Missing the Connection? A case study approach to understanding effective public transit transfers in dispersed lower density cities

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Abstract

Public transit mode share in dispersed lower density cities common in North America and Australia is typically low. Except where users are captive, or where the density of activity is so high that congestion is a significant deterrent, transit generally fails to compete with the private car. Much literature identifies the economic, social and environmental challenges associated with high proportions of private car use. Research which understands the effective approaches to increased public transport mode share is therefore important.

The 'network effect' is a public transit operating approach aimed at serving the complex travel patterns of dispersed lower density cities. The approach relies on effective transfers between transit modes. In compensation for the inconvenience of transfer, passengers are rewarded with a service providing access to a wide, rather than limited, geographic area. Whilst the theory is now well established, analysis of its success in practice is less well researched.

This paper adds to knowledge on the network effect by comparing feeder transit service levels and rates of transfer observed in two case study locations. Feeder transit quality of service is measured by (i), the number of services provided on each route, and (ii), the timetabled wait time between feeder and trunk services (and vice versa). The paper compares rates of transfer between bus and train at stations on the Dandenong Line in Melbourne with the eastern branch of the Montreal metro Green line to Honoré Beaugrand.

The paper reports on on-going analysis that seeks to identify relationships between these variables and rates of transfer observed at stations along both lines. In particular, the analysis is interested in factors influencing the higher rates of transfer seen in the Montreal case study.

The findings will be important for any transit agency looking to benefit from the theoretical advantages of the network effect in suburban land forms common to Australian and North American cities. They are of particular interest in Melbourne given recent investment commitments to grade separations and the Melbourne Metro rail tunnel.

1. Introduction

Public transport mode share in dispersed, lower density cities is typically low. Public transport struggles to compete against the private car, except in situations where congestion and parking cost/scarcity is a significant deterrent (for example, peak period access to Central Business Districts), or where users are captive (those unable for age, disability or financial reasons to drive).

The network effect is a theory of public transport operation. It points to methods by which it is thought possible to substantially increase the efficiency and effectiveness of services through the widespread use of high-quality transfers that allow passengers to reach a broader range of destinations. The creation of good networks may allow public transport to compete more effectively with private cars. The network effect may be particularly effective in dispersed urban areas, through its ability to serve multiple origins and destinations.

1.1. Development of the 'Network Effect'

Thompson (1977) provided an early analysis of the efficiency benefits of networked public transport services. Thompson's work concluded that grid and timed transfer structures can operate 'with a significantly smaller deficit per passenger trip, (and) can theoretically attract many more passengers than alternative radial systems' (Thompson, 1977:158). Mees (2000) expanded on earlier work describing how a networked grid provides access to destinations across the entire urban area, rather than just thosealong parallel or radial lines (Mees, 2000:138). The 'theory challenged established notions of patronage response to service improvements that assume an inelastic relationship between service increases and ridership.

More recent literature by Nielsen et al (2005), Mees (2010) and Dodson et al (2011) have further refined the theory, noting the importance of a simple, stable and direct route structure, multimodal ticketing, free transfers, welcoming interchange environments and centralised rather than laissez-faire operational and strategic planning.

The theoretical efficiency benefits of the network effect sit in contrast to substantial research which identifies passenger reluctance to transfer (see for example Richards 1990:100, Wardman, 1998 in Balcombe et al, 2004:92, Horowitz and Thompson, 1994 in Currie and Willis, 1998:171, amongst others). Additional literature suggests time spent waiting for connections is perceived to be much longer than time spent moving in the transit vehicle (Horowitz and Thomson, 1994 in Currie and Willis, 1998:171, Hine and Scott, 2000:218). However, Nielsen et al (2005:84) and Guo and Wilson (2010:92) combat the idea that transfers are necessarily a negative, noting that research confirming reluctance to transfer is based on preferences of users where transfer conditions are poor. Becker and Spielberg (2008:13) wryly note that 'it is axiomatic in our industry that transfers are bad… experience suggests that it is bad transfers that are bad'.

Despite the conceptual appeal of the network effect, relatively little research has been carried out on its presence and operation in practice. Currie and Loader (2009:8) identified that a service frequency of 10 minutes or better on one route, and 15 minutes or better on the intersecting route was a prerequisite for any substantial level of transfer. The authors also noted very low transfer rates where headway was more than 10 minutes on the better of the two services (2009:9). Overall, the authors indicated some evidence of the effect, but noted the relationship between service frequencies and transfer rate was complex (2009:7).

Effective interchange can also be achieved through 'timed transfers' or 'pulse timetabling' as described in Thompson (1977), Sullivan (1976) Cervero (1998) and Walker (2011). In the timed transfer approach, lower frequency services are scheduled to arrive at an interchange

node concurrently, allowing passenger interchange between various services and destinations. By its nature, timed transfers require rigorous timetable coordination and adherence: a challenging objective where transit vehicles operate in mixed traffic conditions.

Currie and Loader's (2009) observations on service frequencies are consistent with Nielsen et al's assertion that below a 10-minute headway no network effect is demonstrated (Nielsen et al 2005:14). This assumption is based on average waiting times and fails to acknowledge that a functioning timed transfer system would result in average waiting times being very short, despite the frequency of service potentially being low.

The relationship between service frequency, timetable coordination and rate of transfer thus remains a relatively little researched, although important, aspect of any practical application of the network effect concept. Limited analysis has been undertaken on the specific service levels that support or hinder a network effect.

This paper considers the observed rates of transfer between rail and bus in two case study locations- Melbourne and Montreal, Canada. Using station access mode data and service timetables, an analysis is undertaken of the relationship between the rates of rail-bus transfer and transit service levels. The paper compares Melbourne's Dandenong line with the Honore Beaugrand section of the Montreal Metro Green line.

This paper reports on initial findings of a broader study into the relationship between service levels and patronage in the two cities. The broader study is undertaking a statistical and qualitative analysis of the role of additional variables which may influence outcomes, including physical interchange environments, wayfinding, fare structures, extent of park and ride provision and feeder route population density and service directness.

Section 2 outlines the relevance and details of the case study locations. Section 3 describes the data sources and methodology of the investigation, with results outlined in Section 4.

2. Description and relevance of case study locations

Melbourne has an extensive electrified suburban rail network, comprising 15 regular lines and 205 stations. The network is highly radial, with all lines converging on Flinders Street Station and a small central underground loop (see Figure 1). The rail network is augmented by a substantial tram and bus network, with generally poor physical coordination.
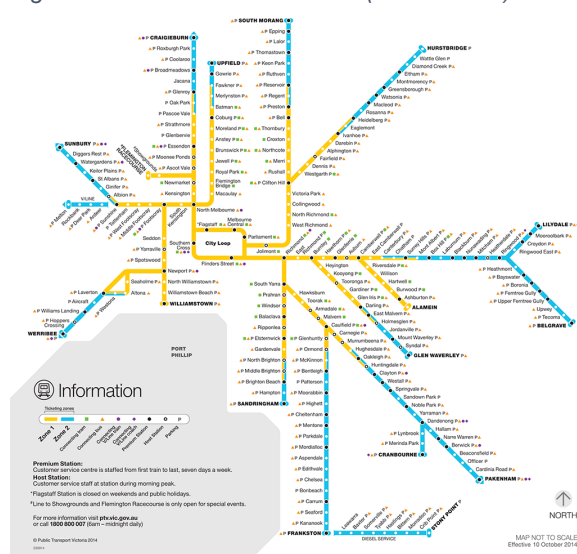
Figure 1-Melbourne Rail network (Source:PTV)   *Figure 2-Montreal Metro network (Source:STM)*

The Dandenong rail line runs through Melbourne's south-eastern suburbs, through a mixture of post-war residential, commercial and light industrial land uses.

Victoria's State Government has committed to substantial investment in the Dandenong line, through an aggressive campaign to eliminate all grade crossings along the Caulfield-Dandenong section (Premier of Victoria, media release 31 March 2015, retrieved 11 May 2015). This investment is justified on the basis of projected future patronage growth and an associated requirement for enhanced service frequencies. Patronage growth of 5.5% per annum is anticipated for the line through to 2021, and 4.5% from 2021-2030 (PTV, 2012:37). This is despite the line traversing a suburban landscape expected to change only incrementally in population along the Caulfield-Dandenong section, with notable growth only along the outer Cranbourne and Pakenham sections (DELWP, 2014). Upgrades to the Dandenong line will complement the larger Melbourne Metro Rail project, designed to achieve '*highly punctual and reliable service where the percentage of scheduled headways delivered are comparable to other <u>world class</u> metro operations*' (PTV, 2012a:83, authors' emphasis). The Dandenong line thus represents a timely case study for analysis against a 'world class' metro system.

Montreal has a substantially smaller fixed rapid transit network, despite a very similar metropolitan population (Figure 2). The city is served by a metro, bus and longer distance commuter rail network. Bus and metro services on the island of Montreal are provided by the public corporation, Société de Transport Montreal (STM). Commuter rail services are provided by the Agence métropolitaine de transport (AMT), a public umbrella corporation with coordinating oversight of public transport services across the metropolitan area. Bus services off Montreal Island are provided by smaller municipal transit authorities (AMT, 2011).

Table 1 shows relevant data for both metropolitan areas. Of note is the substantial difference in per capita public transport use within the STM operation area compared to the broader Montreal metropolitan area, which is very similar to the Melbourne metropolitan results.

Table 1-Key population and ridership data, Melbourne and Montreal

	Melbourne	Montreal
Urban population	3.99m (ABS 2011 census)	3.41m (Statcan 2011 census for Montreal 'Population Centre')
Public Transport mode share (Journey To Work)	16.1% (ABS 2011 census)	22.2% (Statcan 2011 census for Census Metropolitan area)
Ridership per capita (unlinked trips)	131.3 (based on 523.9m annual patronage for 12 months to June 30, 2013- PTV Annual report 2012-13)	133.9 for Metropolitan Area (based on 511.5m annual patronage for 12 months to Dec 31, 2012- AMT 2012 annual report)
Urbanised area population density	17.7 persons/ha (Loader 2012 for Melbourne SA1 with population density above 1 person/ha, from ABS 2011 census)	22.0 persons/ha (Stancan 2011 census- Montreal 'Population Centre')

Montreal's metro comprises 4 lines and 68 stations (see Figure 2). The eastern extent of the green line comprises 12 stations from the interchange hub at Berri UQAM on the eastern edge of the CBD to Honore Beaugrand, extending through mixed residential, commercial and industrial land uses.

Current service frequencies along the Green line are consistent with those proposed for the Dandenong line in response to patronage growth projections (PTV, 2012a:83). Key data is provided in Table 2 below.

As a winner of the Imperial College London's COMET metro benchmarking award for 'Most Productive Metro' for four consecutive years from 2008 to 2011, the STM is a relevant '*world class*' location with which to undertake a case study comparison (STM media release 28 November 2013 http://www.stm.info/en/press/press-releases/2013, retrieved 11 May 2015).

Table 2 -Details, Case study lines-Source AMT 2008 O-D Survey, STM timetable, PTV 2012 rail station patronage data, PTV timetable

	No. stations	Line length	Weekday entries	Weekday Service Frequency (peak/daytime inter-peak/evening)
Dandenong line- Caulfield-Dandenong section	12	19.1km	44176	3/10/20 mins
Green line- Eastern section	12	9.7km	109971	3/6/12 mins

3. Data sources and method

This study aimed to examine some of the factors behind transfer rates between rail and bus in Melbourne and Montreal. We did this by looking at patronage data sets published by PTV for Melbourne and AMT for the STM system in Montreal. For Melbourne, data for the year 2012 was taken from PTV's 'Estimated Station Entries at Metropolitan Stations 2009-2012' ('Station Entries') data set, which the PTV assembled from their internal Origin Destination (OD) Survey, Validation Rate Survey and Metropolitan Station Patronage Model (PTV, 2013). These individual supporting surveys and model were not sighted. Additional data was sourced from the PTV to provide estimates of transfers from specific bus routes. Montreal data was

collected from the AMT's 2008 Origin-Destination Survey (AMT, 2010). Unfortunately, data from AMT's 2013 survey was not yet available. Collectively, survey data was used to assemble patterns of station access and patronage in both cities. Timetable data for services operating during the relevant survey year was also obtained.

With the patronage figures collected by PTV and AMT over numerous days in the survey year, timetable information from regular weekday services was used. This was referenced to weekday patronage data from the relevant surveys. The pattern of the service offer was then established, initially for overall service numbers, and subsequently for timetabled wait time relationships for bus and rail on the case study lines. A further analysis was undertaken to consider the relative efficiency of lower and higher frequency feeder bus services.

Both cities have high and low frequency feeder bus services- not all routes attempt to create a high frequency 'turn up and go' relationship with their corresponding rail service. Nevertheless, to better understand the presence of any network effect- and the service levels above which it might be seen- we analysed the transfer rates of *all* feeder services- both high and low frequency. Whilst lower absolute rates of transfer are to be anticipated with low frequency services, additional knowledge of the network effect can be gained through observing the differing transfer rates between high and low frequency services.

4. Results

4.1. Access to rail stations in Melbourne and Montreal

Using 2012 data from PTV's Station Entries estimates, and results of the AMT's 2008 origin-destination survey, a pattern of overall network station access was assessed, as shown in Figure 3. Key differences are apparent in the number and proportion of passengers accessing each system by car and by public transport. Car access in Melbourne is higher by over 100,000 daily passengers, supported by ample provision of park and ride facilities at most stations. In contrast, auto access plays a relatively small role in accessing Montreal's system, with only six stations having formalised park and ride provision (stm.info, retrieved 10 May 2015). Walk up access draws a similar overall patronage and proportion in both cities, however this is to be assessed against Melbourne's much higher number of stations. The most substantial difference in access patterns is the higher proportional and numerical role of public transport feeder access in Montreal. Over 160,000 more passengers access Montreal's smaller metro system by feeder bus each weekday compared to Melbourne. A comparison of the differing service offer between the two cities in this area is therefore of particular interest.

Figure 3 Weekday rail station access mode split % and numerical total- PTV Melbourne metropolitan rail network and STM Montreal Metro. Source: PTV 2012 Station Entries Data Set & AMT 2008 origin-destination survey.

Note: To avoid double counting, access through transfers from other rail lines is excluded in AMT's O-D survey. Melbourne figures have therefore been adjusted accordingly.
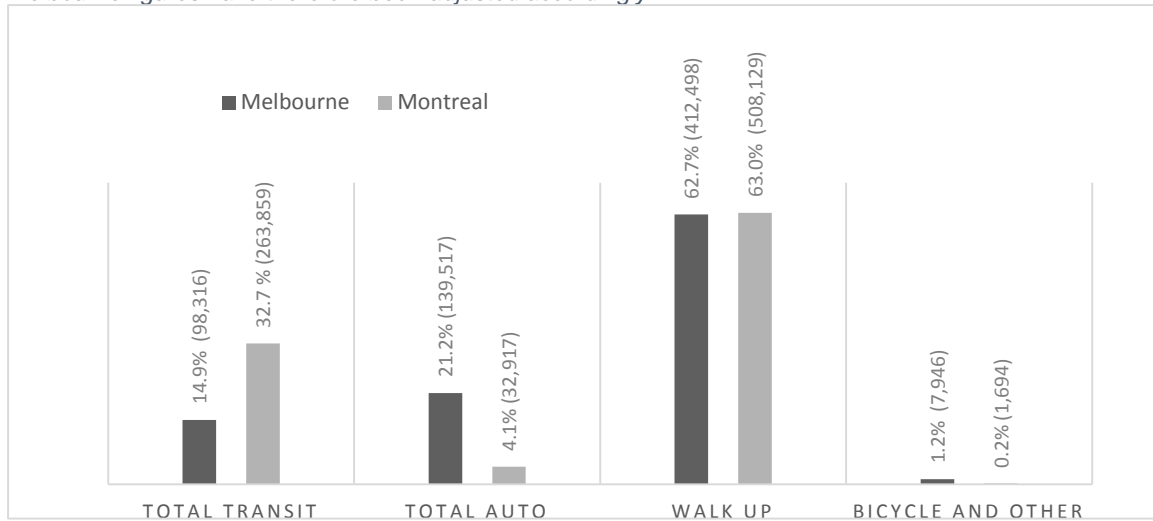

Figure 4 depicts the specific results for the case study lines. Trends apparent in the overall network data shown in Figure 3 are more pronounced for these individual line sections. Walk up access plays a similar proportional role, although numerical levels along the Dandenong line are much lower- reflective of lower overall population densities within station walk up catchments. Again, there is a pronounced difference is in public transit access, both proportionally and numerically. Stations along the Honoré Beaugrand section attract over 44% of their (numerically much higher) patronage from feeder transit, compared to less than 23% along the Dandenong Line. Bicycle and other (motorbike, taxi, commercial vehicle) modes play a relatively minor role in both locations.

Figure 4 Weekday rail station access mode split % and numerical total -Dandenong Line, Melbourne and Green line eastern branch to Honore Beaugrand. Source: PTV 2012 Station Entries Data Set & AMT's 2008 origin-destination survey.
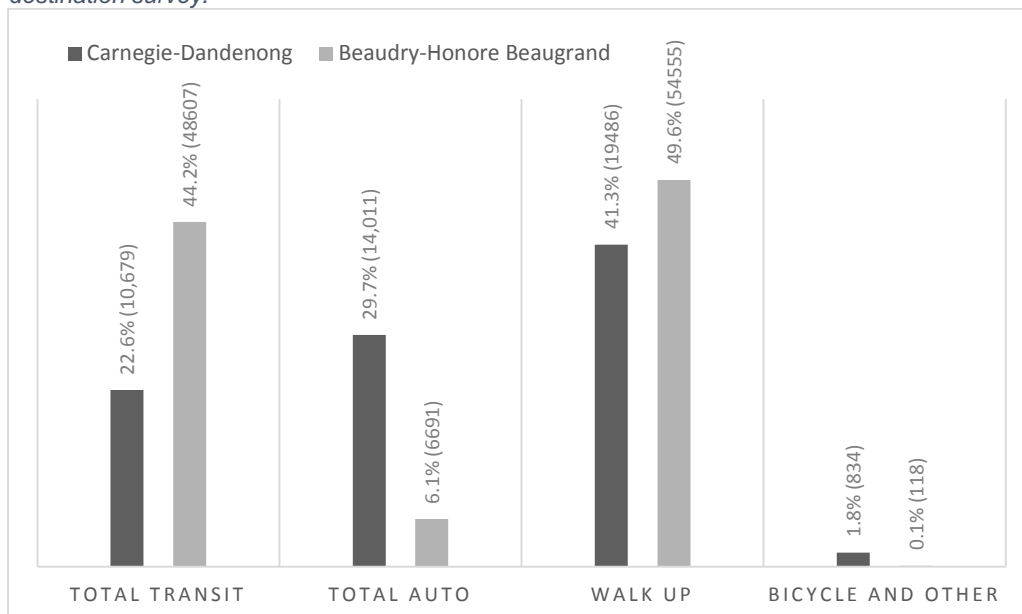
4.2. Number of bus services and station access

To understand the considerable difference in transit access share between the two locations, we investigated data on the proportion of patronage arriving at stations from each bus route.

Rail and bus service levels operating during the respective survey periods (2012 and 2008) were obtained from system timetables. Table 3, below shows stations on each line, the number of bus routes and total daily services provided on each station. We could then examine the relationship between number of bus services each weekday, and rates of transfer between bus and rail observed in patronage data sets.

Table 3 Number of Bus Routes serving stations on the Dandenong Line and Green Line east branch and total weekday bus service arrivals and departures on those routes.

Dandenong Line	Number of Routes	Weekday Services	Green Line Eastern Branch	Number of Routes	Weekday Services
CARNEGIE	2	119	BEAUDRY	1	62
MURRUMBEENA	1	62	PAPINEAU	5	566
HUGHESDALE	1	68	FRONTENAC	5	460
OAKLEIGH	12	900	PREFONTAINE	4	556
HUNTINGDALE	5	721	JOLIETTE	3	475
CLAYTON	6	631	PIE IX	5	811
WESTALL	0	-	VIAU	3	377
SPRINGVALE	5	282	ASSOMPTION	3	359
SANDOWN PARK	0	-	CADILLAC	3	444
NOBLE PARK	3	95	LANGELIER	4	657
YARRAMAN	3	92	RADISSON	5	350
DANDENONG	14	882	HONORE BEAUGRAND	10	1343
TOTAL	52	3852	TOTAL	50	6460

Figure 5 plots the relationship between number of weekday services, and rates of transfer from specific routes to rail services, with dot representing the relationship of one bus route with a rail station. Note, a limitation in the PTV data set is that it tracks only station access by bus- it does not measure station egress. Therefore only station access transfer rates are able to be plotted. Anecdotally, weekday station egress bus loadings are broadly similar to station access bus loadings, however loadings on individual services are lower- reflecting a less 'peaked' nature of the dominant PM peak period travel (PTV pers. coms, Ventura Bus pers. coms). Despite this, all services (both to and from stations) have been measured to provide an indication of the total service levels available at the location. With the network effect requiring multi-directional service, we considered it important to measure the service offer in both directions.

Figure 5 Weekday feeder bus service levels and rates of bus-rail transfer   Source: AMT and PTV
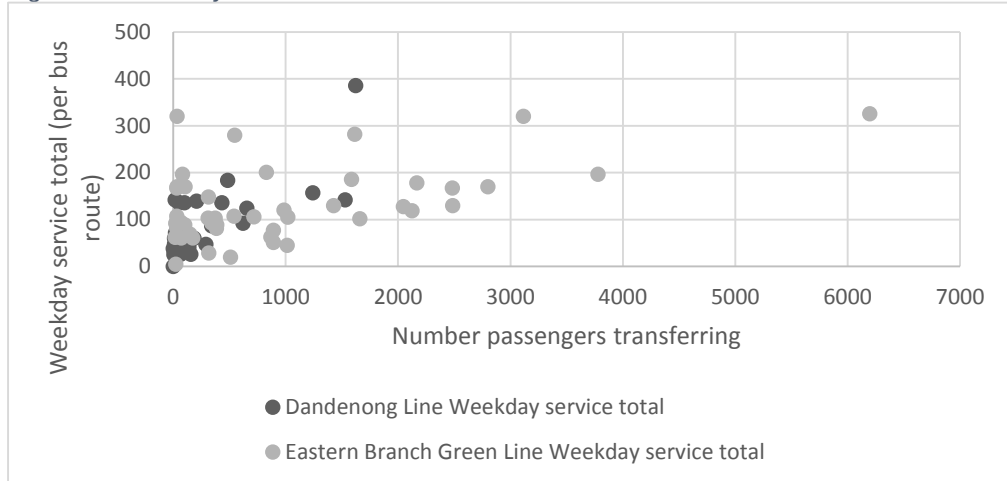
Overall, Figure 5 depicts a relatively indistinct relationship between service numbers and rates of transfer. Specifically, high service numbers do not guarantee high rates of transfer in either city. Numerous outliers exist, where high service numbers achieve very low rates of transfer. Further investigation of these locations uncovers complex patterns of public transport usage in both cities. Three of a cluster of four Melbourne bus services with a relatively high (above 130) number of daily services, but low rates of transfer are, on further examination, each situations where the route merely passes nearby to the station, but does not provide a convenient physical transfer opportunity. The fourth is route 630, which directly shadows the very high frequency route 601 Monash University shuttle, with its ridership potentially being impacted by the parallel, higher frequency shuttle service. Outliers are also seen in Montreal, where some high frequency bus routes directly serving one station have small numbers of their passengers accessing the network at the next station along the line. The two Montreal records with 320 daily services both depict the route 67 bus, which directly serves Joliette metro station. Whilst 3115 passengers transfer from the 67 to the metro at Joliette, 33 passengers enter the metro from the 67 bus at the adjacent Prefontaine station (see Figure 6). It is presumed they walk the short distance between. A similar situation occurs with the route 33 bus (197 daily services) between Langelier and Cadillac stations. Nevertheless, such outliers do not fully explain patterns of transfer, with a wide divergence of transfer rates experienced for routes with bus service levels between 100 and 200 per weekday.

Figure 6 Proximity of Prefontaine and Joliette metro stations, Montreal.
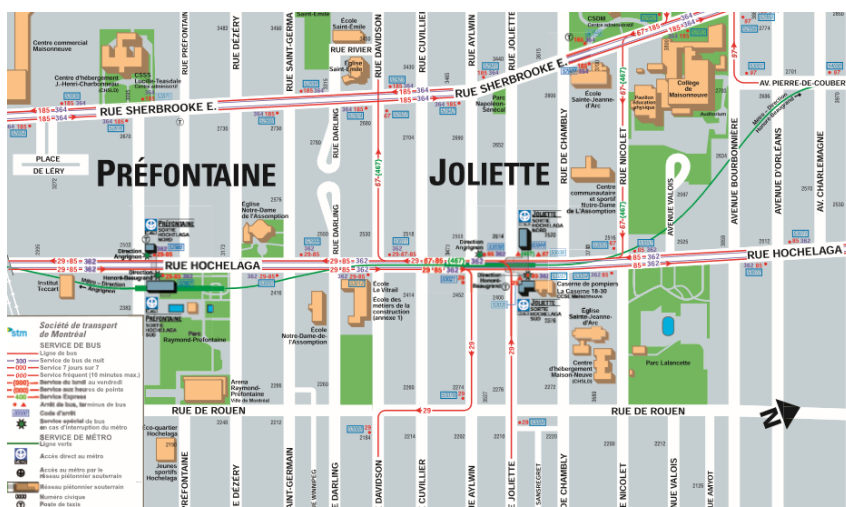
Whilst higher service frequencies are no guarantee of high transfer rates, it does appear that 100 daily feeder bus services (typically reflecting a 20 minute inter-peak service frequency) seems to be the minimum required in order to achieve a daily passenger transfer rate of over 1000.. This holds for both cities, although only three routes- the Monash University 601 shuttle at Huntingdale and 902 and 901 Smartbus services at Springvale and Dandenong reach or exceed this level of transfer in the Melbourne case study. Numerous services in Montreal achieve a weekday transfer rate in excess of 1000, all of which are provided with over 100 daily services. There is some parallel in these findings with Currie and Loader's (2009:8) observations in relation to bus-bus/tram transfers in Melbourne on the need for one route to operate at least every 10 minutes, and the other every 15, in order to see any materially significant rate of transfer.

A further and obvious observation is the strong relationship on the Dandenong line between low levels of service and low rates of transfer. Only three routes achieve a weekday transfer rate above 200 with a service level of fewer than 100 bus services per day.

4.2.1 Transfer efficiency of high v low frequency bus services

With limited exception, rail services in both case studies operate at a higher frequency than their associated feeder buses. Whilst use of journey planner apps may partly overcome this limitation (allowing easy selection of rail services offering better connections), this service imbalance fails to offer a viable 'turn up and go' service. If passengers randomly board a rail service they are likely to experience a lengthy bus transfer wait. It is of interest therefore to compare the average transfer rate per service for lower and higher frequency feeders (taken to be above/below 100 total services per day- i.e. 50 in each direction)

Table 4 below shows the results of this analysis. It is clear that higher frequency services demonstrate a higher average transfer rate per service- a pattern evident in both cities. The Montreal figure for low service routes is boosted by 'peak only' express services- which deliver large numbers of passengers per service for a very limited span of operation. There are no comparable services on the Dandenong Line. Comparing only 'all day' services, Montreal's figure drops to 2.08- comparable with the 1.62 average for lower frequency services on the Dandenong line.

Montreal's higher frequency feeder buses perform much better than those on the Dandenong line (8.29 v 3.67). Whilst a broader analysis is required to isolate all influencing factors, the offering of 28 higher frequency routes (against only 10 for Dandenong), combined with higher all day Metro frequencies (see Table 2) provides Montreal passengers with many more 'turn up and go' opportunities. Simply- Montreal passengers are able to travel more places more often with lower transfer times. Average transfer rates per service are thus higher for high frequency services - providing some evidence of a network effect in operation.

Table 4 Transfer efficiency of case study feeder bus services (Source: PTV, AMT and STM)

	Dandenong Line	Green Line East Branch
Number of routes below 100 services per day	41	23 (17 excluding peak only)
Average bus-rail transfer rate per service	1.62	5.66 (2.08 excluding peak only)
Number of routes above 100 services per day	10	28
Average bus-rail transfer rate per service	3.67	8.29

4.3. Service coordination, wait times and transfer rates

In an attempt to better understand the patterns seen in Figure 5 and Table 4, additional analysis was undertaken on the timetabled relationship between each arriving and departing bus service, and each arriving and departing rail service for both case study lines. This analyses the quality of multi-directional travel opportunities available at stations- a key theme of effective networked public transport. The pattern of timetabled transfer wait times was broken into 4 subsets: waits of 4-10 minutes; 11-15; 16-59; and those of 1 hour and over. The 1 hour and over group also included non-existent connections, where, for example evening rail services operate after the cessation of bus services. Given the requirements to exit vehicle, access or egress station and undertake any necessary fare checking, timetabled relationships of 0-3 minutes were deemed to be too short to facilitate a transfer. These relationships were therefore referenced to the next available departure.

We acknowledge that a 4-10 minute window is not necessarily ideal in all cases: too short where bus stop to rail platform distance is very long, and too long where physical transfer facilities are ideal. Nevertheless, without a detailed site analysis at each station, 4-10 minutes is presented as an appropriate timeframe to achieve a convenient transfer.

Service provision to achieve optimal transfers is highly complex from an operator perspective. Where multiple routes meet at a rail corridor (common at many stations in the case studies), arranging timetables, equipment and labour to achieve an optimal 'pulse timetable' operation is immensely challenging. Much literature is dedicated to mathematical analysis of this problem (see for example Chakroborty et al 1995, Pattnaik et al, 1998 and Jansson 1980, amongst others). Some operators, exemplified by the Swiss, have sought to simplify the task through systematic 'clockface' service frequencies specifically designed to achieve optimal multi-destinational connections at key nodes (Bergmaier, 2010). Currie and Bromley (2005:3) note however, that in practice, an intuitive rather than mathematically optimised approach is usually taken by transit operators.

Analysis of the quality of bus-rail and rail-bus coordination is likewise complex. Each arriving bus service has an opportunity to connect to both inbound and outbound rail services. Each arriving rail service in both line directions likewise has an opportunity for connection to departing bus services. Complexity is increased where bus routes pass rather than terminate at stations- multiplying the connection options to be analysed for quality.

Unfortunately, AMT and PTV data sets do not identify the onward route of passengers arriving at stations by bus: it is not possible to identify proportions transferring to city bound or outbound rail services. Likewise, with egress mode data unavailable for Melbourne, analysis of train arrival times and bus departure times against transfer rates can only be viewed in the context of an overall 'quality of service' being provided. Despite these data limitations, the most relevant measure for 'quality of service' is however *rail-bus*, rather than bus-rail. With daytime rail service frequencies typically 10 minutes or better along the Dandenong line, and more frequent again in Montreal, all bus-train connections in both cities show a high percentage within the preferred 4-10 minute wait time period (71.0% and 92.7% respectively). If analysis against bus-rail were taken, it would lead to a potentially misleading conclusion about the overall quality of the interchange. Essentially, for a system to provide multi-destinational travel options, it must provide high quality transfer opportunities in all directions: not just the bus-rail leg.

Therefore, the relationship between *rail-bus* timetabled wait-time is likely to be more instructive as a measure of quality of service, and therefore the measure which is likely to have most influence on rates of transfer. An average of 24.7% of rail-bus transfers on the Dandenong line occur within the 4-10 minute period, against 36.8% in Montreal.

Figure 7 depicts the relationship between rates of transfer, and the average number of *rail-bus* connections within the 4-10 minute wait time block. With no data available on the origin of transferring passengers, an average is taken of each rail-bus service connection for each bus route (measuring both city bound train-bus connections and outbound train-bus connections). This analysis identifies some interesting patterns. At a high level, observations can be made of the relationship between timetabled wait time, and passenger response to that quality of service in terms of transfers occurring. Similarly to the analysis of service numbers (shown in Figure 5), the relationship is not entirely linear, with a range of outlier results present.

Figure 7 Timetabled weekday rail-bus wait time (% of connections within 4-10 minutes) and rates of transfer: Eastern Branch Green Line and Dandenong Line, Montreal and Melbourne. Source: AMT and PTV
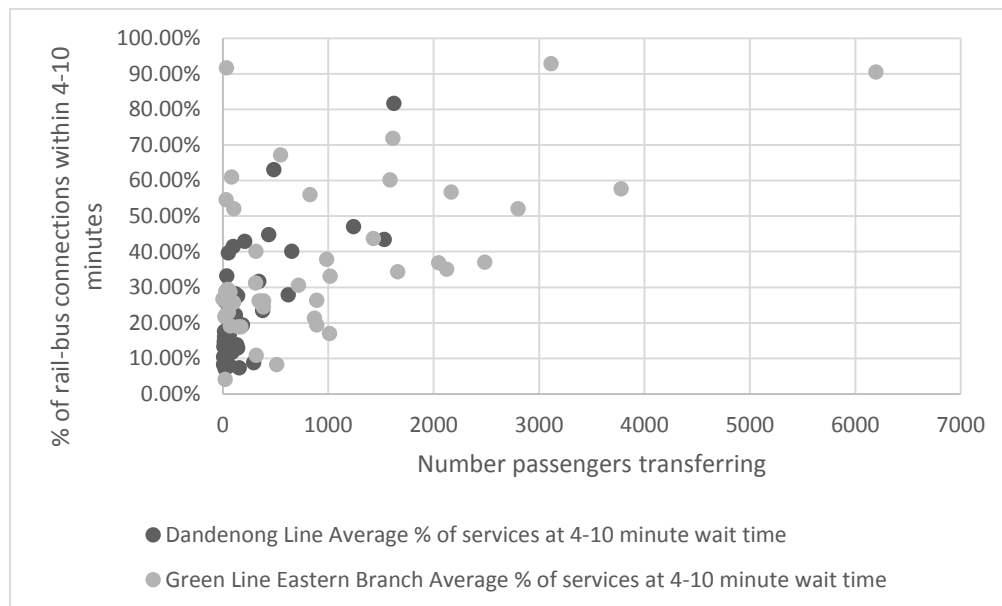
Overall:

- A high percentage of bus services departing within 4-10 minutes of train arrivals is no guarantee for high levels of interchange.

- A number of locations in both cities see a high percentage of 4-10 minute connections, but low (below 250 transfers per weekday) rates of transfer. A number of these are locations where passengers are walking some distance from frequent bus services to a more distant station. This pattern is present to some extent in both cities, and may represent a passenger preference to utilise a high quality bus service to access frequent rail services, even in circumstances where that bus does not directly serve the rail station.

Nevertheless, these issues do not fully explain all outlier results- particularly the large variation in transfer rates in Montreal for locations with an optimal interchange average between 30 and 40%;

In addition, Figure 7 shows also that:

- High rates of transfer, those above 1000 per day, do seem to be related to higher rates of optimal rail-bus interchange. In particular, there are no locations with an interchange rate over 1000 where fewer than 30% of services are within the 4-10 minute block.

- The highest rates of transfer have a strong correlation with low wait time transfers. All locations with greater than 2000 transfers have rates above 35%.

- Very high rates of transfer seen in three Montreal locations: route 33 at Langelier, 139 at Pie IX and 67 at Joliette have over 55% of bus services departing within 4-10 minutes of rail arrival. The latter two (139 and 67) have rates over 90%, offering a very high quality of service reflected in very high rates of transfer. Substantial patronage along the Pie IX corridor has prompted plans to upgrade the route to a full Bus Rapid Transit standard (see Figure 8). Network effects appear to be occurring.

- Inversely, there is a strong correlation between very poor levels of service connectivity and very low levels of interchange. A substantial proportion of the Dandenong line's services fall into this category.

5. Conclusions

This paper has reported on results of an ongoing research effort into the relationship between public transport interchange quality of service, and rates of transfer. The research compares case study locations in Melbourne and Montreal and is primarily interested in the factors behind materially higher rates of feeder transit access in the Canadian city.

Analysis of the relationship between service levels, timetabled wait time and rates of transfer outlined in this paper confirm that the issue is complex. Overall, a high rate of service and a high proportion of bus-rail and rail-bus timetabled coordination in a 4-10 minute connection wait time period appears mandatory for substantial levels of transfer to occur. This holds true for both case studies. However, results are inconsistent, with high levels of service and coordination not guaranteeing high rates of transfer. Equally, moderately high rates of transfer are seen where a lower proportion of services connect within a low-wait time period. A more consistent relationship is observed between low rates of service (below 100 buses per day), sub-optimal timetable coordination and low rates of interchange. In a result of interest for Melbourne, a substantial number of services along the Dandenong Line have low service frequencies and correspondingly poor connectivity and rates of transfer.

The evidence in both cities points toward a minimum service standard of around 100 services per day (roughly equivalent to a 20 minute inter-peak headway) in order to achieve meaningful rates of transfer. The Montreal case study provides many more services at or above this level (see Table 4). Combined with high frequency Metro services, this provides Montreal passengers with frequent access to a wider part of the city. Average rates of transfer are substantially higher for Montreal's higher frequency bus services, providing some evidence of a 'network effect'.

This research is limited by data sets available. In particular, the PTV station access data set does not measure station egress modes, thus rates of transfer from bus-rail must be used as a proxy for passenger response to the quality of interchange in both directions. This is obviously imperfect. Analysis has shown that substantial differences exist in the quality of bus-train service levels compared to train-bus in both cities, although less so in Montreal. With the very high performing transfer pairs in Montreal as notable exceptions, the service offer in the train to bus direction is consistently poorer in both case studies. PTV's establishment of a station egress patronage data set would be beneficial. Optimally, a more nuanced analysis may be possible with broader access to smart card data, allowing consideration of fine grained patterns of transfer between particular bus and rail services in both directions.

Within the limitations of available data, further research is underway into other factors potentially influencing the varying rates of transfer seen in the case studies. This incorporates a statistical analysis of additional variables, including extent of park and ride provision, service punctuality, catchment population density and the directness of feeder transit access to stations. This latter measure will directly investigate the influence of Nielsen et al's (2005) observations on importance of simple and stable line route and operating patterns. Qualitative

consideration of the physical interchange environment will add further understanding to the observed patterns.

5.1.   Does it matter? For a genuine 'metro' service in Melbourne: YES.

The findings of this paper, and results of further research outlined above, will be important for planners interested in the network effect from a practical perspective. However, the impending multi-billion dollar investment in Dandenong line grade separations and Melbourne Metro Rail project mean they will be of particular importance to planners in Melbourne. These immense investments are substantiated by projected patronage growth and designed 'to transform Melbourne's rail network into an international-style metro system' with high frequency services (http://mmrailproject.vic.gov.au/, retrieved 5 June 2015). Currently nearly 85% of access to Melbourne's rail network is via walk up or auto access, with just 15% arriving by feeder transit (PTV, 2013). In contrast, Montreal's metro achieves a 33% access mode share by feeder transit (AMT, 2010). Although strategic land use plans envisage incremental population growth around Melbourne's existing and growth corridor rail stations (DEWLP, 2014), this, along with any rational enhancement of park and ride provision will in no way satisfy the additional 850,000 daily riders envisaged by PTV in 2030 (PTV, 2012a:14). Transforming the effectiveness of bus feeder transit in Melbourne, to a level approaching the best seen in Montreal, will therefore be critical to ensure new infrastructure will achieve the patronage growth on which it has been substantiated. Failure to do so will fundamentally undermine the economic logic of the largest investment in Melbourne's public transport since the City Loop.

Figure 8 ~~'Build it and they'll come'~~ 'They came so we'll build it'. Image of proposed Bus Rapid Transit along Boulevard Pie IX, Montreal (Route 139). Source amt.qc.ca/en/news/projects/pie-ix-bus-rapid-transit
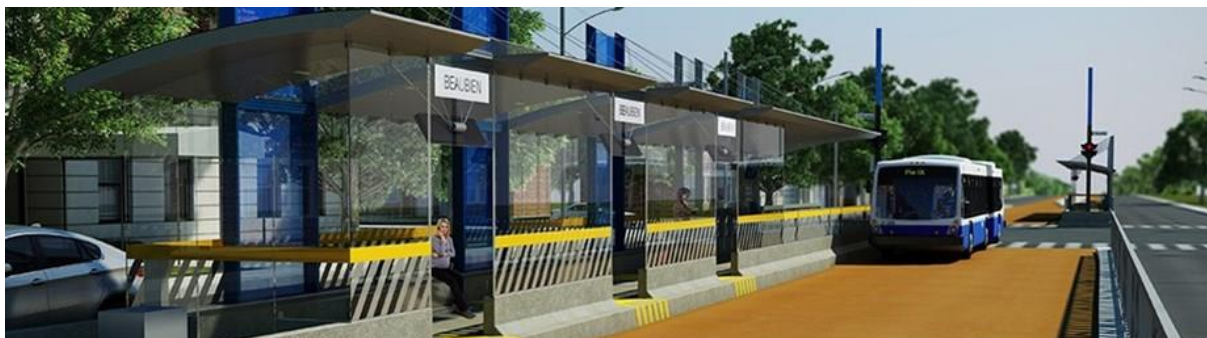
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