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Exploring How Rail Turnouts Impact Rail Replacement Outcomes

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Abstract

This research paper explores the importance of turnout location on the provision of bus replacement services that are required during periods of service disruption on a railway network. Turnouts allow trains to be guided from one railway track to another, enabling trains to turn around at a point where services are cancelled. They adjoin railway stations that will inevitably serve as an intermediate termination or commencement location on a railway line and where bus replacement services are provided to and from. A theoretical modelling exercise was undertaken to determine the impacts of altering turnout location based on fixed unplanned service disruption assumptions on the Sandringham railway line, in Melbourne's suburban rail network. Attributes such as annual number of disruptions, level of commuter demand and volume of disruptions were assumed. Performance indicators including turnout cost, bus bridging costs and commuter disruption costs were assessed for each option.

Results indicate that turnout location plays a significant role on the design of bus replacement services and can be a cost effective means of reducing costs to both users and operators. Based on a cost/benefit analysis for three different turnout locations it was determined that a turnout located in close proximity to the service disruption location provides the best return on investment. Sensitivity analyses tested the number of disruptions per annum and the assumed level of commuter demand. This identified that a minimum of three service disruptions per annum were required to warrant the installation of a turnout at all three locations investigated. Only the preferred turnout location remained viable at lower demand levels.

The results have implications for both research and practice. Research in the area of bus replacement has been quite limited. Furthermore although turnout location has been highlighted as affecting service recovery in railway systems it has never been discussed purely in the context of bus replacement planning. Implications for future research and practice are identified.

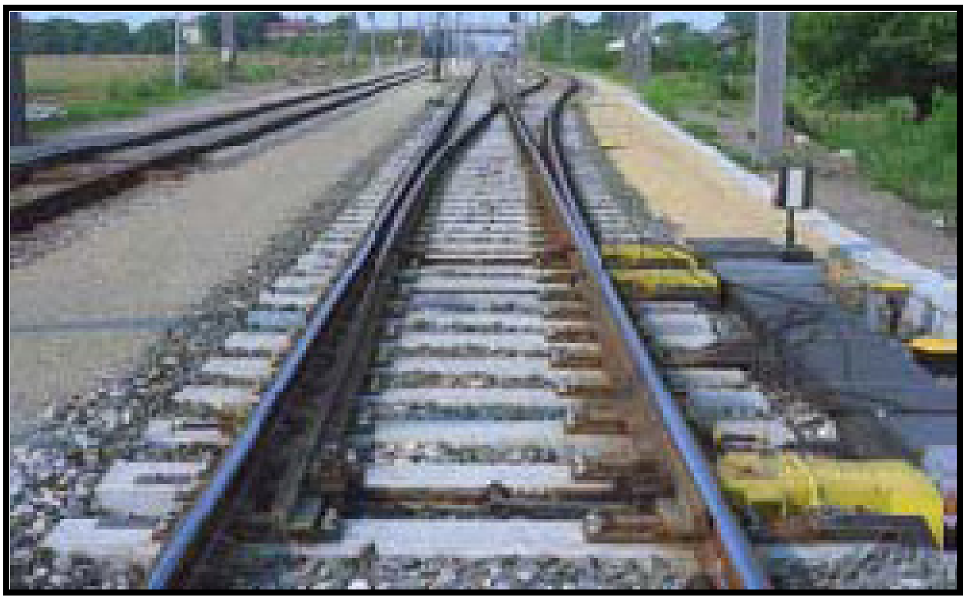
1. Introduction

Rail transit networks such as metros, commuter railways and regional railways provide superior performance compared with other transport alternatives, primarily due to increasing levels of road congestion (De-Los-Santos, Laporte et al. 2010). Unfortunately, unexpected operational disruption can lead to rapid degradation of the provided service levels (Kepaptsoglou and Karlaftis 2009). If a link fails in the road network, it is relatively straightforward to re-route traffic, but railway systems are not quite so simple. As a result, service disruptions in railway networks are normally addressed by the provision of alternative transportation modes such as buses, otherwise known as the bus replacement (termed bus bridging) problem (De-Los-Santos, Laporte et al. 2010)

Bus bridging, involves establishing short-term bus routes to restore connectivity between railway stations that have experienced some form of intervening service disruption. This could be as a result of planned activities such as track maintenance or unplanned activities such as network failure or some form of accident (Kepaptsoglou and Karlaftis 2009).

Although quite limited to date, academic literature pertaining to bus bridging has focussed primarily on the development of a decision support system for the bus bridging problem (Kepaptsoglou and Karlaftis 2009). Additionally Codina and Marin (2010) conducted an analysis of the performance of the bus bridging system and in particular modelled the resultant congestion. Ultimately turnout location impacts on the provision of bus bridging services and to date this has not been documented in the research literature. However, Schmocker et al. (2005) in a comparison of recovery strategies and constraints on managing incident delays in Metro systems note that the limited number and location of turnouts reduces service disruption responses, because it restricts the ability to return trains back in the direction from which they came. Figure 1 provides an illustration of a turnout.

Figure 1 – An Example of a Turnout (Esveld 2001)



This research paper aims to explore the importance of turnout location in providing solutions to the bus bridging problem. It identifies and evaluates the trade-offs for key performance indicators including turnout capital/installation costs, bus bridging service provision and commuter delay. A central focus is a theoretical modelling exercise in which different turnout locations were tested and this included a sensitivity analysis.

The paper commences with a summary of relevant research literature. The modelling methodology and approach are then described including all relevant assumptions. This is followed by an outline of the major results. Modelling the impacts of altering the annual number of disruptions as the basis of a sensitivity analysis is then explained and the results summarised. The paper concludes with a summary of key findings and a discussion of their implications for planning and practice. Future areas for research are then described.

2. Research context

When public transit services are disrupted, travel can be severely affected. In cases where no preparations are made, uncoordinated responses can leave the system in paralysis (Meyer and Belobaba 1982). Service disruptions can be either planned or unplanned (Silkunas 2006). Transit agencies should prepare contingency plans to deal with such disruptions, however, research suggests that transit agencies, have limited policies to govern the disruption of such operations (Janarthanan and Schneider 1984). Whilst the design of rapid transit systems provide them with superior performance (Vuchic 2005), their technological dependence can lead to major disruptions if a malfunction occurs. Any disruption in a train line segment can prohibit movement, since in most cases such lines cannot be detoured and locations for turnouts are limited. If a complete train is to pass from one track to another whilst moving, turnouts are essential (Esveld 2001).

Research on transit disruption is limited (Balog, Boyd et al. 2003). In a study, Heimann (1979) examined the availability of a railway system during an incident. Meyer and Belobaba (1982) investigated contingency planning during service interruption, stating that one key difficulty was motivating personnel to participate when there was no crisis. Janarthanan and Schneider (1984) proposed contingency plans by replacing train operations with buses. A key finding was that only 50 per cent of trips could be served by substitute buses. Evans and Morrison (1997) extended conventional economic models for public transport to incorporate measures to reduce disruption and non-scheduled delay. In work by Silkunas (2006), it was discovered that few transit agencies have sufficient policies to deal with disruptions.

Following a disruption, establishing alternative transportation is paramount to ensure network credibility (Kepaptsoglou and Karlaftis 2009). This includes diverting travellers to other operating lines and bridging stations using buses (Boyd, Maier et al. 1998). Rerouting of passengers is dependent on the network topology as well as the disruption extent. The disruption duration impacts the decision for bridging stations. If the disruption is expected to be minimal, service restoration may need less time. Bus bridging can be deployed subject to available buses and drivers and the road network (Kepaptsoglou and Karlaftis 2009).

Bus bridging involves planning new bus routes. Route layouts connecting stations are designed, their frequencies determined and, buses and drivers assigned (Ceder 2003). Demand patterns and flows between stations at the time of the disruption will dictate bus bridges, whilst resource availability, route and service constraints will dictate the substitute bus network's supply and performance capabilities. Authorities need to dispatch available buses quickly, as minimising response time is critical for substitute service quality. If buses are not available, buses may be retracted from existing routes (Kepaptsoglou and Karlaftis 2009). The capacity of replacement buses will be less than the disrupted demand so it is expected that bridging services will operate at congestion (Codina and Marin 2010).

A substitute service should focus on increased passenger satisfaction, whilst maximising supply and performance at the expense of operating costs (Kepaptsoglou and Karlaftis 2009). This is a common process adopted by transport authorities internationally, however, its application is determined on a case by case basis (Janarthanan and Schneider 1984).

3. Case Study

The case study concerns the Sandringham Line in Melbourne, Australia. Metro Trains' are responsible for the operation of Melbourne's suburban railway network. Melbourne's metropolitan train network operates 150 six-carriage trains across 830 kilometres of track. The train fleet covers more than 30 million kilometres per year servicing more than 200 million customer journeys. The Metro train network has 15 lines, 212 train stations and a workforce of 3,700 (MetroTrains 2010).

In designing bus bridging for planned disruptions, every attempt is made to maximise the number of projects (i.e. track upgrades) and maintenance that are carried out simultaneously on a section of track. This is done to reduce the number of service disruptions required. Sections of track are defined by what is manageable in respect to the provision of rail replacement services e.g. space for loading of replacement bus services etc. and by the location of turnouts. Ultimately trains need the ability to switch tracks and return to the termini from which they came. Metro Trains has divided their suburban train network into four i.e. north, east, south and west and then contracted these areas out to bus companies by tender for the provision of rail replacement services. One of the requirements for these contracted companies is that in the case of unplanned disruptions they must provide five buses within 20 minutes of a disruption as a reserve standard (MetroTrains 2010).

In this paper the train line investigated was the Sandringham train line which is part of the Melbourne suburban railway network and operates in south-eastern Melbourne (Figure 2). Currently on this train line there is one operational turnout which is located just south of Elsternwick railway station. As a result during service disruptions between Elsternwick and the terminus at Sandringham, Elsternwick is a key interchange point between the operational part of the train network and the substitute bus service. Please note there are operational turnouts at the termini although they are not of relevance in this paper. There is an additional turnout just north of Brighton Beach railway station but it is not operational.

Figure 2 – Map of Sandringham Railway Line highlighting Existing Turnout Location

Source: (Metlink Melbourne 2011)

4. Modelling Methodology

4.1. Modelling Aim

The modelling aims to assess the performance of alternative turnout locations on the outcomes of bus bridging. The following key performance measures to be assessed for each alternate turnout location based on a given disruption are:

- Cost of turnout installation;
- Cost of the provision of bus bridging services; and
- Cost to the commuter incorporating delay in substitute service commencement and additional travel time.

4.2. Modelling Methodology

In assessing the associated impacts a cost/benefit evaluative approach is adopted for each turnout location. The Cost of providing a turnout is based on information from the local regulatory authority (Department of Transport (Victoria) 2011). These values are as follows

- Capital Costs – AUD $250,000 (2011); and
- Installation – AUD $750,000 (2011).

The Cost of Bus Bridging Services were based on current bus industry standards in regards to the hire of buses for the purposes of bus bridging (Victorian Bus Industry 2011). For weekday unplanned disruptions, this was defined as(AUD) $125.00 per hour.

The following formula calculates bus bridging costs between given station pairs:

$$OpCost_{ij} = \lfloor (u * BT_{ij}) + AT] * NBus \qquad \text{Formula 1}$$

Where:

$OpCost_{ij}$ = Operator Costs of Bus Bridging between Station i to Station j
u = Unit cost per bus minute of bus replacement services
BT_{ij} = Bus travel time in minutes between Station i to Station j
AT = Access time for bus replacement buses to access station from first rail failure (assumed to be 20 mins in this case and fixed for each turnout location)
nBus = Number of buses required to match rail capacity based on relative capacity

Since AT, the timing of replacement buses arriving at the first station, is a constant in all options, this is excluded from the analysis. Inter-station travel times are shown in Table 1. The train travel times were based on the public timetable (Metlink Melbourne 2011) whilst the bus travel times were provided by the bus companies currently responsible for the provision of these bus bridging services (Victorian Bus Industry 2011).

The costs to commuters are based on travel time delays associated with bus versus rail for travel between station pairs. These are calculated for each station pair as follows:

$$UCost_{ij} = (VOT * (BT_{ij} - RT_{ij})) + AT \qquad \text{Formula 2}$$

Where:

$UCost_{ij}$ = User Costs of Bus Bridging between Station i to Station j

VOT = Unit User Value of Time cost per minute. A Value of \$20.20/hr is based on current values in Australia (Australian Transport Council 2006)

BT_{ij} = Bus travel time in minutes between Station i to Station j

RT_{ij} = Rail travel time in minutes between Station i to Station j

AT =Access time for bus replacement buses to access station from first rail failure (assumed to be 20 mins in this case and fixed for each turnout location)

Since AT, the timing of replacement buses arriving at the first station, is constant in all options, and this only affects passengers on the first disrupted train, once again this value is excluded from further analysis.

Modelling focussed on the PM weekday peak period between 3:00pm and 7:00pm. This time period was chosen given that this is when available bus resources are at their lowest and commuter demand is at its highest. Furthermore a four-hour time window was selected to not only account for the PM peak period but additionally because this is a bus industry standard in respect to minimum hire requirements (Victorian Bus Industry 2011). During this time period the frequency of train service in each direction was ten minutes; therefore were a total of 24 trains (Metlink Melbourne 2011). The train line is operated by Siemens trains with a crush passenger capacity of 1,584 passengers (MetroTrains 2011).

Travel demand assumed a fixed matrix of travel as shown in Table 1. Outbound direction (peak) flow is assumed to be at crush passenger capacity upon departure from Richmond railway station. Given that there are twelve railway stations between Richmond and including the terminus at Sandringham railway station it is assumed that one-twelfth of the commuters disembark at each station. Furthermore it is assumed that there are no further commuter boardings after Richmond. The level of patronage demand for the inbound direction (counter-peak flow) is assumed to be at twenty per cent of the crush passenger capacity upon arrival at Richmond. One-twelfth of this amount is assumed to board at Sandringham and similarly at every station between Sandringham and Richmond. Furthermore it is assumed that no commuters disembark between these two locations.

Four unplanned **service disruptions** per annum are initially assumed. The disruption location was fixed and occurred between Hampton and Sandringham; the last two stations.

The **bus bridging services** are provided by two-door low-floor route buses (Model: Volvo B7RLE) with a total capacity of 73 commuters (Victorian Bus Industry 2011). The buses required for the outbound direction are based on the equivalent relative capacity of bus versus rail. A five minute bus recovery time was allowed prior to the beginning and upon the conclusion of the bus bridging trip. This allows for passenger boardings and disembarking and to provide the driver with a break (Victorian Bus Industry 2011).

Table 1 – Inter-Station Estimated Demand Profile and Travel Times (Bus and Train)

To	Elsternwick			Gardenvale			North Brighton			Middle Brighton			Brighton Beach			Hampton			Sandringham		
From	**Pax No.**	**Train Time**	**Bus Time**	**Pax No.**	**Train Time**	**Bus Time**	**Pax No.**	**Train Time**	**Bus Time**	**Pax No.**	**Train Time**	**Bus Time**	**Pax No.**	**Train Time**	**Bus Time**	**Pax No.**	**Train Time**	**Bus Time**	**Pax No.**	**Train Time**	**Bus Time**
Elsternwick				*792*	*2*	*15*	*660*	*4*	*18*	*528*	*6*	*21*	*396*	*8*	*24*	*264*	*11*	*27*	*192*	*14*	*30*
Gardenvale	158	2	15				*660*	*2*	*3*	*528*	*4*	*6*	*396*	*6*	*9*	*264*	*9*	*12*	*192*	*12*	*15*
North Brighton	158	3	18	132	1	3				*528*	*2*	*3*	*396*	*4*	*6*	*264*	*7*	*9*	*192*	*10*	*12*
Middle Brighton	158	5	21	132	3	6	106	2	3				*396*	*2*	*3*	*264*	*5*	*6*	*192*	*8*	*9*
Brighton Beach	158	7	24	132	5	9	106	4	6	79	2	3				*264*	*3*	*3*	*192*	*6*	*6*
Hampton	158	10	27	132	8	12	106	7	9	79	5	6	53	3	3				*132*	*3*	*3*
Sandringham	158	12	30	132	10	15	106	9	12	79	7	9	53	5	6	26	2	3			

Note: Values are calculated for the PM peak. Values in italics are in the peak direction (outbound) and non-italic are in the counter-peak direction (inbound)

4.3. Modelling Scenarios

The base case is reflective of current operating requirements with a turnout at Elsternwick railway station. In this case, a service disruption as assumed would result in buses replacing the train between Elsternwick and Sandringham. The other three scenarios are as follows:

- **Scenario One:** Addition of a Turnout at North Brighton railway station;
- **Scenario Two:** Addition of a Turnout at Brighton Beach railway station; and
- **Scenario Three:** Addition of a Turnout at Hampton railway station.

Figure 3 illustrates the locations of the turnouts tested on the Sandringham railway line.

The cost of providing the replacement bus service in each scenario was determined based on the number of buses required and the cost of bus hire (Formula 1). The number of buses required was computed using the assumed level of patronage demand and the overall bus travel time to complete one full loop service i.e. for the base case from Elsternwick railway station to Sandringham railway station and return taking into account the recovery times.

Similarly the overall cost to the commuter was computed for each scenario based on the costs associated with the time delay prior to the commencement of the bus bridging service and the additional travel time associated with this service (Formula 2).

The turnout cost was only considered for scenarios one, two and three as in the base case there is already a turnout in operation. These costs were in accordance with the unit costs identified above. Ongoing maintenance costs for turnouts were not considered given that turnout maintenance is done concurrently with adjoining track maintenance so in this modelling exercise it was negligible (Department of Transport (Victoria) 2011).

4.4. Evaluation Approach

For an assumed project life span of 30 years a cost/benefit analysis is undertaken for the base case and the three scenarios. The Net Present Values (NPV) for both the costs and the benefits are determined assuming a discount rate of 6 percent[1]. From this the Net Present Worth (NPW) is then calculated as follows.

$$\mathbf{NPW_{Scenario\ X} = NPV_{Benefits} - NPV_{Costs}} \qquad \textbf{Formula 3}$$

$$\mathbf{NPV_{Benefits} = NPV\ (\Delta\ Commuter\ Costs_{(Scenario\ X - Base\ Case)})} \qquad \textbf{Formula 4}$$

$$\mathbf{NPV_{Costs} = NPV\ (Turnout\ Cost + \Delta\ Bus\ Bridging\ Costs_{(Scenario\ X - Base\ Case)})}$$

Formula 5

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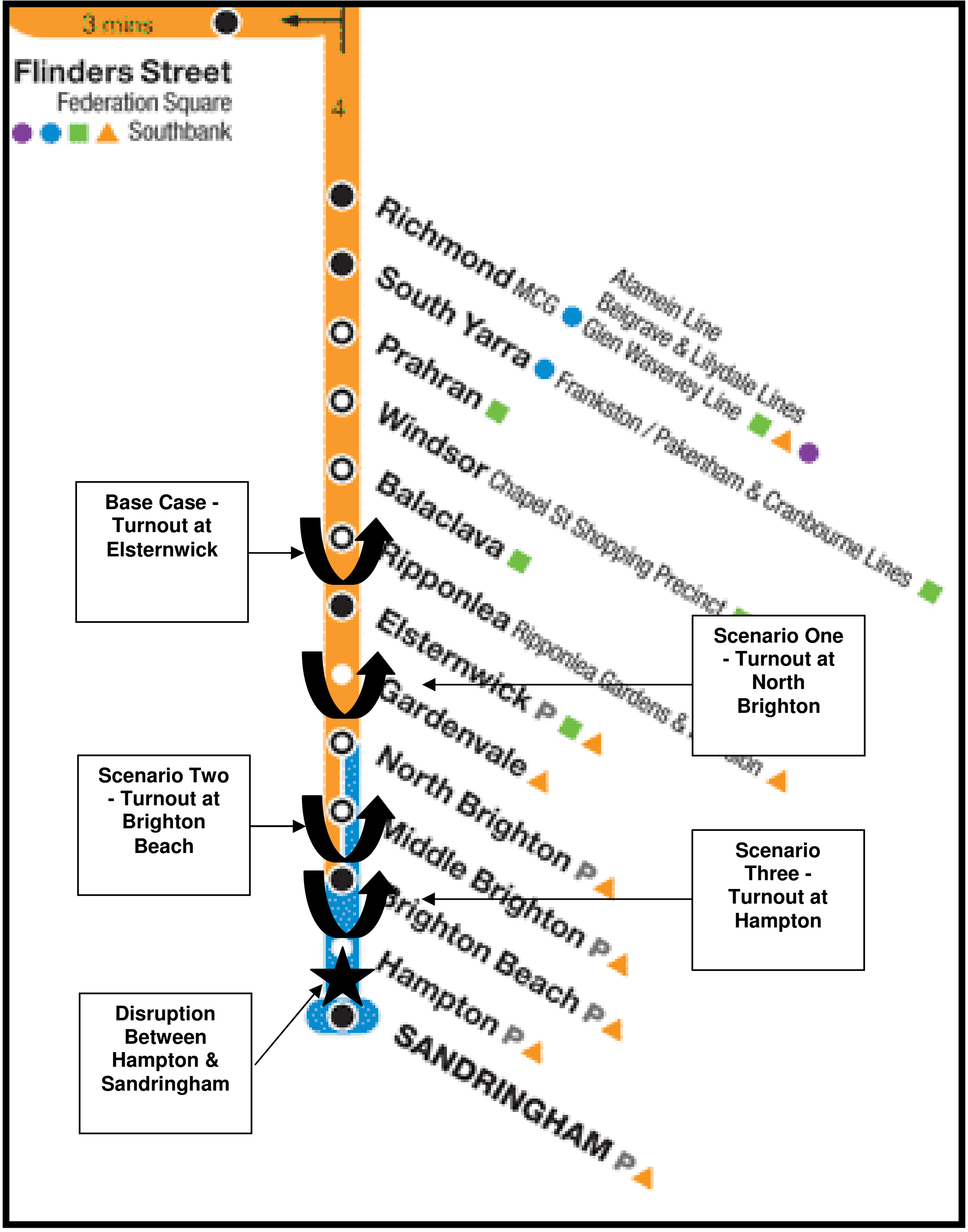
[1] Discount rates of 2, 4 and 8% were also trialled in this research. Although the magnitude of Net Present Worth for each alternative varied (i.e. lower discount rates resulted in higher values of Net Present Worth), Scenario Three remained the preferred alternative in all cases. Similarly with the exception of the base case for all discount rates positive values of Net Present Worth were experienced for all scenarios. Given these outcomes this sensitivity analysis was not included in the results section of this paper.

In the base case scenario the costs relate purely to the cost of the bus bridging services as there are no turnout costs. In line with Formula 5 in the other three scenarios the costs will take into account the turnout costs and also the difference in bus bridging costs between the base case and the respective scenario. In the base case scenario there will be no benefits. However, in the remaining three scenarios the benefits relate to the reduction in commuter costs of the relevant scenario and the base case. This is represented in Formula 4.

Figure 3 – Map of Sandringham Railway Line highlighted Proposed Turnout Locations and Location of Service Disruption



Source: (Metlink Melbourne 2011)

5. Modelling Results

5.1. Bus Bridging Costs (Bus Hire)

The bus bridging costs illustrating the number of buses required in each scenario for each incident is highlighted in Table 2

Table 2 – Bus Bridging Costs

Buses	Base Case	Scenario One	Scenario Two	Scenario Three
Number Required	88	32	16	6
Hire Costs	$44,000	$16,000	$8,000	$3,000
Net Cost	-	-$28, 000	-$36,000	-$41,000

Negative costs in this context represent the reduction in bus hire costs under scenarios one to three compared to the base case. Locating turnouts closer to the actual disruption reduces the cost of bus hire for the provision of the bus bridging services. There is a still a cost to the railway companies for the provision of bus bridging services but this amount is lower than in the base case. Although negative cost could imply a benefit it is important to distinguish in this context that it refers to a reduction in cost compared to the base case.

5.2. Commuter Impacts

Tables 3 and 4 illustrate the number of affected commuters, the subsequent additional travel time and the resultant cost incorporating the associated cost delay whilst waiting for the commencement of the substitute service. This is calculated for the base case and scenarios one, two and three and takes into account commuter travel in both directions.

Table 3 – Commuter Costs (Outbound)

Affected Passengers Destination	Base Case (Turnout @ Elsternwick)			Scenario One – Turnout @ North Brighton			Scenario Two – Turnout @ Brighton Beach			Scenario Three – Turnout @ Hampton		
	Pax No.	Extra Time	Cost	Pax No.	Extra Time	Cost	Pax No.	Extra Time	Cost	Pax No.	Extra Time	Cost
Gardenvale	132	18	$879	132	0	-	132	0	-	132	0	-
North Brighton	132	19	$928	132	0	-	132	0	-	132	0	-
Middle Brighton	132	20	$977	132	6	$293	132	0	-	132	0	-
Brighton Beach	132	21	$1,026	132	7	$342	132	0	-	132	0	-
Hampton	132	21	$1,026	132	7	$342	132	5	$244	132	0	-
Sandringham	132	21	$1,026	132	7	$342	132	5	$244	132	5	$244
Total Commuter Cost			**$5,861**			**$1,319**			**$488**			**$244**
Net Benefit			**-**			**$4,542**			**$5,373**			**$5,617**

Table 4 – Commuter Costs (Inbound)

Affected Passengers Origin	Base Case – (Turnout @ Elsternwick)			Scenario One – Turnout @ North Brighton			Scenario Two – Turnout @ Brighton Beach			Scenario Three – Turnout @ Hampton		
	Pax No.	Extra Time	Cost	Pax No.	Extra Time	Cost	Pax No.	Extra Time	Cost	Pax No.	Extra Time	Cost
Sandringham	26	23	$225	26	8	$78	26	6	$59	26	6	$59
Hampton	26	22	$215	26	7	$68	26	5	$49	26	0	-
Brighton Beach	26	22	$215	26	7	$68	26	0	-	26	0	-
Middle Brighton	26	21	$205	26	6	$59	26	0	-	26	0	-
North Brighton	26	20	$195	26	0	-	26	0	-	26	0	-
Gardenvale	26	18	$176	26	0	-	26	0	-	26	0	-
Total Commuter Cost			**$1,231**			**$273**			**$108**			**$59**
Net Benefit			**-**			**$958**			**$1,123**			**$1,172**

5.3. Cost/Benefit Analysis

Table 5 provides an illustration of how the economic evaluation was conducted for the proposed 30-year project life cycle using Scenario One. This shows how each of the costs and benefits contributed to the results obtained in the cost/benefit analysis.

The net rail replacement costs and benefits for each year of the project life cycle represent the annual figures for each given financial year discounted back to the current year i.e. the financial year commencing July 2012. This was done by applying the assumed discount rate of 6% mentioned in section 4.4. The figures provided in the last row of Table 5 represent the total of all discounted net costs and benefits, i.e. the Net Present Value (NPV).

Table 6 highlights the results of the economic evaluation in which the NPW was determined for the base case scenario in comparison to scenarios one, two and three. The NPV for costs was determined by adding the NPV capital costs plus the NPV rail replacement costs. The NPV benefits were the net benefits.

Table 5 – An Example of Economic Evaluation (Scenario One)

Financial Year	Year Number	Capital Costs	Replacement Costs	Benefits
2012	0	$1,000,000	-$112,000	$21,998
2013	1	-	-$105,660	$20,752
2014	2	-	-$99,680	$19,578
2015	3	-	-$94,037	$18,470
2016	4	-	-$88,714	$17,424
2017	5	-	-$83,693	$16,438
2018	6	-	-$78,956	$15,507
2019	7	-	-$74,486	$14,630
2020	8	-	-$70,270	$13,802
2021	9	-	-$66,293	$13,020
2022	10	-	-$62,540	$12,283
2023	11	-	-$59,000	$11,588
2024	12	-	-$55,661	$10,932
2025	13	-	-$52,510	$10,313
2026	14	-	-$49,538	$9,730
2027	15	-	-$46,734	$9,179
2028	16	-	-$44,088	$8,659
2029	17	-	-$41,593	$8,169
2030	18	-	-$39,239	$7,707
2031	19	-	-$37,017	$7,270
2032	20	-	-$34,922	$6,859
2033	21	-	-$32,945	$6,471
2034	22	-	-$31,081	$6,104
2035	23	-	-$29,321	$5,759
2036	24	-	-$27,662	$5,433
2037	25	-	-$26,096	$5,125
2038	26	-	-$24,619	$4,835
2039	27	-	-$23,225	$4,562
2040	28	-	-$21,911	$4,303
2041	29	-	-$20,670	$4,060
2042	30	-	-$19,500	$3,830
NPV Totals		**$1,000,000**	**-$1,653,661**	**$324,790**

Table 6 – Summary of Economic Evaluation

Alternative	NPV Costs	NPV Benefits	NPW
Scenario One	-$653,661	$324,790	**$978,451**
Scenario Two	-$1,126,136	$383,633	**$1,509,769**
Scenario Three	-$1,421,432	$400,940	**$1,822,372**

The results illustrate that Scenario Three is the best alternative (i.e. turnout located at Hampton railway station). This is logical given that the location of the service disruption is in close proximity to the station. However, all three scenarios produced positive values of NPW thus justifying their viability from an economic perspective. This is further substantiated by the fact that in all three scenarios the costs were negative, that is, their30-year lifespan cost is lower than the base-case scenario.

6. Sensitivity Analysis

Sensitivity analysis was undertaken to test the impact of altering key modelling assumptions. This including variation in:

- The assumed number of disruptions; and
- The level of commuter demand.

6.1. Disruption Frequency Test

Table 7 shows the results of the economic evaluations for the three scenarios tests for the following five tests of frequency of annual service disruptions:

- One disruption per annum;
- Two disruptions per annum;
- Three disruptions per annum;
- Five disruptions per annum; and
- Ten disruptions per annum.

(Note that four disruptions per annum were tested in the main analysis)

Table 7 – Summary of Economic Evaluation – Disruption Frequency Test

Alternative	One Disruption Per Annum		Two Disruptions Per Annum		Three Disruptions Per Annum		Five Disruptions Per Annum		Ten Disruptions Per Annum	
	NPW	% Change to Base Case	NPW	% Change to Base Case	NPW	% Change to Base Case	NPW	% Change to Base Case	NPW	% Change to Base Case
Scenario One	-$470,774	-152%	-$10,775	-101%	$483,838	-51%	$1,473,064	51%	$3,946,127	303%
Scenario Two	-$372,558	-125%	$254,884	-83%	$882,326	-42%	$2,137,211	42%	$5,274,421	249%
Scenario Three	-$294,407	-116%	$411,186	-77%	$1,116,779	-39%	$2,527,965	39%	$6,055,930	232%

Table 8 – Summary of Economic Evaluation – Demand Volume (Off Peak) Test

Alternative	Peak Disruption NPW (Base)	Off Peak Disruption NPW	% Change to Base (Peak)
Scenario One	$978,451	-$301,143	-127%
Scenario Two	$1,509,769	-$163,410	-109%
Scenario Three	$1,822,372	-$9,993	-100%

The results of the sensitivity analysis indicate that the viability of additional turnout location improves based on the increased likelihood of a service disruption. Furthermore at least three unplanned service disruptions are required for a positive outcome to result. If there is only one disruption per annum adding a new turnout is not viable. Whilst if there are only two disruptions adding a new turnout is only not viable at North Brighton railway station (i.e. Scenario 1). Regardless of the volume of disruptions, Scenario 3 remains the preferred option; turnout locations adjacent to the site of service disruptions remain the preferred location.

6.2. Commuter Volume Test

The main evaluation was based on the PM peak including peak passenger volumes. A sensitivity test of lower demand and off peak services was also tested as a sensitivity test. Off peak demand was based on 528 commuters per train (MetroTrains 2011) and services were assessed between 09:00am and 3:00pm on weekdays. All other assumptions in the main case were adopted (e.g. the number of annual disruptions was fixed at four and these occur between Hampton and Sandringham railway stations).

Table 8 illustrates the results of the economic evaluation for this sensitivity analysis. The results show that:

- All three scenarios had negative results although the result was only marginal in the case of Scenario 3.
- Overall project worth is 100% less for Scenario 3 than in the peak.

Overall the findings of these tests suggest there is a threshold of demand volume and of service disruption frequency beyond which investment in rail turnouts is warranted. However, this threshold varies according to turnout location.

7. Discussion and Conclusions

This research paper has explored the importance of turnout location in providing solutions to the bus bridging problem. The bus bridging problem is a relatively recent addition to academic research agenda and although turnouts have been referenced as impacting service recovery possibilities in railway networks they have never been discussed in the context of bus bridging. This paper has investigated the significance of rail turnouts by conducting a theoretical modelling exercise in which alternative locations for turnouts were modelled for the Sandringham railway line in Melbourne. Currently there is only one operational turnout on this railway line (not including termini) and this exercise trialled three alternative locations based on a fixed service disruption location.

The results suggest a strong economic performance for adding turnout locations based on a reasonable set of assumptions about cost and the scale of peak service disruption. This suggests that, as long as the physical and operational constraints regarding the provision of rail turnouts are considered, investment in new turnouts should have positive impacts on bus bridging. The fact that the Net Present Values for costs are negative reflect the reduction in life-cycle investment required in comparison to the base case. These results demonstrated a strong preference for locating turnouts near major disruption locations.

Two sensitivity tests examined alternative frequency of service disruptions and the impact of lower (off peak) demand levels. These established that the viability of additional turnout location improves based on the increased likelihood of a service disruptions and the volume of ridership. However, there is a threshold for both variables below which adding turnouts is no longer viable. At least three unplanned service disruptions are required for a positive outcome to result in these tests whilst all three scenarios were no longer viable in the off peak demand test. This was only marginally the case for Scenario 3. Regardless of the volume of disruptions or demand, Scenario 3 remains the preferred option; turnout locations adjacent to the site of service disruptions remain the preferred location.

Although these results demonstrate the importance of turnout location in obtaining solutions to the bus bridging problem ideally a more detailed and realistic set of data is required to truly test the relationship. At the time this analysis was conducted, data relating to patronage levels and unplanned service disruptions were unable to be obtained. Ultimately unplanned service disruptions are probabilistic events in respect to number, timing and location. This is not truly reflected in the analysis undertaken given the assumed location and timing of a disruption. The disruption frequency test did try to test the probability associated with unplanned service disruptions but it did not allow for a proper weighted analysis of options with high benefits and low probability or alternatively low benefits with high probability. The patronage levels assumed do not allow for travel between stations in either direction. Although realistic in respect to peak flow, counter-peak flow is based on personal experience and not patronage provided by railway companies or Government sources. The use of theoretical data in this paper proved useful in this context, but ultimately a lack of railway company data represent a limitation that will be explored with further research.

From a practical perspective it is anticipated that these results could be useful to railway companies in assessing better measures of dealing with the problem of sourcing alternative transport solution to service disruptions. It is hoped that research such as this will provide a more proactive approach to a problem that until now has been viewed in a reactive context.

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