Table 1: Road/Rail and Rail/Rail grade separations in Australia & New Zealand 1996-2016

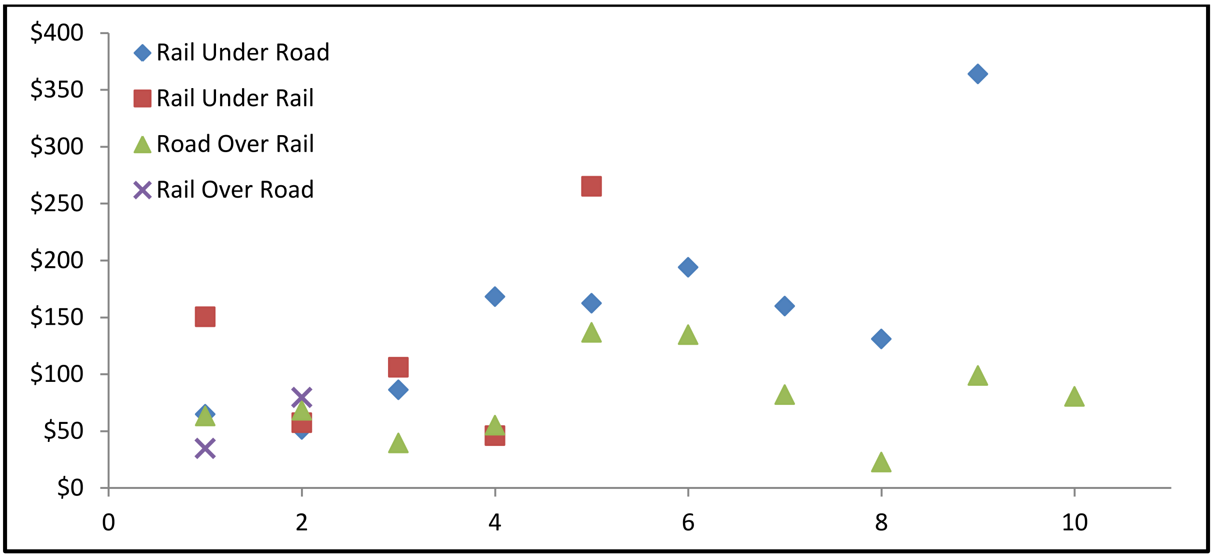
Year	Location	Type	City	Cost $ OTD	Cost $ 2016	Grade Seps	Length (km)	New Station
1996	Merrylands-Harris Park 'Y-Link'	Rail Under Rail	Sydney	$80.0	$150.5	1	1.6	-
1998	Subiaco, Perth	Rail Under Road	Perth	$35.0	$64.8	2	0.9	1
1998	Boronia & Dorset Rds Boronia	Rail Under Road	Melbourne	$28.0	$51.4	2	1.1	1
1999	Flemington Junction	Rail Under Rail	Sydney	$31.0	$57.4	1	0.6	-
2001	Westall Rd, Clayton	Road Over Rail	Melbourne	$37.0	$63.3	1	0.8	-
2006	Sandgate flyover	Rail Over Rail	Newcastle	$80.0	$106.1	1	0.9	-
2007	Taylors Rd, Keilor Downs	Road Over Rail	Melbourne	$54.0	$68.3	1	1.1	-
2007	Middleborough Rd, Laburnum	Rail Under Road	Melbourne	$66.0	$86.3	2	1.3	1
2007	Somerton Rd, Roxburgh Park	Road Over Rail	Melbourne	$34.0	$39.6	1	0.7	-
2008	Kororoit Rd, Altona	Road Over Rail	Melbourne	$48.5	$55.2	1	1.1	-
2009	Dynon-Port rail link	Road Over Rail	Melbourne	$116.0	$136.8	3	-	-
2009	Beaudesert Rd, Acacia Ridge	Rail Under Road	Brisbane	$114.0	$134.8	1	1.4	-
2009	Mawhinney St, Beerwah	Road Over Rail	Brisbane	$70.0	$82.1	1	1.2	-
2010	Daddow Rd, Kewdale	Road Over Rail	Perth	$19.8	$22.8	1	1.0	-
2010	New Lynn, Auckland	Rail Under Road	Auckland	$114.1	$168.2	2	1.0	1
2010	Springvale Rd, Nunawading	Rail Under Road	Melbourne	$140.0	$162.4	1	0.8	1
2010	South Road Tram Overpass	Rail Over Road	Adelaide	$30.0	$34.8	1	0.6	1
2013	CityLink, Perth	Rail Under Road	Perth	$360.0	$364.4	0	1.3	-
2013	Goodwood Junction	Rail Under Rail	Adelaide	$45.0	$46.0	1	0.6	-
2014	Robinson Rd, Geebung	Road Over Rail	Brisbane	$98.0	$98.9	1	1.0	-
2014	Telegraph Rd, Bracken Ridge	Road Over Rail	Brisbane	$80.4	$80.5	1	0.8	-
2014	Mitcham & Rooks Rd, Mitcham	Rail Under Road	Melbourne	$192.0	$194.0	2	1.3	1
2014	Springvale Rd, Springvale	Rail Under Road	Melbourne	$159.0	$159.9	1	1.0	1
2015	Lloyd St, Midland	Rail Over Road	Perth	$80.0	$79.6	1	0.6	-
2015	North Strathfield Junction	Rail Under Rail	Sydney	$264.0	$265.2	1	4.0	1
2016	Burke Rd, Glen Iris	Rail Under Road	Melbourne	$131.0	$131.0	1	0.8	1

rail corridor, a short section of driven tunnel, extensive new trackage and station reconstruction. As with Rail-under-Road projects, the range of costs is dependent upon each project's level of complexity, level of disruption and the amount of additional work for new or upgraded stations and track incorporated into the project scope.

Only two examples of ‘Rail over Road’ grade separations were identified in this process, costing between $34 million (South Road Tram Overpass) and $80 million (Lloyd St, Midland). The relatively low cost of these projects compared to other types of projects may be due to the engineering differences between light and heavy rail (South Road), their relatively easy constructability in existing corridors and reduced disruption to both road and rail traffic through shorter road and rail network closures and alternative road traffic routes.

A scatter plot showing the capital costs (in 2016 $ million) of each grade separation category in chronological order is shown in Table 2 below.

Table 2: Capital costs of grade separations by type in Australia and New Zealand 1996 - 2016



From Table 2, it is clear that there are a band of 12 relatively ‘simple’ grade separation projects (almost half the sample) across all formats in the sub-$100 million cost range, particularly Road-over-Rail, Rail-over-Road and less complex Rail-under-Rail projects.

Table 3 below shows the indicative range of costs for each of the four types of grade separations based on the Table 1 dataset, with the median cost for each type shown. For the purposes of road/rail grade separations, Table 3 clearly shows the lower average cost and lower range of costs for the Road over Rail or Rail over Road (elevated rail) alternative options compared to Rail under Road (entrenched rail) grade separation options.

Table 3: Typical capital cost range and median cost of grade separations in Australia and New Zealand 1996 - 2016

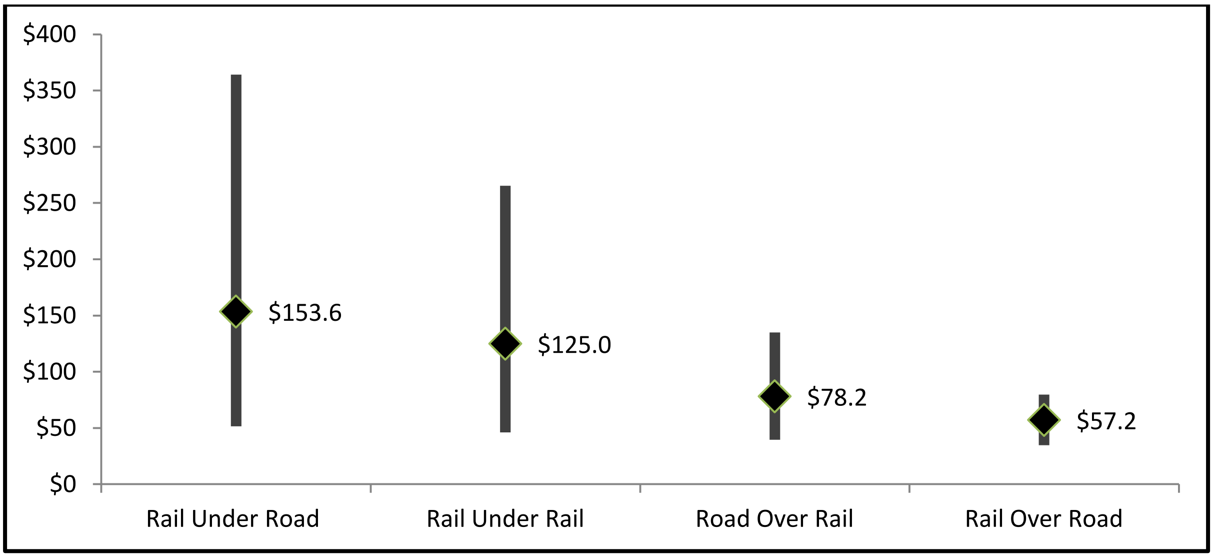


Table 4: Indicative capital cost data for elevated, trenched and tunnelled rail

Project Name	City	R-O-W	% Elevated	Date	Length (km)	Stations	Cost ($A OTD)	Cost (2016 $A PPI)	Cost/km (2016 $A PPI)
Airtrain	BNE	Elevated railway	100% elevated	2001	8.5	2	$220.0	$375.6	$44.2
Sydney Metro NW Skytrain	SYD	Elevated railway	100% elevated	2016	4.2	0*	$389.7	$394.5	$93.9
Rowville Line (Estimated)	MEL	Elevated railway	90% elevated / 10% trenched	2012	5.8	0*	$290.0	$301.8	$52.0
New Lynn trench	AKL	Entrenched railway	100% trenched	2010	1.0	1	$106.2	$119.4	$119.4
Beaudesert Rd Acacia Ridge Grade separation	BNE	Entrenched railway	100% trenched	2009	1.4	0	$114.0	$134.8	$96.3
Perth CityLink Fremantle line tunnel	PER	Tunnelled railway	100% tunnelled	2014	1.3	0	$335.0	$339.1	$260.8
Skytrain Expo Stage 1	YVR	Elevated railway	7% tunnelled / 93% elevated	1986	21.4	15	$917.8	$2,248.4	$105.1
Skytrain Expo Stage 2	YVR	Elevated railway	100% elevated	1990	3.1	3	$196.3	$369.4	$119.2
Skytrain Expo Stage 3	YVR	Elevated railway	100% elevated	1994	4.4	2	$149.5	$288.6	$65.6
Skytrain Millenium Line	YVR	Elevated railway	5% tunnel / 6% trench / 89% elevated	2002	20.5	11	$1,367.0	$2,136.2	$104.2
Skytrain Canada Line	YVR	Elevated railway	48% tunnelled / 52% elevated	2009	19.2	16	$1,671.5	$1,827.5	$95.2
Skytrain Evergreen Line	YVR	Elevated railway	82% elevated / 18% tunnelled	2013	11.0	6	$889.0	$910.6	$82.78
South Morang rail extension	MEL	Entrenched railway	100% trenched	2012	3.5	2	$261.0	$274.8	$78.5
Epping-Chatswood Railway Line	SYD	Tunnelled railway	100% tunnelled	2009	12.5	5	$2,350.0	$2,770.5	$221.6
Sydney Airport Rail Link	SYD	Tunnelled railway	100% tunnelled	2000	10.0	0*	$762.0	$1,335.1	$133.5
Perth-Mandurah Railway 'Package F'	PER	Tunnelled railway	100% tunnelled	2007	2.2	2	$398.1	$520.8	$236.7
Sydney Metro NW Tunnel contract	SYD	Tunnelled railway	100% tunnelled	2016	15.5	5*	$1,150.0	$1,183.0	$76.3
Mitcham & Rooks Road Grade separation	MEL	Entrenched railway	100% trenched	2014	1.6	1	$192.0	$195.3	$122.0
Bangkok Skytrain	BKK	Elevated railway	100% elevated	1999	23.1	23	$1,038.8	$1,742.9	$75.4
Alameda mid-corridor trench	LAX	Entrenched railway	100% trenched	2002	16.0	0	$518.4	$905.9	$56.6
Caulfield – Dandenong corridor (Estimated.)	MEL	Elevated railway	43% elevated / 5% trenched / 52% surface	2018*	19.4	5	$1,600.0	$1,600.0	$82.5

5. Elevated, trenched and tunnelled rail

This next section deals with capital cost data for elevated, trenched and tunnelled railway lines, as there has been relatively little research into the capital cost differences of all options in an Australasian context. Some international knowledge of the capital cost differences for each approach exists, particularly the work of Flyvbjerg, Bruzelius & Van Wee (2008) on capital costs for international urban rail projects, but generally knowledge on capital costs in Australasian conditions is relatively thin, apart from the work of this paper's secondary author (Martin 2011, 2012a) and work done as part of inquiries for the Productivity Commission and Parliamentary Committee reports in NSW and Victoria.

5.1. Capital cost data for elevated, trenched & tunnelled rail

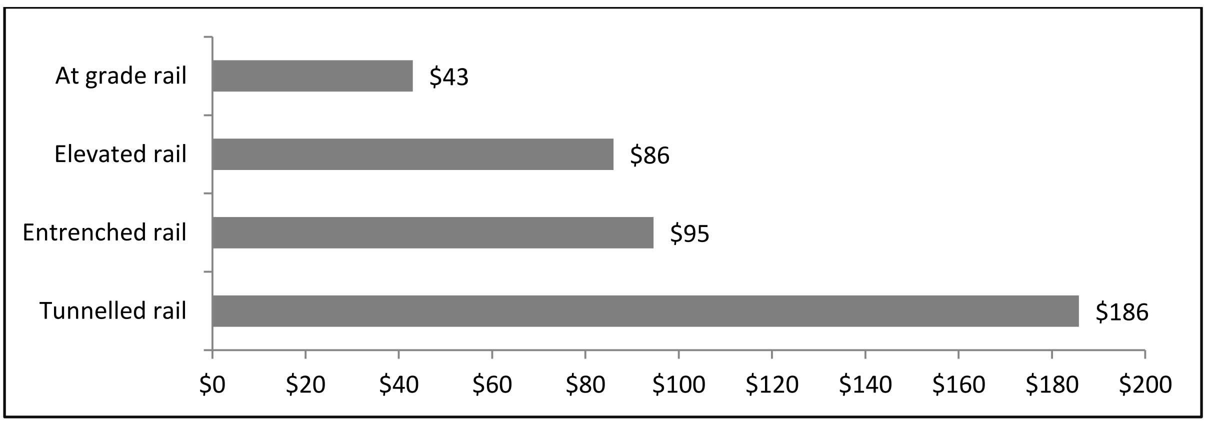
The lack of capital cost estimation data for elevated and entrenched rail options in Australia and New Zealand is a serious gap for policy makers and transport planners. It is telling, that the key document providing guidance on economic appraisal and modelling of transport projects (*National Guidelines for Transport System Management in Australia*) contains only per-kilometre cost estimates for at grade and tunnelled alignments, with no estimates for entrenched or elevated right-of-way options in its list of indicative costs (ATC 2006: 43).

A capital cost dataset for elevated, trenched and tunnelled rail construction is shown at Table 4 below. The small group of actual and proposed Australian rail projects were augmented with global examples (Vancouver, Bangkok). For trenched rail, international data (LA's Alameda trench) was augmented with data from grade separations in Australia and New Zealand cities where trench lengths longer than one kilometre were constructed.

Based on the capital cost estimates from Table 4 above, indicative per-kilometre capital cost estimates for each construction type (at-grade, elevated, entrenched and tunnelled) of heavy rail construction were estimated and shown in Table 5 below. Estimates of the capital costs of at-grade and tunnelled rail use median indicative costs quoted by the Australian Transport Council (ATC) escalated to 2016 dollars and sensitivity tested against the secondary author's dataset of actual construction costs in 2016 dollars (Martin 2012a). Estimates of median elevated and tunnelled rail costs in Table 5 use figures developed from Table 4.

In Table 5, indicative capital cost ratios from elevated and entrenched rail show that both construction types cost approximately twice as much as at-grade, with ratios of 2:1 and 2.2:1 respectively, with tunnelled rail at 4.3:1. Differences in cost ratios between right-of-way types are close to those cited in Flyvbjerg et al (2008: 25), of elevated rail at 2-2.5:1 and tunnelled rail at 4-6:1. The surprising discovery in Table 5 was the slightly higher capital cost ratio (10%) for entrenched rail (2.2:1) over (2:1). The authors offer that higher costs of infrastructure relocation and transport network disruption encountered in entrenched construction may account for the 10 percent construction cost premium.

Table 5: Indicative median per-kilometre cost of rail construction types (2016 $A)



6. Concluding discussion

In this paper, we have shown that elevated rail has a small per-kilometre capital cost advantage (around 10%) relative to entrenched rail, based on thorough examination of capital cost data for rail construction in a range of rights-of-way. The authors also contend that along with this slight advantage in construction cost, elevated rail has many of the benefits of the most expensive tunnelling options.

Analysis of projects shows the relative novelty of elevated rail construction in an Australian context (with only two new-build examples in the past 15 years) means the ability of transport policy makers to properly evaluate elevated rail in comparison to other methods has not yet caught up with engineering decisions to proceed on elevated rail construction in Melbourne and Sydney. Of particular concern is that the current revision of the 2005 ATC Guidelines does not appear to have taken account of elevated and entrenched rail rights of way into account for its costing guidelines, with existing arrangements still in use.

In addition, we have yet to see an updated list of level crossing removal priorities for Melbourne that adequately addresses the policy implications of the recent body of research in this area. The current list of 50 removals taken to the last Victorian state election has so far seen one amendment: one additional crossing removal at Cheltenham due to proximity to the one already mandated for removal. The list of 50 only bears a passing resemblance to the ALCAM safety rankings, it lacks strong alignment with rankings for high modal interchange locations (Woodcock & Stone 2015) and is disconnected from many corridors and places identified for urban renewal. The next 50 grade separations should be prioritised to create conditions for enhanced tram and bus priority and rail service frequencies.

Elevated rail's benefits derive from two main sources. Firstly, it is less disruptive to services and utilities in construction and can be built over a live rail environment, reducing network disruption. This advantage is where most of the cost savings associated with construction are claimed to lie. Secondly, elevated rail releases land in the rail corridor formerly occupied by tracks. The third, and main benefit is the potential for incorporating a wide range of ground level land uses, including retaining heritage structures and creating new public open spaces to better integrate stations and the railway corridor into the surrounding natural and built environment, while enhancing local movement networks and access to public transport.

In these discussions of costs and benefits, it has been shown that the exercise to determine costs and benefits needs to be recalibrated and incorporate new thinking about how to value a wide range of benefits going beyond differences in construction costs. An additional aspect that also needs consideration is the political dimension of focusing solely on costs alone. The perception that elevated rail is less expensive than other options has allowed opponents to characterise it as 'cheap and nasty'. In mature suburban environments of Australian cities where aesthetic notions of neighbourhood character have driven planning and politics for at least three decades, this can be a powerful refrain. There is a risk that the benefits of elevated rail could be foregone if the intestinal fortitude to ensure these benefits are fully realised is lacking among the political class and the bureaucracy.

The major potential negatives hinge on how well elevated rail is executed, ensuring that design and construction of the infrastructure is as good as it can possibly be. Stations must have full-weather protection, universal access, and multiple entrances to paid areas, alongside the best possible transfer arrangements to other modes to make the most of the potential offered by elevated rail. Viaducts need to be imaginatively designed as they will become prominent parts of the urban landscape and the daily lives of people who pass over, under and around. Open spaces need to be managed by locally engaged and accountable groups with a strong sense of ownership. Where deemed necessary, noise attenuation barriers and privacy screens should be opportunities for creativity and individuality. In the final analysis, elevated rail done well provides the best potential for making the great public places that the best of public transport infrastructure around the world has fostered.

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