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Impact of Bus Depot Location on the Provision of Rail Replacement Services (Bus Bridging)

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Abstract

This research explores the importance that depot location has on rail replacement service provision (bus bridging) during unplanned passenger rail disruptions. Through an analysis of unplanned disruption data pertaining to MetroTrains Melbourne, this paper highlights the impact of travel time to locations where bus bridging commences, likelihood of a disruption requiring bus bridging and commuters affected has on ideal depot location. Although literature exists on depot location for regular bus operations, research to date has not investigated depot location in the context of bus bridging.

When rail disruptions unexpectedly occur, re-establishing network connectivity is paramount and the provision of bus bridging is common. Minimising response times are critical in reducing impacts to affected commuters. Currently, reserve buses for such purposes are sourced from existing bus depot locations, which are generally situated to suit regular operations. Strategically locating bus reserves according to criteria such as disruption likelihood provides the opportunity to better cater for disrupted demand.

The data analysis highlights how ideal depot locations within the network changes as consideration is given to travel time to locations where bus bridging commences, likelihood of a disruption warranting bus bridging and commuters affected. Initially, preferred depot locations were determined according to minimal response times whilst when disruption likelihood was considered, the depot locations shifted to better suit this criteria. In most cases when passengers affected were assessed, ideal depot sites were located in areas anticipated to experience greater disrupted travel demand.

The paper discusses the implications of findings for future research and practice.

1 Introduction

Unplanned incidents in railway operations may be inevitable and require real-time rescheduling. Disruptions can be regarded as incidents requiring significant change to pre-defined resource schedules (Nielsen et al. 2012). Given that the impacts of disruptions can be quite significant, emergency response to such occurrences has become a critical issue (Dong et al. 2012). Current disruption management practice in passenger railways focuses on mitigating the impacts of unplanned service disruptions by real-time adjustments (Clausen et al. 2001; Yu and Qi 2004).

Following unexpected disruptions, establishing alternative transport is one of the main actions undertaken (Boyd et al. 1998). Bridging stations using buses is a common approach (Kepaptsoglou and Karlaftis 2010), however, it's subject to available buses (Kepaptsoglou and Karlaftis 2009). Kepaptsoglou and Karlaftis (2009) suggest an important option for sourcing buses is reserve buses, however, no reference is made to bus depot location.

Research focussing on regular bus operations acknowledges that optimally allocating buses to depots can yield operating savings (Kepaptsoglou et al. 2010). However, no research specifically addresses depot location in the context of bus bridging services.

One area of research, previously not viewed in this environment is location science. Location science research locates facilities subject to constraints, whilst minimising demand costs (Hale and Moberg 2003). Related research has focussed on reduced ambulance response times by optimising station locations (Andersson and Varbrand 2007), a similar problem faced by rail agencies when looking to source bus bridging resources.

This paper presents a new method for assessing bus depot location to best service unplanned rail service disruptions. The aim is to explore the influence that travel time to locations where bus bridging commences, likelihood of a disruption requiring bus bridging and passenger volume has on determining ideal depot locations for bus bridging resources. The paper commences with a literature review, followed by a description of the research methodology. Results are described and conclusions are presented including a summary of key findings and a discussion of their implications for future planning, practice and research.

2 Research Context

The rapid implementation of replacement services is essential for the successful substitution of disrupted rail services (bus bridging) (Kepaptsoglou and Karlaftis 2009). The key objectives in such situations are (Kepaptsoglou and Karlaftis 2010):

- Minimisation of travel times to stations where bus bridging services are initiated; and
- Minimisation of operational effects to the rest of the bus network.

Kepaptsoglou and Karlaftis (2009) suggest that rail replacement buses comprise either buses extracted from existing bus routes or reserve buses located at existing depots. Although the proximity of existing bus routes to disruption location is considered, the depot location is fixed. In this research and related work by Codina and Marin (2010), reference is not made to how depot location may be determined. Operationally this is logical, given such locations would be based around existing operations and not ad-hoc substitute services. Consequently, consideration is not given to the location of bus bridging resources. Although the retraction of buses is a reasonable alternative, Toronto Transit Commission, operators of Toronto's rail and bus networks noted, "you may in fact be simply shifting the problem or causing additional ones" (Pender et al. 2013). Similarly Zeng et al. (2012), in exploring mitigation strategies for unplanned short-term tram disruptions, highlighted that the retraction of buses from regular service can interrupt bus schedules and cause passenger angst.

Although there are financial implications to locating bus depots based on service disruptions, it is worthy of investigation given the benefits to affected commuters by reduced response times. Work done to date to optimise bus depot locations has related to regular bus operations (Kepaptsoglou and Karlaftis 2010). The focus has been on reducing operational costs whilst the focus of bus bridging is minimised response times. Given the lack of literature that specifically addresses the issue of depot location in a bus bridging context, investigation of how these problems are addressed is required.

Given the inherent issues of sourcing buses from existing routes, Zeng et al. (2012) analysed the role of taxis to address short-term unplanned disruptions to tram networks. In addition to the associated flow-on effects already documented, these authors note that traditional approaches require considerable time for the buses to arrive at the disruption site and do not always provide prompt recovery service (Zeng et al. 2012). As a consequence Zeng et al. (2012) consider alternatives to traditional depot locations. Admittedly the differing operating characteristics of taxis compared to buses does provide natural alternatives to the traditional static bus depot location. The three options for taxi sources are (Zeng et al. 2012):

- Empty taxis awaiting jobs;
- Taxis that are close to existing passenger's destination; and
- Taxis with passengers that are in close proximity to the disrupted tram.

Location science research assists in determining physical locations for a given set of facilities. The key objective is to minimise the cost of satisfying a given set of demands subject to certain constraints. Such decisions regarding facility locations are integral to a particular system's ability to satisfy its demands efficiently. Because these decisions can have lasting impacts, choices regarding the physical location of facilities will also affect the system's flexibility to meet the evolving demands (Hale and Moberg 2003).

Interest in location theory has developed strongly since the 1960's when Hakimi (1964) sought to locate police stations in a highway system. In an attempt to minimise the total distance between customers and their closest facility, Hakimi considered the issue of locating one or more facilities on a network. The most basic facility location problem formulations can be characterised as both static and deterministic. A number of researchers, have examined multi-objective extensions of these basic models (Owen and Daskin 1998). Church and ReVelle (1976) measured the effectiveness of a facility location by determining the average distance travelled by those requiring access. As average travel distance increases (used interchangeably with travel time), facility accessibility and the location's effectiveness decrease. This is consistent for facilities such as emergency services. Although the consequences of response times are not as severe in the cases of unplanned rail disruptions as they are for emergency response vehicles the same methodology can be applied interchangeably.

This previous work suggests that the location of reserve bus depots can have a significant impact on response times to rail disruptions. This has never been directly measured in the context of bus bridging. The present analysis fills this research gap by exploring the effect of travel time to locations where bus bridging commences, likelihood of a disruption requiring bus bridging and passenger volumes on selecting an ideal bus depot location.

3 Research Methodology

3.1 Research Aims

This paper presents a new method for assessing bus depot locations to best service unplanned rail service disruptions. Specifically, the impact of travel time to locations where bus bridging commences, likelihood of a disruption requiring bus bridging and passenger volumes were explored. The following four key scenarios were applied to determine 'optimal' depot locations:

- ***Base Case***;
- ***Scenario One*** – impact of travel time to locations where bus bridging commences;
- ***Scenario Two*** – impact of travel time to locations where bus bridging commences and likelihood of a disruption requiring bus bridging; and
- ***Scenario Three*** – impact of travel time to locations where bus bridging commences, likelihood of a disruption requiring bus bridging and commuters affected.

3.2 Research Approach

This paper uses an analysis of 36 months of unplanned passenger rail service disruption data to Melbourne's (Australia) rail network provided by the operator MetroTrains Melbourne. The data analysis focussed purely on those unplanned service disruptions that required the initiation of bus bridging services. Over the three-year period in question, MetroTrains Melbourne required the initiation of bus bridging services due to unplanned service disruptions approximately 2-3 times a week. The methodology applied is based around the aforementioned four key scenarios which aimed to assess the impact of the following three key control variables that are of most influence:

- Travel time to locations where bus bridging commences;
- Likelihood of an unplanned service disruption requiring bus bridging; and
- Commuters affected.

The key objective in each of the four scenarios was minimised travel time, i.e, response time. Travel time to locations where bus bridging commences was considered given bus bridging services inevitably commence at the locations of rail crossovers and not at the actual disruption itself. Rail crossovers enable trains to turn back onto return tracks and hence act as a defining location for termini for bus bridging services during disruptions (Pender et al. 2012).

3.2.1 Base Case

For the base case a series of random depot location were identified to act as a basis for assessing performance in the subsequent scenario models. Using Google Maps for Melbourne's rail network, grids were drawn which divided each of the four rail groups into a series of scaled squares of area 1 km^2. For each rail group each square was numbered. Ten random depot locations were then selected for each of the four rail groups. The actual location selected for each depot was the nearest address to the midpoint of the randomly selected square. The reason only ten locations were chosen was simply to demonstrate the method. If the method was to be applied, obviously more potential locations would be considered.

3.2.2 Scenario One – Ideal Depot Location According to Travel Time to Locations where Bus Bridging Commences

This scenario determined the performance of depot location based on the travel time to the locations where bus bridging commences. The ten depots for each rail group were evaluated. The key objective was to minimise the travel time to locations where bus bridging services commence. Bus bridging services can only commence/terminate at stations that have crossovers.

The travel time (T) between each depot location (i) and each station location (j) was determined using Google Maps for the weekday peak period between 3:00 p.m. and 7:00 p.m. This time period was chosen because traffic congestion and commuter demand is at its highest and available bus resources are at their lowest. Once all required travel times (T_{ij}) were determined, the ideal depot location was calculated using Equation 1.

$$i(ideal_1) = MIN\left[\sum T_{ij}\right] \qquad \textbf{(1)}$$

where i= 1 to n_1
j=1 to n_2
n_1 = number of deport location
n_2 = number of station location

In the formulation of the model it was assumed that spare buses were readily available for bus bridging purposes and that the travel time remained constant during the highlighted period.

3.2.3 Scenario Two – Impact of Travel Time to Locations where Bus Bridging Commences and Likelihood of a Disruption requiring Bus Bridging

This scenario identifies the ideal depot location based on the travel time to locations where bus bridging commences and the likelihood a disruption requiring the initiation of bus bridging services (IL_j). The latter was determined based on the provided MetroTrains Melbourne disruption data. Within each rail group there is series of rail lines, whilst within each rail line, rail corridors are defined according to the location of crossover tracks. Every section of track between two operational crossovers is defined as a rail corridor. For each rail group, the disruption likelihood is equal to the percentage of disruptions that happen within a selected rail corridor of all disruptions that occur within the rail group. Using the travel times (T_{ij}) previously determined and the calculated disruption likelihood (IL_j), the ideal depot location for each rail group was calculated using Equation 2.

$$i(ideal_2) = MIN\left[\sum T_{ij} * IL_j\right] \quad \textbf{(2)}$$

3.2.4 Scenario Three – Impact of Travel Time to Locations where Bus Bridging Commences, Likelihood of a Disruption requiring Bus Bridging and Commuters Affected

This scenario identifies the ideal depot location based on the number of commuters affected (α) by disruptions and the travel time to locations where bus bridging commences and the likelihood a disruption warranting bus bridging services. The steps taken (including assumptions) to determine the passengers affected were:

- The current number of trips in each direction at all station locations (j) within each rail group for the pre-determined time period i.e. the weekday peak period between 3:00pm and 7:00pm were ascertained using current timetables.
- It was assumed that train lines were operated by Siemens trains with a crush passenger capacity of 1,584.
- Outbound or down direction (peak flow) is assumed to be at crush capacity upon departure from the last central city train stations.
    - On each rail line it was assumed that 1/nth of the commuters disembark at each station where n equals the number of stations between the central city station and the outer termini. Boardings after the central city station are assumed negligible.
- The level of patronage demand for the inbound direction (counter-peak flow) on each rail line is assumed to be at 30% of the crush passenger capacity on arrival at the first central city station. It is then assumed that 1/nth of the commuters board at the terminus of the train line and at every station between this terminus and the first central city station. Commuters disembarking between these two locations were assumed negligible.

The time period between 3:00pm and 7:00pm (i.e. the weekday PM peak period) was deemed of high importance in demonstrating this new approach due to high patronage levels and restrictions on bus availability at such times. Rail agencies comment that sourcing buses during peak period is problematic giving the existence of school bus services and regular bus operations. Furthermore these agencies comment that affected commuters at such time are ‘captive’ than during disruptions in the AM peak. In the AM peak most commuters are coming from home and therefore have more alternative travel options i.e. private car and alternative public transport services. Given boarding/alighting data by corridor for three years is very complex to compile, estimates were used to demonstrate the method.

Based on the determined total number of trips in each direction (according to current public train timetables) and the patronage demand to each station according to the assumed fixed matrix of travel demand it was possible to determine the percentage of commuters affected by disruptions requiring bus bridging services within any given rail corridor. Accordingly the ideal depot location was calculated using Equation 3 factoring in the travel times (T_{ij}) and disruption likelihoods (IL_j) previously determined and a parameter representing a percentage of commuters that will be affected by unplanned disruptions (α):

$$i(ideal_3) = MIN\left[\sum T_{ij} * IL_j * \alpha\right] \tag{3}$$

4 Results

4.1 Base Case

Utilising the method documented in Section 3.2.1, Figure 1 highlights the ten depot locations randomly selected for each of the four rail groups.

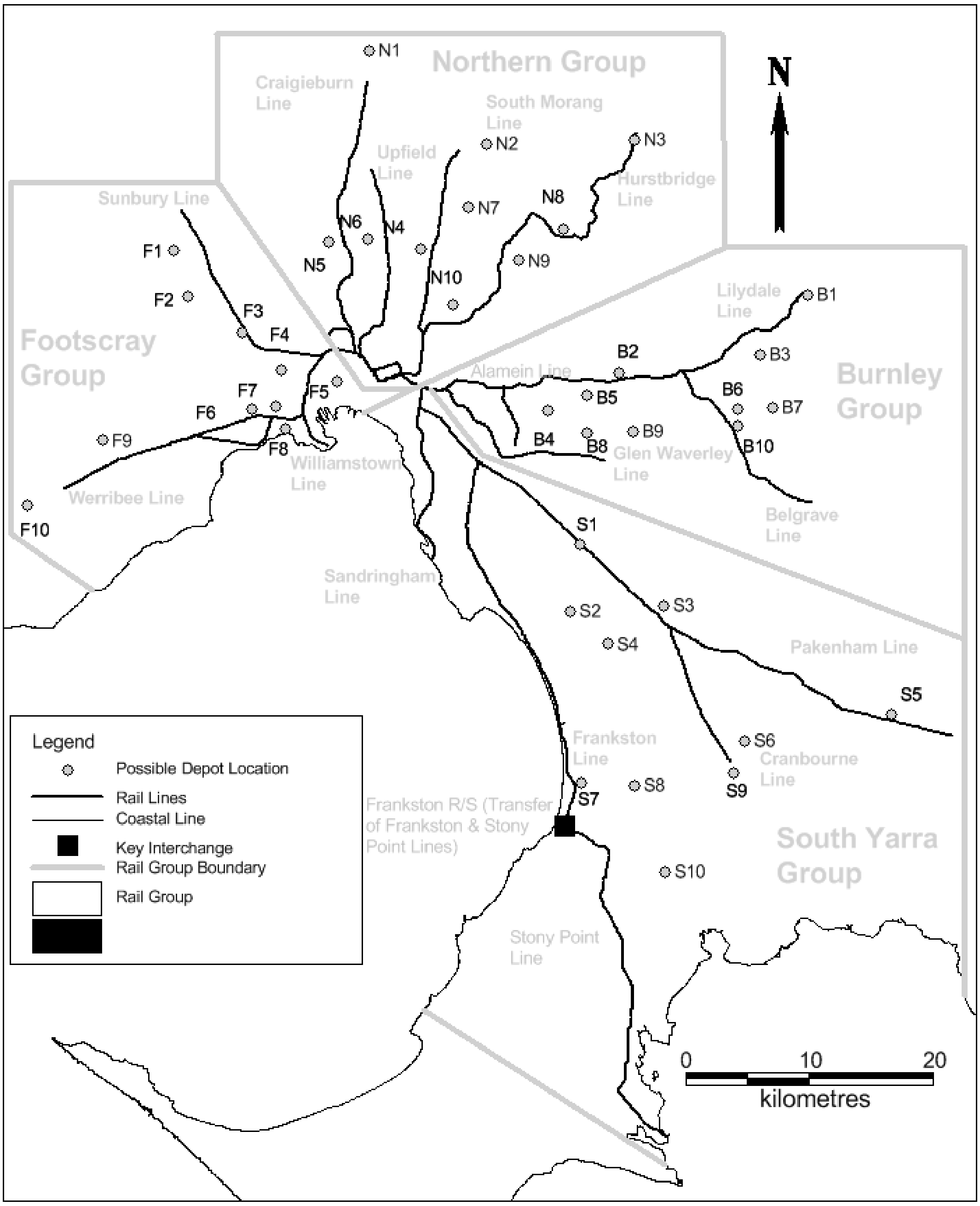

Figure 1: Melbourne's Rail Network highlighting Rail Corridors, Rail Lines & Possible Depot Locations

4.2 Scenario One – Impact of Travel Time to Locations where Bus Bridging Commences

Table 1 applies Equation 1 to calculate the travel time between each depot and each station location where bus bridging services commence (assuming PM peak direction travel). Table 1 illustrates the results for all rail groups and the location (s) with the lowest travel time highlighted. Figure 2 applies a graphical representation of ideal depot locations, where crossover locations (marked with X) indicate locations where bus bridging can commence.

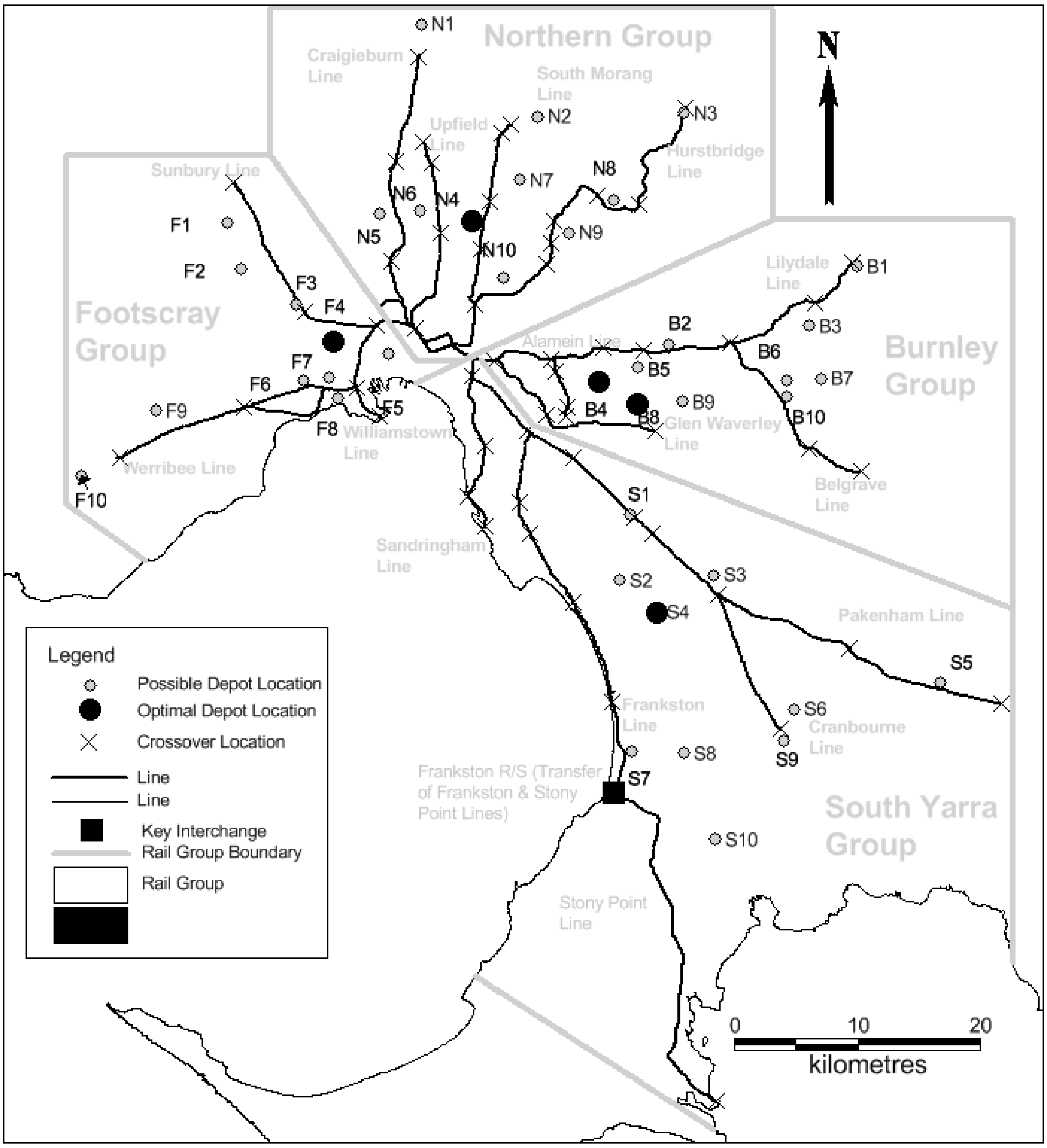

Figure 2: Scenario One – Ideal Depot Location by Travel Time to Locations where Bus Bridging Commences (Crossovers)

When only the impacts of travel time are considered, potential depot locations situated in the approximate mid-points of all train lines that comprise the Burnley Group are deemed most ideal, i.e. depot sites B4 and B8. Similarly in the Footscray Group, depot site F4 which is centrally located to all included rail lines was deemed the most preferable when only travel time was considered in determining the most ideal depot location.

Within the Northern Group, depot site N4, is centrally located to the four rail lines that comprise this group. It is, however, situated closer to the outer termini of the four affected lines. The proposed depot site S4 for the South Yarra rail group is centrally situated to all rail lines, however, given its position in Melbourne's outer south-eastern suburbs it is not ideal if bus bridging is required on the Sandringham line, i.e. inner west in this group. Furthermore its position is a significant distance from the Stony Point line that extends to the southern-most portion of this group; a common location for bus bridging service requests.

Table 1: Scenario One – Ideal Depot Location by Travel Time to Locations where Bus Bridging Commences

Depot Locations							
Burnley Group	$\sum T_{ij}$	**Footscray Group**	$\sum T_{ij}$	**Northern Group**	$\sum T_{ij}$	**South Yarra Group**	$\sum T_{ij}$
B1	465	**F1**	255	**N1**	460	**S1**	490
B2	285	**F2**	210	**N2**	409	**S2**	490
B3	385	**F3**	180	**N3**	540	**S3**	505
B4	**260**	**F4**	**165**	**N4**	**320**	**S4**	**460**
B5	275	**F5**	185	**N5**	425	**S5**	715
B6	370	**F6**	185	**N6**	390	**S6**	605
B7	410	**F7**	170	**N7**	350	**S7**	580
B8	**260**	**F8**	185	**N8**	385	**S8**	650
B9	305	**F9**	250	**N9**	365	**S9**	650
B10	380	**F10**	280	**N10**	419	**S10**	730

4.3 Scenario Two – Impact of Travel Time to Locations where Bus Bridging Commences and Likelihood of a Disruption requiring Bus Bridging

Scenario Two takes into account both the travel time to a location where bus bridging commences and the likelihood that a disruption requiring bus bridging will occur. Table 2 applies Equation 2 to calculate the 'weighted' travel time between each depot and each station location where bus bridging services commence (assuming PM peak direction travel). Table 2 illustrates the results for all rail groups and the location (s) with the lowest 'weighted' travel time taking into consideration disruption likelihood highlighted. Figure 3 presents a graphical representation of disruption location and ideal depot location based on these criteria.

For the Northern, Burnley and South Yarra rail groups, disruptions are more likely to occur in the outer corridors of rail lines. In the Footscray rail group, much of the Werribee line is shared with V/Line (country rail operator) and this could be the reason why this rail line has a high percentage of unplanned service disruptions requiring bus bridging (see Figure 3).

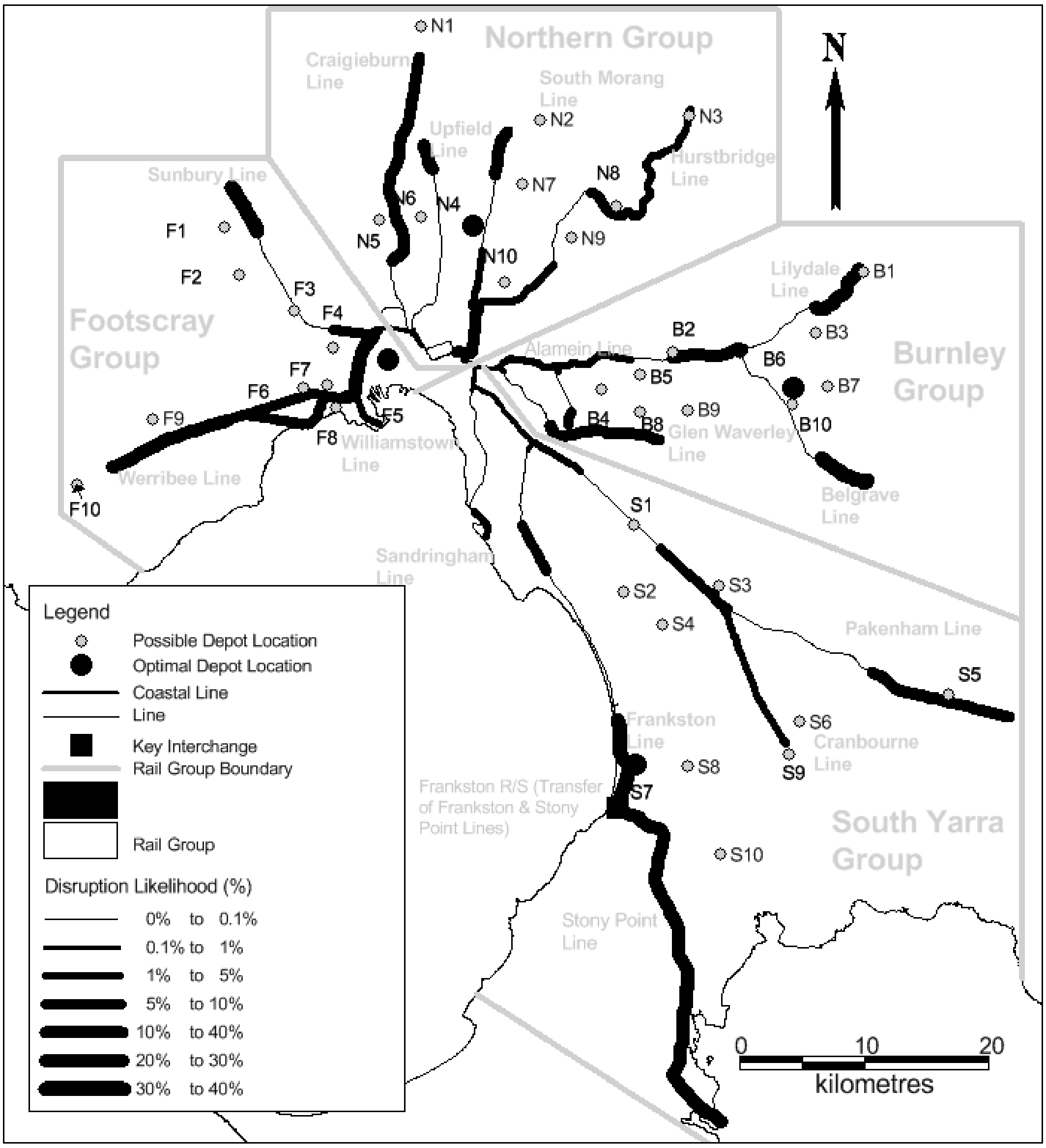

Figure 3: Scenario Two – Ideal Depot Location by Travel Time to Locations where Bus Bridging Commences and Likelihood of a Disruption requiring Bus Bridging

*Note: Disruption likelihood percentages present likelihood of disruption requiring bus bridging occurring within a rail corridor for any given rail group

When the likelihood of an incident in the Burnley Group is considered, the ideal depot location shifts from one that is centrally positioned in Scenario One (i.e. B4 and B8) to one that is located in close proximity to the Belgrave line (B6). This is to be anticipated given the outer rail corridor of the Belgrave line had the highest incident likelihood of all rail corridors within the Burnley Group.

Table 2: Scenario Two – Ideal Depot Location by Travel Time to Locations where Bus Bridging Commences and Disruption Likelihood

Depot Locations							
Burnley Group	$\sum T_{ij} * IL_j$	**Footscray Group**	$\sum T_{ij} * IL_j$	**Northern Group**	$\sum T_{ij} * IL_j$	**South Yarra Group**	$\sum T_{ij} * IL_j$
B1	27.2	**F1**	34.0	**N1**	21.0	**S1**	38.2
B2	24.2	**F2**	28.4	**N2**	21.3	**S2**	33.4
B3	25.1	**F3**	21.8	**N3**	30.8	**S3**	35.1
B4	26.7	**F4**	16.7	**N4**	**17.7**	**S4**	32.5
B5	27.1	**F5**	**14.9**	**N5**	22.9	**S5**	44.6
B6	**21.5**	**F6**	21.5	**N6**	21.8	**S6**	32.1
B7	24.8	**F7**	17.9	**N7**	20.7	**S7**	**27.5**
B8	24.5	**F8**	21.1	**N8**	22.9	**S8**	30.2
B9	24.0	**F9**	33.0	**N9**	23.2	**S9**	32.0
B10	23.7	**F10**	36.2	**N10**	28.1	**S10**	30.6

*Note: all times in Table 2 are in weighted minutes and do not represent physical travel times.

The ideal depot location within the Footscray Group shifted south east to site F5 (previously F4 in Scenario One) after the likelihood of an unplanned disruption warranting bus bridging is considered (i.e. F4). Although the outer rail corridor of the Sunbury line is the most likely to experience an unplanned disruption requiring bus bridging in this rail group, the more centralised position of depot F5 from a disruption likelihood perspective reinforced this shift. Coupled with the high likelihood of bus bridging related disruptions occurring on the Werribee and Williamstown lines, meant this location was better suited.

The ideal depot location within the Northern Group remained the same in both Scenarios One and Two (i.e. N4). In excess of 50 per cent of unplanned disruptions occurred on the outer rail corridors of the Craigieburn, South Morang and Upfield lines which are all located at the northern ends of their respective rail lines. Therefore the position of depot N4 located on the western side of the South Morang line is deemed most ideal.

Within the South Yarra group, when consideration is given to disruption likelihood the most ideal depot location shifted south (i.e. S4 in Scenario One to S7 in Scenario Two). Given in excess of fifty per cent of unplanned disruptions in the South Yarra group occur on the outer corridor of the Frankston line and the Stony Point line the altered ideal depot location is logical.

4.4 Scenario Three – Impact of Travel Time to Locations where Bus Bridging Commences, Likelihood of a Disruption requiring Bus Bridging and Commuters Affected

Table 3 illustrates the results for all rail groups and the location (s) with the lowest weighted travel time taking into consideration likelihood of a disruption requiring bus bridging and passengers affected highlighted. Figure 4 applies a graphical representation.

Table 3: Scenario Three – Ideal Depot Locations by Travel Time to Locations where Bus Bridging Commences, Likelihood of a Disruption requiring Bus Bridging and Commuters Affected

Depot Locations							
Burnley Group	**i (ideal$_3$)**	**Footscray Group**	**i (ideal$_3$)**	**Northern Group**	**i (ideal$_3$)**	**South Yarra Group**	**i (ideal$_3$)**
B1	0.73	**F1**	12.25	**N1**	1.76	**S1**	**0.20**
B2	0.36	**F2**	10.42	**N2**	1.55	**S2**	0.22
B3	0.55	**F3**	8.13	**N3**	1.82	**S3**	0.21
B4	**0.27**	**F4**	6.32	**N4**	1.12	**S4**	0.21
B5	0.33	**F5**	**5.20**	**N5**	1.13	**S5**	0.33
B6	0.57	**F6**	8.06	**N6**	1.12	**S6**	0.30
B7	0.65	**F7**	6.78	**N7**	0.94	**S7**	0.32
B8	0.35	**F8**	8.00	**N8**	1.35	**S8**	0.37
B9	0.47	**F9**	12.11	**N9**	1.15	**S9**	0.33
B10	0.65	**F10**	13.32	**N10**	**0.93**	**S10**	0.36

*Note: all times in Table 3 are in weighted minutes and do not represent physical travel times.

Factoring in the passengers affected by unplanned disruptions at stations where bus bridging services commence/terminate the ideal depot location within the Burnley Group shifted west towards Melbourne's city centre (i.e. B6 in Scenario Two to B4 in Scenario Three). Despite an increased likelihood of service disruptions within the outer rail corridors, particularly on branch lines, given the number of commuters potentially affected by such incidents is higher in closer proximity to Melbourne's city centre, the revised depot location (B4) is better suited.

After consideration is given to the passengers affected by unplanned service disruptions, the ideal depot location in the Footscray Group remained the same as the ideal site determined in Scenario Two (i.e. F5). Although the outer corridor of the Sunbury line does have the highest likelihood of a rail disruption, the larger number of passengers potentially affected at stations in closer proximity to Melbourne's city centre, resulted in depot location F5 being deemed most ideal.

The most ideal depot location within the Northern group was previously N4. When consideration was given to the commuters affected by disruptions, the most ideal depot location shifted south to site N10. During the nominated weekday peak PM period there are more outbound trips operated on the Hurstbridge and South Morang lines than the Craigieburn and Upfield lines resulting in more commuters affected by unplanned service disruptions warranting bus bridging. When considered in conjunction with the fact that the Hurstbridge line experienced the highest likelihood of a disruption warranting bus bridging services meant it is justifiable that a depot location in close proximity to the Hurstbridge and South Morang lines is most ideal.

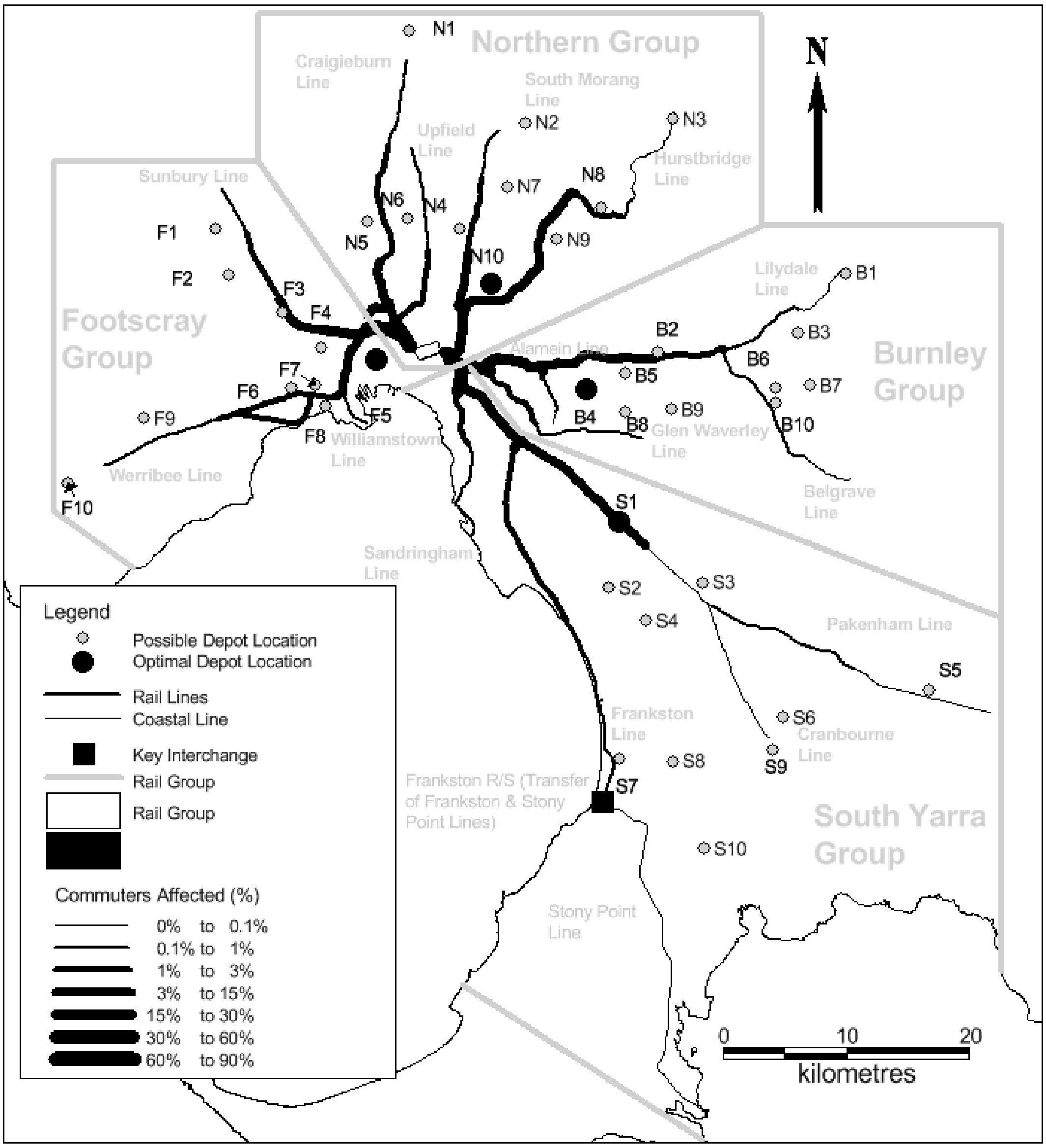

Figure 4: Scenario Four Optimal Depot Location by Travel Time to Locations where Bus Bridging Commences, Likelihood of a Disruption requiring Bus Bridging & Commuters Affected (Scenario Three)

The South Yarra group is a perfect example of the impacts that the three key criteria of travel time to a location where bus bridging commences, likelihood of a disruption requiring bus bridging and commuters affected has on the impacts of an ideal depot location. When only travel time was considered S4 was deemed ideal, i.e. central to all rail lines. Given the high propensity of unplanned disruptions on the Stony Point line, when the likelihood of a disruption necessitating bus bridging was additionally considered the ideal depot location shifted closer to the affected rail line i.e. site S7. Lastly when the impacts of commuters affected by such disruptions is factored in the ideal depot location shifted north (i.e. S1) to a location that is approximately equidistant between the key rail lines within this group and ultimately in closer proximity to Melbourne's city centre.

5 Discussion and Conclusions

This research paper explores the impact that depot location has on bus bridging outcomes. In particular the focus was on exploring the influence that variables including travel time to/from depot and disruption locations, likelihood of a disruption requiring bus bridging and commuters affected has on determining an ideal depot location. Previous research in this field noted the importance of geographical location when retracting buses from existing routes, however, the depot location for reserve buses was commonly assumed to be fixed.

The changes for ideal depot location for each rail group is interesting to note as travel time to disruption, disruption likelihood and commuters affected is considered. Initially, when only travel time was considered, the ideal depot location was generally positioned at a central location. When consideration was given to the disruption likelihood, generally the ideal depot location shifted within closer proximity to rail corridors of higher disruption likelihood. Lastly when the impacts of potential commuters affected by disruptions were explored, with the exception of one rail group the ideal depot location shifted in favour of those rail corridors expected to carry the most affected commuters.

Traditionally bus depots are situated to suit regular operations and in the bus bridging literature to date consideration is not given to determining the ideal location. In related literature pertaining to location science, greater emphasis is placed upon determining ideal site locations for industries such as emergency response and logistics. The benefits of bus depot locations situated specifically to aid disruption responses would deliver significant benefits to affected commuters in respect to improved response times. This is because the geographical position of depots would be based purely on the rail network's operational history and not of the subsequent bus service provider.

Further work in this area involving more complex modelling approaches could be used to determine ideal depot sites and also take into account the minimum and maximum number of depots within a network as a whole. The methodology applied in this research paper was based upon a deterministic approach. Although original in the context of this research area, it does not consider variability in assumed key elements i.e. travel time fluctuations during peak periods and occurrences when required number of buses are not available. It is anticipated that a stochastic approach to this problem is an area for future research that will address these issues. It does become apparent that the issue of reserve bus location cannot be viewed in isolation to the issue of how many buses should be kept in reserve. Companies who provide bus bridging vehicles generally make use of buses in their fleets that are not specifically designated as bus bridging vehicles and in fact are surplus to the current 'time of day' requirements. A separate depot facility to specifically house bus bridging vehicles raises the issue of a separate independent bus fleet given that in most cases such a fleet would not be productive when not required for bus bridging purposes. Ultimately greater consideration needs to be given to the important elements of bus drivers. Even when bus resources are available during off-peak periods, particularly on weekends there are often no drivers on-site to deliver the required bus bridging services.

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