Exploring Bus Transfer Behaviour in Metropolitan Melbourne

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ABSTRACT:

Although passengers dislike transferring between routes, quality transit systems need to facilitate easy transfers to provide competitive city wide access to the private car. This paper reviews bus transfer behaviour in Melbourne, Australia and aims to understand factors which enable transfer behaviour with a particular focus on buses. The research also explores if high transfer rates can be associated with 'network effects'; high ridership associated with frequent services/ simple (grid) networks.

Around half of bus travellers make transfers – mostly to rail. Transfers between trams/buses are low overall, however in inner/CBD areas where trams run they dominate bus transfers. Younger people, secondary students, males, commuters and those using periodical and full fare tickets (like commuters) have higher bus transfer rates. Middle and older age groups, off peak travel, shopping trips and concession ticket holders have lower bus transfer rates. Because commuters transfer more, weekday peaks have high transfer rates. Analysis of bus route types shows that transfers are higher for more frequent and longer distance routes, those with simpler (straighter) route design, commuter based services and those which operate in networks which require transfers. Schedule coordination with rail was shown to increase transfer rates but not by much. Analysis of transfer route pairs demonstrated a modest (R^2= 0.25) though significant relationship between the volume of transfer trips and service frequency. Analysis of the best or highest frequency transfer route pairs showed that high volume transfers tend to occur where one of the routes has a frequency of 10 minutes or better. This is an important finding because current bus network plans are for a 15 minute based grid route network. These findings suggest that if major routes in the grid network have 10 minute headways or better then a significantly higher share of transfers would result.

Analysis of very high bus transfer sub-networks showed a concentration of transfers around a grid network with high frequency service near the CBD. A comparative analysis found that this area has high service frequency, network density and residential density. The analysis concluded that this transfer behaviour was highly consistent with the 'network effect' but this cannot act as conclusive proof the effect exists since high transfer rates can also be explained by the nature of travel patterns in this area. In simple terms the 'network effect" though intriguing remains an unsubstantiated theory which informs good practice but should be treated with caution when applied in the real world.

Keywords: Bus, Transport, Interchange, Travel behaviour, Public Transport, Network Effect

1. INTRODUCTION

The principal planning goal of most transit agencies worldwide is increased ridership (e.g. Hemily 2004). Expanding services and investing in new infrastructure is widely seen as effective in growing ridership but faces significant cost effectiveness and funding challenges (Balcombe et al. 2004; Currie and Wallis 2008). Financial barriers also act to constrain the spatial coverage of transit investments leaving planners with limited scope to address the metropolitan wide access, congestion and environmental problems facing growing 21st century cities. There is now a growing amount of literature suggesting that the most cost effective means of addressing city wide public transport issues is the operation of a quality public transport network which encourages interchange between routes in an efficient and effective manner (Nielsen et al. 2005). Urban private car travel in cities can achieve direct door to door access to almost all destinations using road networks. However transit travel can rarely achieve direct transfer-free access using a single route to more than about 5% of all urban destinations. Transfers between routes and a network to encourage them are therefore essential features of an effective public transport system.

A range of research has suggested that simple, frequent grid-based[1] transit networks can act to create a 'network effect' whereby ridership growth is substantially higher than might be achieved using individual, route-based investment (Mees 2000; Nielsen et al. 2005). High ridership is said to be generated because the network is easy to use and remember and routes are operated at high frequencies making transfers easy to make. However evidence supporting this concept in public transport systems is limited. The case for encouraging transfers is also constrained by the substantive evidence which shows that passengers dislike making transfers (Horowitz and Thompson 1994; Currie 2005). There is therefore clearly scope to explore existing transfer behaviour as a means of informing policy as to ways forward in encouraging transfers.

This paper concerns a review of bus transfer behaviour in Melbourne, Australia. The aim of the research is to better understand factors which act to encourage interchange between public transport routes with a particular focus on the bus network. The research is also seeking to explore if high levels of transfer behaviour can be associated with network effects. The paper analyses travel survey evidence and reviews network and service features to address these objectives.

The next section of the paper presents a summary of the research literature associated with transfer behaviour, transfer network design theory and the concept of the 'network effect'. This is followed a brief description of the bus network context in Melbourne which is the focus of the research. The research methodology is then described followed by a review of the results. The paper concludes with a discussion of the major findings and some conclusions from the research.

2. RESEARCH CONTEXT

Networks with city wide coverage and offering good quality transfer opportunities have been seen as an essential component of effective public transport systems:

> "To attract passengers and compete with private automobiles throughout an urban area, transit must offer integrated services by area wide networks. To achieve intramodal integration.... convenient and efficient transfers amongst lines must be provided"
>
> (Vuchic 2007, p215)

Evidence suggests that multi-destination based transit networks such as grid and timed transfer based systems are more robust than networks which overly focus on central or CBD destinations (Thompson 1977). Multi-destination based networks have been shown to be more effective in terms of mode share, service effectiveness and cost effectiveness (Brown and Thompson 2008). On this basis, policies which have encouraged decentralisation of transit systems have not necessarily been shown to be detrimental to transit (Brown and Thompson 2007).

"Network Synergies" is a concept developed from the field of communications economics and refers to cohesiveness, cooperation and efficient interconnectivity within communications networks resulting in

[1] Grid based networks including straight routes running north-south and east-west creating a network of boxes around suburbs. They contrast to the typical radial transit network operating to the CBD in typical western cities.

performance which exceeds the sum of the individual parts of the network (Capinerni and Kamann 1998). Within public transport a number of theorists have suggested that well designed networks can create a 'network effect' whereby ridership is higher than might otherwise be expected (Mees 2000; Nielsen et al. 2005). The effect applies to all modes of public transport including bus and rail. Typical features of successful networks in this context are:

- Networks using high (forget the timetable) frequency (services with headways less than 10 minutes)
- Stable routes with fixed stopping patterns
- Direct simple network structures using as few individual routes as possible

It has been suggested that creating a successful network of this kind can result in ridership growth which might be more than 10 times higher than that experienced when improving individual, route-based services (Nielsen et al. 2005). While there is some empirical analysis suggesting that transit systems which have high transfer rates also have higher mode share (Terzis and Last 2000), this is hardly a conclusive basis for expecting such enormous ridership impacts. The case for the 'network effect' whilst intriguing remains a purely theoretical concept until proven empirically.

A major barrier to generating transfers is the behavioural resistance which passengers display towards them. This is encapsulated in the 'transfer penalty'; the perceived disadvantage of making a transfer measured in terms of equivalent in-vehicle travel time. A wide range of research has measured transfer penalties and indicates they are of a significant size. A meta-study of some 22 measurement studies (Currie 2005) showed that bus-bus transfer penalties can range from 5 minutes to 50 minutes with an average value of around 22 minutes. The same research indicates that transit systems with better design features can reduce the scale of the transfer penalty. These features include higher frequency services, better quality of amenities provided for making the transfer and proximity between transfer locations. For example underground subway systems have transfer penalties at an average of 8 minutes with some values as low as 1-2 minutes. Rail services of this type were shown to have lower transfer penalties and all tend to involve simpler rail based network structures (Currie 2005).

US based research concerning the design of interchange facilities has also used transfer penalties as a means to establish principles for good design (Horowitz and Thompson 1994). Transfer penalties as high as 32 minutes for interchange locations without weather protection were identified. Values were halved to 16 minutes when interchange locations had weather protection provided. Interchanges where scheduled transfer (or synchronisation) of times between routes were coordinated was shown to reduce transfer penalties from 8 minutes to 4 minutes.

Based on the above discussion it can be concluded that achieving multi-destination transit networks (grid and timed transfer networks) which encourage transfers are a positive objective for urban transport. Some research suggests high frequency, simple and stable networks can generate 'network effects' which have substantial ridership growth potential. However research supporting this theory is minimal. A more substantial evidence base suggests transfer penalties are a major problem for transit users. However the same evidence shows that transfer penalties are lower for transit systems with higher frequency, simpler route structures, and with coordinated timetables (e.g.Ceder 2007) and better quality of amenities at interchange locations. Clearly both the network design and transfer penalty research fields share a common view on what design for increased transfer rates involves. It is within this context that research on Melbourne's bus transfer behaviour was undertaken.

3. MELBOURNE BUS NETWORK

Melbourne is a city of some 3.8 million people on the Southern coast of Australia. The city's public transport network consists of trains, trams and buses, attracting around 13% of all motorised trips (Department of Treasury and Finance 2007). There are some 451M p.a. boardings on Melbourne's public transport system with Bus representing 101M (2007/8, Department of Transport 2009).

Melbourne has some 314 regular bus routes, predominantly providing cross-town services in the middle and outer suburbs. Only about 30 bus routes provide direct access to the central city which is mainly catered for by tram and train (Loader and Stanley 2007). Studies have shown that Melbourne bus service levels are low compared to other cities (Currie 2003). A review in 2003 noted that on average weekday bus headways were some 40 minutes in the peak and 50 minutes off peak (Currie 2003). The average evening finishing time for bus services was 6:53 p.m. Only some 20% of bus services ran on Sundays at all. It has also been suggested that the bus network in Melbourne is complex with many circuitous routes (Mees 2000; Nielsen et al. 2005).

Melbourne bus service levels were recognised as a major problem and recent policy has invested in new bus routes and services (Department of Infrastructure 2006). Between November 2005 and July 2008 some 111 bus routes were converted to higher base service levels and 19 completely new bus routes were introduced. The bus network and major tram and rail services are being restructured around the concept of the ‘principal public transport network’. This envisages a grid of major routes based around 15 minute headways operating to all major activity centres in the city.

Melbourne’s’ tram network is the largest in the world operating over 250 kms of track on 28 routes (Currie and Shalaby 2007). Services are operated with a largely grid based network structure within the CBD and a radial network covering the inner suburbs connecting to the CBD. The network in its present form has been operating for about 100 years with only minor changes over this period. Average peak headways are around 7.5 minutes (8-10mins off peak) for each route reducing to about a minute on parallel route sections entering the city from the south on St Kilda Road.

The rail network in Melbourne is an electrified suburban system covering 372 km of track on 15 lines with 211 stations. The network is entirely radial to the CBD area. Average peak headways in the peak are about 10 mins (about 15-20 minutes off peak).

4. RESEARCH METHODOLOGY

The aim of the research is to better understand factors which act to encourage high rates of interchange between public transport routes with a particular focus on the bus network. The research is also seeking to explore if high levels of transfer behaviour can be associated with the network effect concept.

Analysis is based on the results of a Bus Origin and Destination Survey (BODS) – which involved intercept surveys on board buses on most of Melbourne’s bus routes between February 2007 and November 2008. Surveys were undertaken on buses between around 6am and 8pm, with a representative sampling of timetabled vehicle trips through the day. As this is an intercept survey, and the interview took several minutes to complete, off-peak travellers, people travelling longer distances and people with good English language skills are likely to be over-represented in the sample. Persons under 15 years of age were not interviewed.

The central focus of the analysis was bus transfer behaviour. Analysis concentrated on bus-bus and bus-tram behaviour however some bus-rail patterns were also illustrated.

5. RESULTS

Results are organised into the following groups to explore the research questions identified above:

- Passenger Type and Transfers
- Trip Type and Transfers
- Bus Route Type and Transfers
- Transfer Volume and Service Frequency
- Spatial Variation in Transfer Rates
- Exploring High and Low Bus Transfer Rate Networks.

Passenger Type and Transfers

The BODs survey questionnaire was necessarily short leaving only limited room to ask questions about wider socio-economic passenger characteristics. Table 1 shows the share of bus trips making transfers by mode and age group and overall by gender. Bus ridership has a 48% transfer rate which is almost half of trips made. Bus transfers to rail are the most common followed by bus-bus and then bus-tram transfers.

Bus passengers aged 20-29 make the most transfers overall and make the most train transfers and tram transfers. Bus passengers aged 15-19 make the most transfers between buses. Bus passengers make less transfers to trams compared to other modes.

Overall a significantly higher share of male bus passengers make transfers than female bus passengers. Analysis by age group shows male bus passengers are more likely to transfer with heavy rail, and the difference from females is highest for the 40 and 59 age groups. This is likely to reflect white collar males travelling to the city by bus and train.

Overall these patterns suggest young people and males make transfers more often. While bus-heavy rail/ bus-bus transfer behaviour is more common this is likely to be associated with the limited network opportunities to make bus-tram transfers and the proliferation of bus-bus and bus-heavy rail opportunities.

TABLE 1: Bus Transfer Behaviour by Age Group

Age Group	Heavy Rail	Bus	Tram	Total
15 – 19	25%	21%	7%	51.1%
20 – 29	32%	14%	10%	54.6%
30 – 39	27%	16%	8%	49.8%
40 – 49	25%	14%	8%	46.2%
50 – 59	21%	17%	9%	44.9%
60 – 69	13%	14%	7%	33.9%
70 +	9%	14%	9%	31.9%
Grand Total	**25%**	**16%**	**8%**	**47.7%**
Male	29%	16%	8%	51%
Female	21%	16%	8%	44%

Source: *Bus origin and destination survey*

Table 2 suggests that passengers with long term periodical tickets make more transfers than those with (short trip) '2 hour' (generally single trip) tickets. This is suggestive that commuters make more transfers than other passengers. Seniors ticket holders make fewer transfers while Student ticket holders make more. This is supported by the analysis of transfers by age group above. People using concession tickets make a lower share of transfers than full fare passengers. Again age group (seniors have concession tickets) and commuters (who are a major element of full fare passengers) are acting to affect these patterns.

TABLE 2: Share of Transfers by Ticket Type

Ticket Type	Transfer Rate[1]
2 Hour (time based)	38.3%
Daily (all day)	55.1%
Monthly	63.5%
Seniors	39.1%
Student	61.7%
Weekly	61.1%
Yearly	63.0%
Concession	42.8%
No Concession	55.5%
Zone 1	46.8%
Zone 2	36.1%
Zone 1+2	73.7%

Note: [1]*Bus O-D Survey 2008*

The Melbourne fare system is divided into two large fare zones, with zone 1 covering the city centre and inner suburbs, and zone 2 being the middle and outer suburbs. Passengers must purchase a ticket valid in zone 1, zone 1 and 2 or zone 2 only. Table 2 shows considerably higher transfer rates for Zone 1+2 ticket holder, reflecting the likely higher need to transfer to make longer distance trips – particularly commuting trips where a combination of bus and train to reach the inner city is required.

Analysis also considered the share of bus transfers made by passengers who had access to a car for that journey (termed 'choice' passengers this suggests passengers chose a bus over a car). Some 49.4% of choice bus passengers made transfers whilst 46.9% of other passengers made transfers. Again a plausible theory is that commuters are associated with choice travel because they make trips to CBD locations with poor parking availability. A higher share of transfers for choice passenger might be associated with commuters.

Trip Type and Transfers

Figure 1 shows the distribution of transfers by trip purpose. Student and commuter travel have high shares of transfers as do social and visiting friends and relative trips. Shopping appears to have a particularly low rate of bus transfer behaviour, probably because most bus routes directly service local shopping centres.

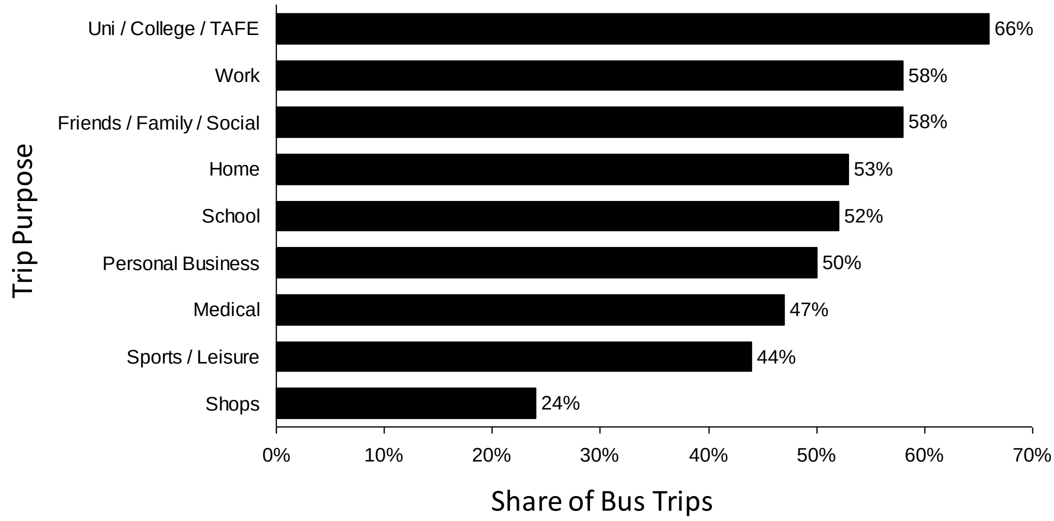

FIGURE 1: Share of Bus Transfers by Trip Purpose

The above suggests peak (commuter based) trips might have higher transfer rates than off peak (shopping based) trips. This is confirmed by analysis in Figure 2. Total transfers are higher in the a.m. and p.m. peak largely due to high bus-rail transfers at these times. Bus-bus based transfers are slightly higher off peak while bus-tram transfers are relatively stable throughout the day.

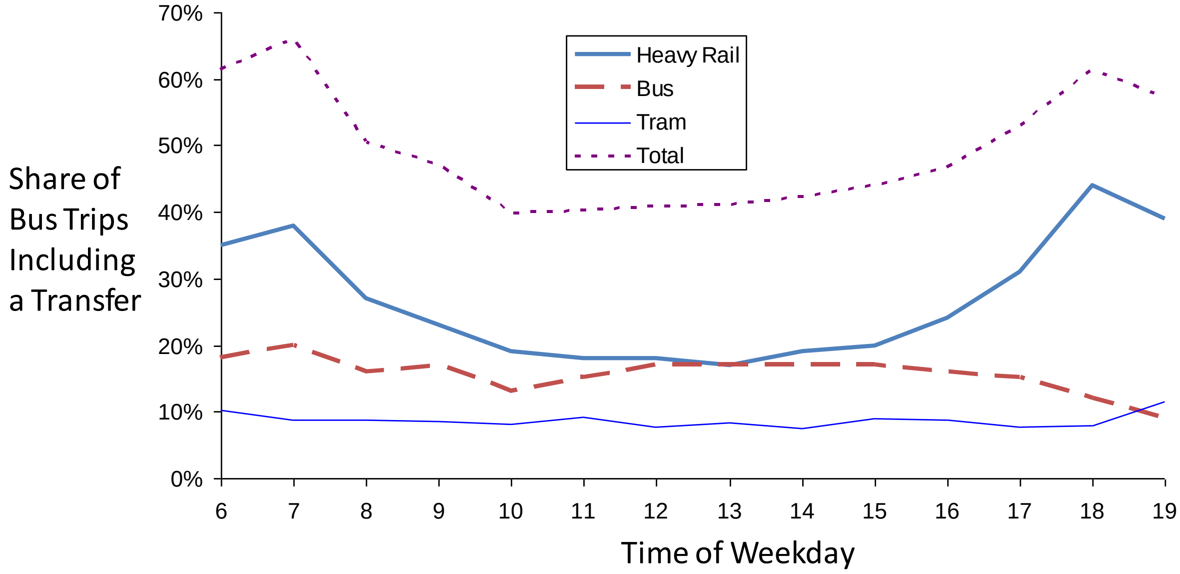

FIGURE 2: Share of Bus Transfer Trips by Time Period

Bus Route Type and Transfers

Table 3 shows a tabulation of the share of bus transfers by type of route. By comparing the characteristics of routes with above and below average transfer rates the following key drivers of transfer behaviour can be hypothesised:

1. High Frequency Service Basis
2. Longer Distance ‘Straighter’ Route Alignments Basis (as opposed to local and shorter distance services)
3. Commuter Based Service Basis (including weekday services and those bus routes feeding to rail and tram)
4. Not Involving Direct Routes into the City (routes directly feeding into major traffic generators do not need transfers for most passengers e.g., the Eastern Freeway Corridor routes identified).

TABLE 3: Share of Bus Transfers by Bus Route Group

Bus Route Type	Explanation	Share of Transfers [1]
Above Average		
Tram Link	• Bus route that includes shuttle services that meets every tram at the tram terminus for a section of the route, effectively extending the radial service further out. The full route (running at around half the frequency) connects to two train stations.	58.1%
Local routes	• Bus Routes operating in local areas only (not the city centre), with the vast majority as feeder to rail service, excluding routes with relatively high service levels	53.7%
Full	• Bus routes that operate at relatively high frequencies and have long hours of service. These are typically orientated towards the central business district.	56.0%
SmartBus	• High service level cross-suburban routes (high frequency and long service spans) with bus priority and features like BRT lite services	54.3%
Trainlink	• Two bus routes operating as a direct feeder to rail, that connect with every rail service at two rail termini points	50.7%
Below Average		
Safety Net	• Local routes that have a relatively long span of hours – with services until 9pm seven days a week	44.8%
Eastern Freeway Corridor	• Bus operating directly to the CBD from Doncaster, a region without any local rail services • Reasonable service levels focussed mainly on the peak but with direct access to the city	30.7%

Note: *[1]Bus O-D Survey 2008*

Analysis also considered whether bus transfer to rail were affected by whether bus service had a service headway that “harmonised” with rail headways (by harmonised, we mean the inter-peak bus headway was a round multiple of the inter-peak train headway). Results show that bus routes without rail harmonised headways have a rail transfer rate of 22.8% while those with rail harmonised headways have a rail transfer rate of 24.7%. While schedule coordination clearly acts to increase rail transfer rates the difference it makes appears to be small. This might partly be related to the reliability and timetabling constraints of bus services making schedule coordination difficult to achieve at all interchange points in practice.

Transfer Volume and Frequency

A separate analysis of bus-bus and bus-tram transfer route pairs was undertaken to explore the features of high and low transfer activity between routes. This excluded bus transfers associated with heavy rail since this was clearly based on long distance and commuter based behaviour. The bus/tram analysis sought to explore transfers excluding these influences.

Figure 3 shows the relative volume of transfers per day against the **average headway** of the two route pairs where transfers were being made.

This highlights that while there is a relationship between service frequency and transfer behaviour it is not a simple one. There is a group of very high transfer route pairs (transfers above 100 per day) which all occur on high frequency services (average headways below 20 minutes). Conversely, when average headways are low e.g. more than 40 mins, transfers per day never occur above about 50 with most lying between zero and 20. Nevertheless there are many high frequency bus services which have a low volume of transfers. Overall a statistical fit between average headway and volume of transfers does exist but it explains only 25% of the variance between the two variables.

The very high transfer route pairs (over 100 per day) were found to be all made between bus and tram and spatially concentrated in the largely grid based network of bus and tram routes north of Melbourne CBD called Moreland South (see Figures 5 and 6) . Since this network involves a grid of higher frequency services this and other comparable networks in the city were further analysed to assess if this behaviour could be part of a 'network effect' (see later).

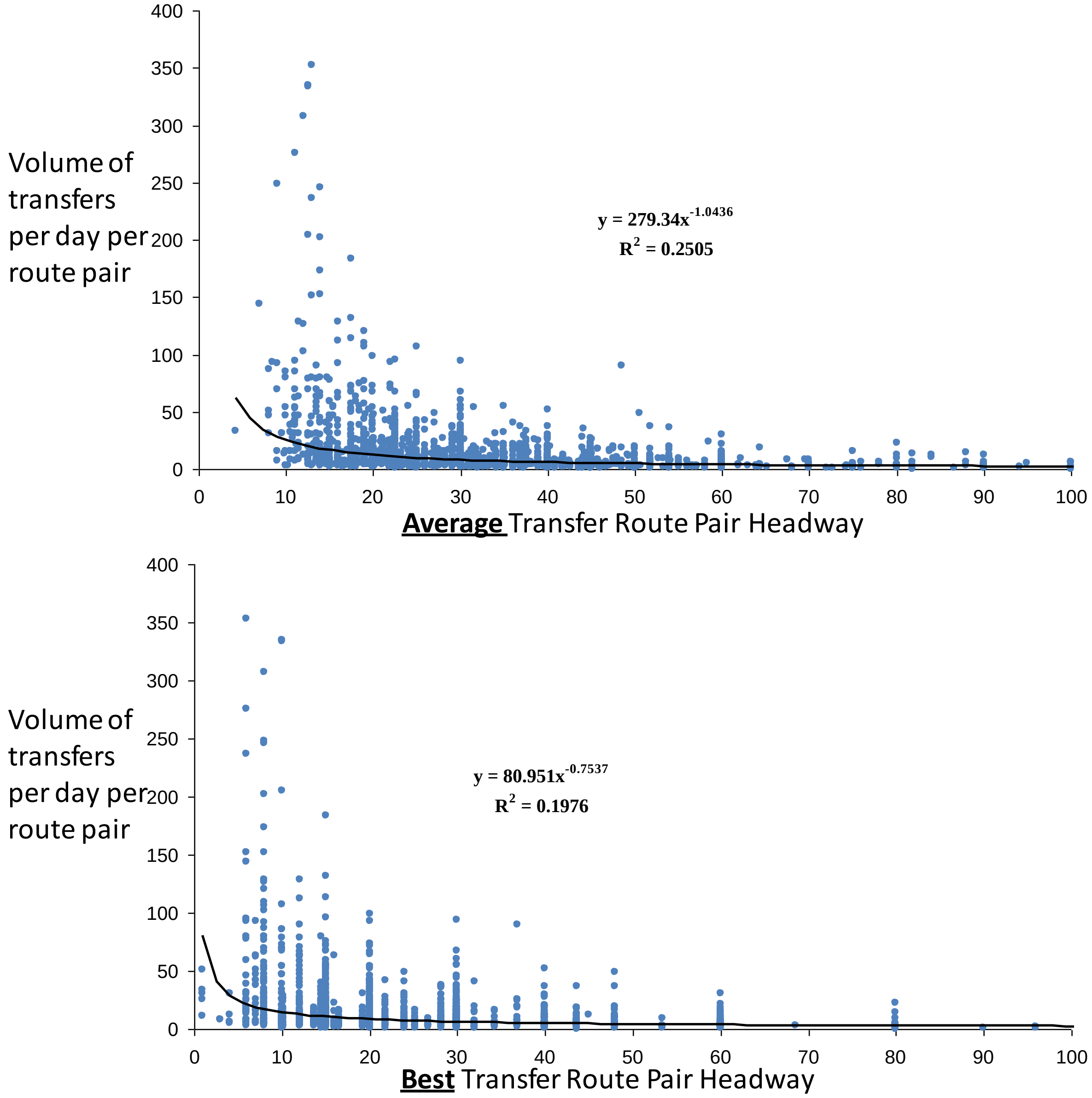

FIGURE 3: Volume of Bus Transfers by Average and Best Headway – Bus and Tram Route Transfer Pairs

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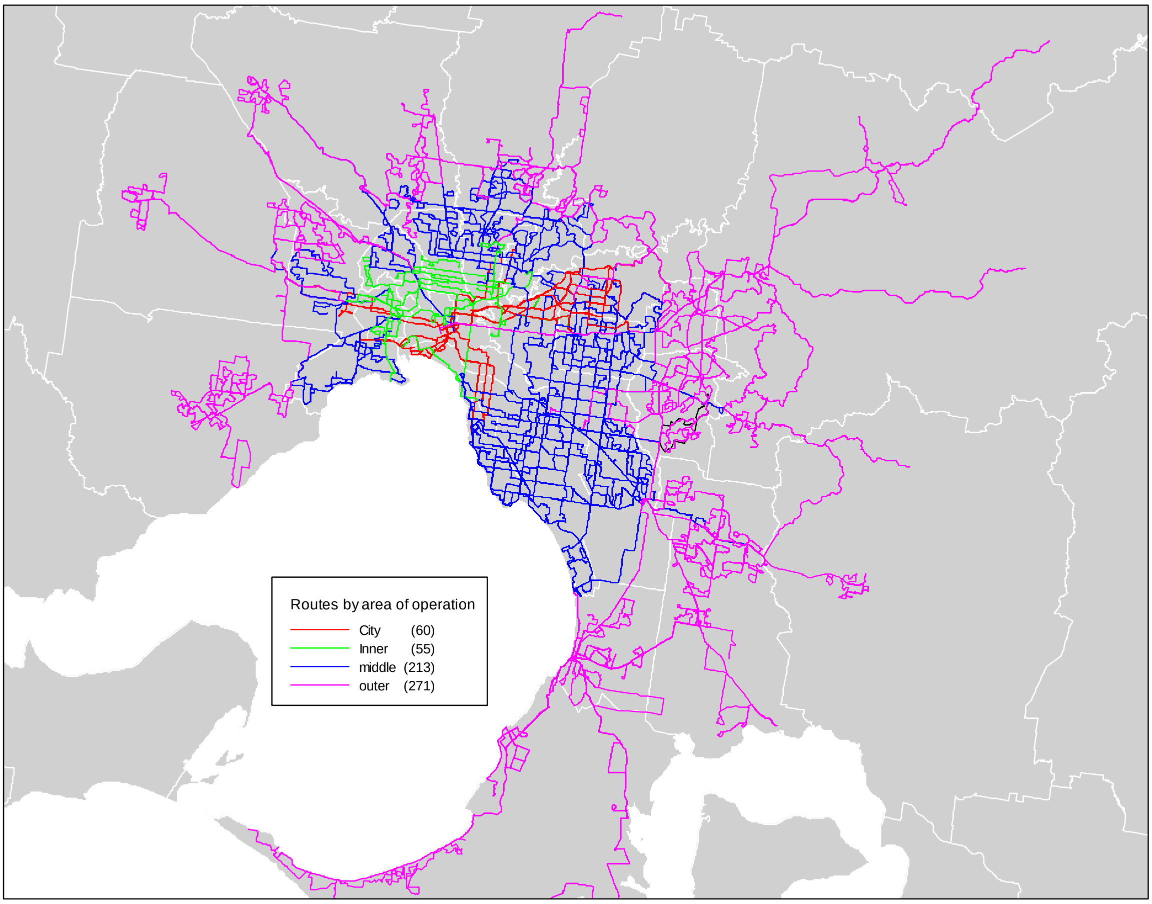
Figure 3 also explores if it is the headway of the transfer route pair with the **best headway** (highest or best frequency) which might be explaining high transfer behaviour. This had a lower overall statistical fit (R^2=0.2) however it does suggest a strong association between higher volume transfer pairs and routes with high frequency. The vast majority (81%) of all transfer pairs over 100 per day occurred when one of the transfer routes had a headway at or better than 10 mins.

These findings suggests that an average headway of 15 minutes, and at least one route with a headway of 10 minutes or better appear to be necessary to facilitate high transfer rates (at least well above the general trend in relation to service levels). In Melbourne, only two bus routes meet the 10 minute headway requirement, and so invariably these high transfer locations must involve tram routes (which almost always run at headways of this level).

Interestingly, for occasions where 15 minute bus routes intersect, the data shows transfer volumes were still relatively low – less than 60 per day. This suggests that a grid network of 15 minute headway bus routes may be insufficient to facilitate large numbers of transfers. Currently it is proposed to roll out a grid of 15 minute headway bus routes across Melbourne's middle and outer suburbs (the Principle Public Transport Network), which may be insufficient to facilitate trips requiring transfers. However, if half of the routes in the grid network were to operate at 10 minute frequencies (similar to tram), then these findings suggest that transfer rates, as well as ridership might be significantly higher.

Spatial Variation in Transfer Rates

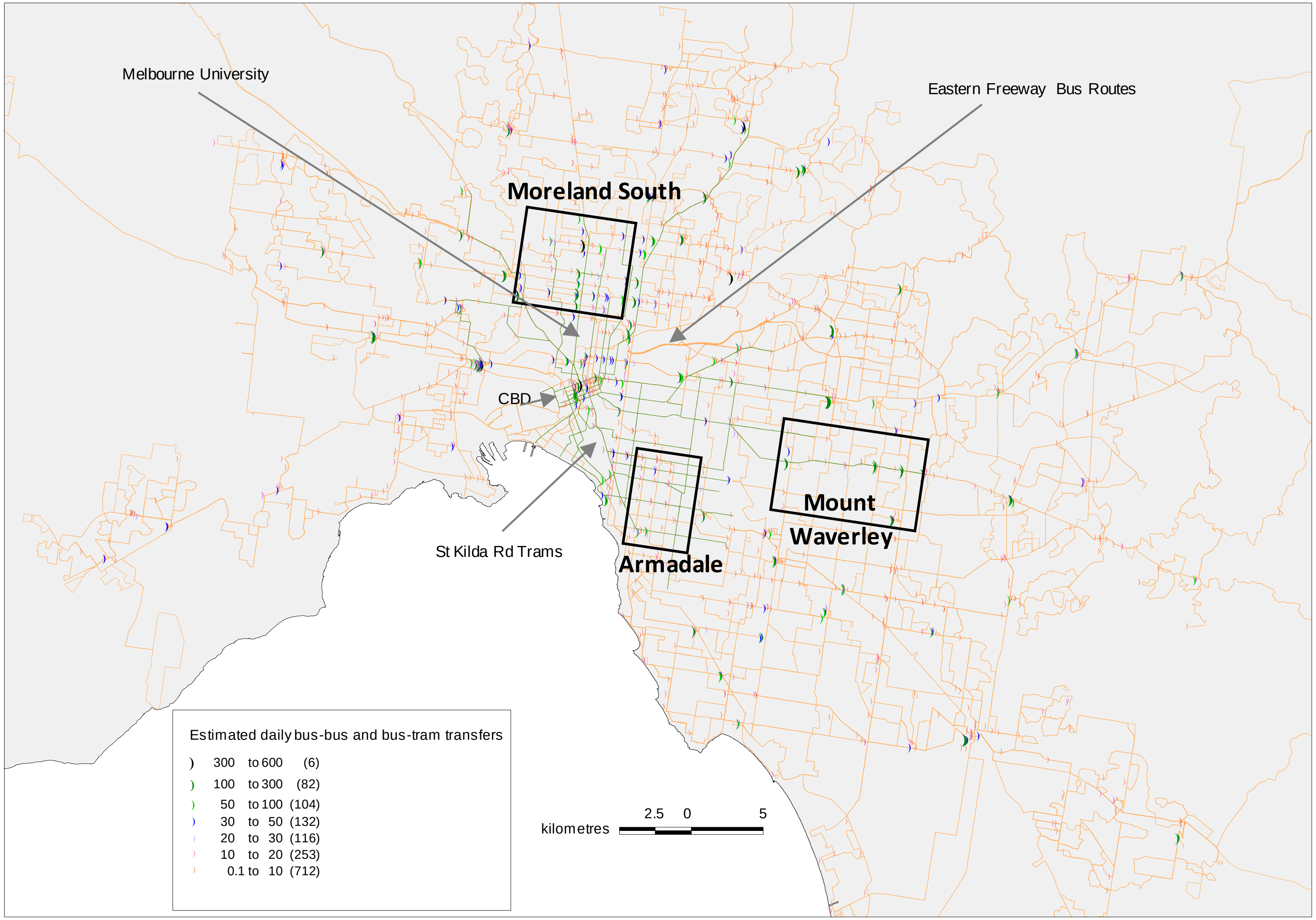
Figure 4 shows the share of bus travel which involves transfer by spatial route classification (CBD, Inner, Middle and Outer) and also by transfer mode to/from bus. This indicates low bus transfer rates for CBD routes which might be expected since only direct long distance bus routes feed to the CBD in Melbourne. These routes have relatively high penetration of the city and are thus likely to generate high shares of walk access/egress rather than inter-modal transfers. Of the transfers which do occur in the CBD they are highest to tram which might also be expected given the high density/ high frequency CBD tram grid network which is the principle form of CBD transport distribution. Transfer rates don't vary much between inner, middle and outer areas. Of these inner areas, again with higher density networks and higher frequency service have the highest rates. Trams have high transfer rates with bus in Inner as well as CBD areas but little beyond this (because there are very few tram routes in middle and outer suburbs). Rail-bus transfers dominate all areas except CBD routes.



Route Classification	Heavy Rail	Bus	Tram	Total
CBD	8.1%	8.9%	15.7%	30.7%
Inner	23.7%	14.4%	19.9%	56.6%
Middle	28.8%	17.3%	5.1%	50.4%
Outer	33.5%	18.1%	1.3%	45.9%

FIGURE 4: Bus Transfer Share by City Zone and Mode

FIGURE 5: Spatial Distribution of Bus Transfer Volume



Exploring High and Low Bus Transfer Rate Networks

Figure 5 shows the distribution of transfer volumes by the specific location of the transfer. Transfer volume is shown in both size of dot and colour coding. The graphic also shows the structure of the bus routes (brown) and tram routes (green).

Figure 5 shows that real world transit networks do not easily fit into the simple grid vs radial structures of theory. Although the CBD clearly has a number of radial transit routes (notably rail and tram) in practice there are grid route structures in many parts of the city. As noted, the bus network doesn't have many routes into the city. There are some clearer grid-like route networks which are highlighted for further analysis. These include "Moreland South", "Armadale" and "Mount Waverley". These networks were selected due to their bus and grid network nature. "Moreland South" and "Armadale" are inner grid networks where higher frequency tram routes provide major elements of the grid. "Moreland South" has very high transfer rates while "Armadale" has less. They are selected to explore reasons for variation in transfer rates despite similar network structures. "Mount Waverley" is a middle suburban grid bus network with a larger grid spacing selected to explore the lower transfer rates identified in this area.

Figure 6 demonstrates the network structures of the bus routes in the three case study bus networks selected. This includes a summary of average daily bus transfers at each location. The case study networks are now discussed:

- **Moreland South -** This area lies 4-8kms directly north of the Melbourne CBD. Sydney Road (tram route 19) is a significant shopping strip. All tram routes (shown as dotted lines in Figure 6) operate radially towards the CBD, while bus routes are mostly in an east-west orientation. Most bus routes provide strong connections to the west and east, except routes 503, 509 and 512. The train line (shown in black) operates to Melbourne CBD every 20 minutes (peak and inter-peak). One major bus-bus interchange is visible at Moonee Ponds to the western side of the map. An informal interchange (merely nearby bus and tram stops) exists at the intersection of Bell Street and Sydney Road in the north. Tram routes 1, 8 and 19 go past Melbourne University to the south – a significant attractor for public transport users (where no student parking is provided).

  It is evident that transfers are highest at the intersection of highest frequency routes (tram 55 shows lower transfer rates – which may be explained by the lower inter-peak frequency). While tram 55 does travel into the CBD, it operates to areas about 1km west of the retail core, which is some distance from the more popular trip attractors). The intersection of Sydney Road and Bell Street is the highest ranked on-street interchange for bus-bus and bus-tram transfers in Melbourne, despite having no formal interchange infrastructure – shelters are only provided at some stops, walking paths between stops are not covered, and passengers need to cross extremely busy and noisy streets.
- **Armadale -** This location lies 6-12 kms south east from the CBD. In this case bus routes provide north-south links (routes 605, 220 and 216/9) while tram routes provide the east-west links (routes 67, 3/16, 5/64, 6 and 72). A key difference with the Moreland South network is that in Armadale almost all routes converge onto St Kilda Road and operate into the city. In the Moreland case only rail operates directly to the city. This may well affect transfer behaviour since it is not necessary to transfer to get to and from services to the city in Armadale. This area is generally of high socio-economic status.
- **Mount Waverley** – In this case most of the network comprises bus routes. There is a single tram route (route 75) and a rail route operating east-west to the CBD. The Mount Waverley case study network lies from 12-20kms from the CBD. Route spacing is generally wider than the other networks.

Table 4 presents some summary statistics for each of the case study networks based on the BODs survey and an analysis of services. These statistics are designed to measure bus transfer behaviour and to explore factors driving this behaviour. This indicates that:

- Armadale has a number of factors which would suggest a high usage of transit and high transfer rates; it has the highest network density the highest residential density and the highest frequency of service. However the data shows it has the lowest transfer rate overall. Perhaps significantly however, a high share of all routes in Armadale go directly to the CBD. This clearly means transfers are unnecessary for this major market.
- Moreland has a significantly higher transfer rate per interchange location than the others. It has a number of supporting factors which may be causing this; relatively high service frequency, high residential density and a high network density. Perhaps importantly for this area, a large share of trips travel to the south (the city and the University) yet only about half of the routes go there. This means transferring is going to be necessary for travellers to/from the east-west bus routes.

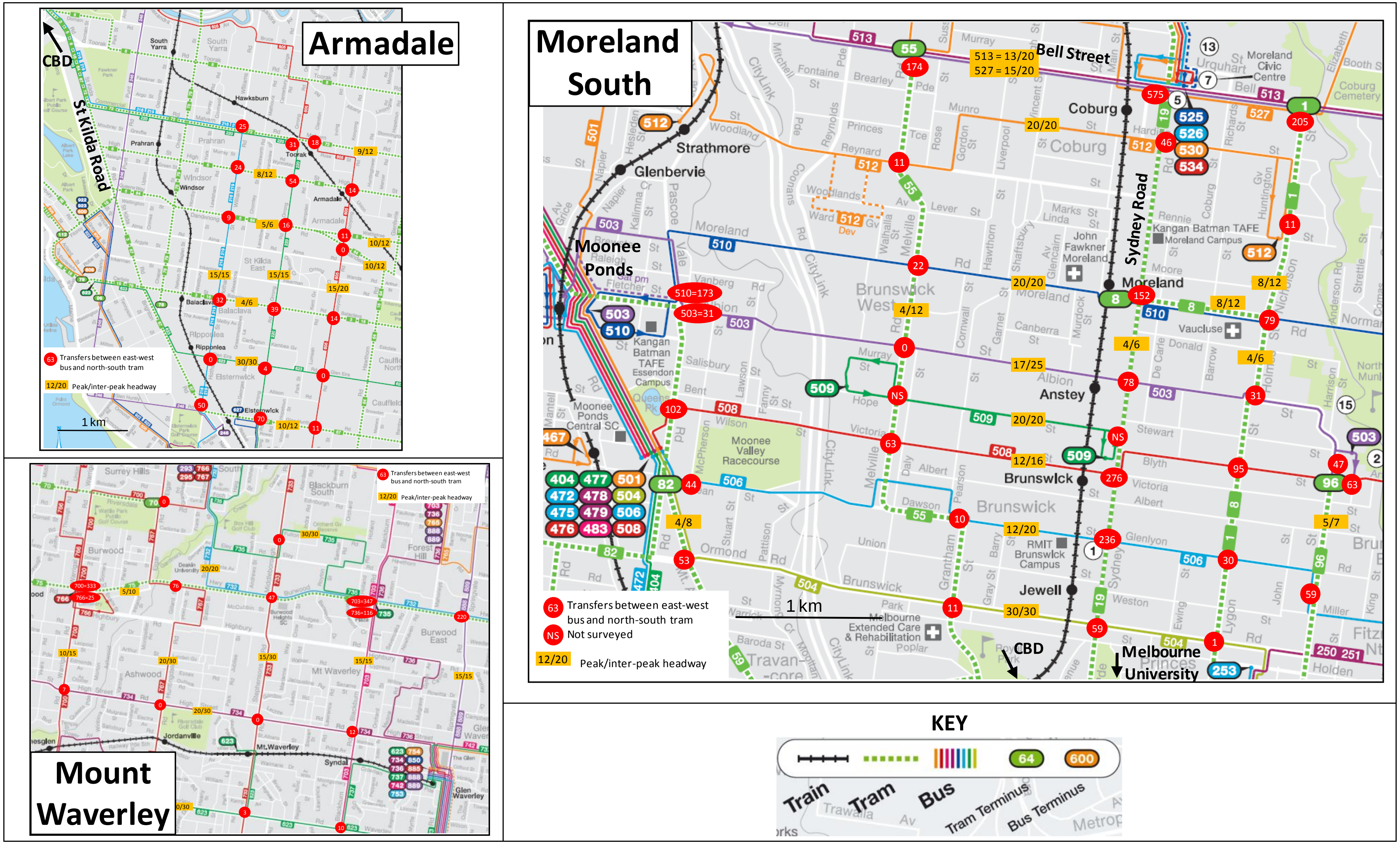


FIGURE 6: Case Study Bus Grid Network Areas (average daily bus transfers indicated at each location)

- Mount Waverley has a transfer rate lower than Moreland but substantially higher than Armadale. This area has the lowest frequency of service, residential density and network density. Being further from the city, the CBD is not as significant a destination hence the share of services operating directly to the city is less important.

TABLE 4: Comparison of Network Statistics

Measures	1. Moreland South	2. Mount Waverley	3. Armadale
TRANSFER STATISTICS			
Total bus transfers/ day	2,737	1,239	422
No. bus transfer locations	29	17	18
Average transfers/interchange location/ day	94	72	23
AREA STATISTICS			
Network area (km^2)	21.4 km^2	32.8 km^2	12.9km^2
Residential population (2006)	37,115	36,778	27,566
Average population density	1,735 km^{-2}	1,120 km^{-2}	2,133 km^{-2}
SERVICE STATISTICS			
No. Routes	12	10	9
Average peak service headway	13	18	12
Average inter-peak service headway	16	22	14
Direct routes to city centre (%)	5/12 (42%)	1/10 (10%)	8/9 (89%)
Route density (no. rtes/km^2)	1.8	3.3	1.4

So is the Moreland South area an example of a grid network demonstrating a 'network effect' and can the other case study networks help inform understanding of the concept? After some consideration it is only really possible to conclude that Moreland South is displaying symptoms and conditions highly related to a 'network effect' however it is not possible to definitely conclude the effect exists from this evidence. High transfer rates might be caused by high urban density and also the proximity to Melbourne University (a very high nearby trip attractor which is not directly accessible from east-west routes without transferring). Hence it may well be the nature of the travel market in Moreland South is resulting in high transfer rates rather than the nature of the network. The finding that Armadale has low transfer rates provides a useful insight into the network effect. High transfer rates will not occur if transferring is not necessary and in this case direct routes to the city make transfer access unnecessary. Does this mean that the Armadale network is overly generous in terms of service levels and route coverage? Perhaps the direct services should be cut back to encourage transfers? Such an argument is illogical since forcing transfers in this manner would disadvantage a significant share of the bus market. It is difficult to see how disadvantaging the market in this would act to 'improve' the network. It is difficult to conclude much about the Mount Waverley case in relation to the 'network effect' apart from the fact that transfer rates are lower and frequencies, network densities and residential density is also low as may be expected given the area is distance from the city and part of the lower density middle and outer suburbs.

6. DISCUSSION AND CONCLUSIONS

Although passengers dislike transferring between routes, quality transit systems need to facilitate easy transferring to provide competitive city wide access to the private car. This paper reviews bus transfer behaviour in Melbourne, Australia. The aim is to better understand factors which act to encourage interchange between public transport routes with a particular focus on the bus network. The research is also seeking to explore if high levels of transfer behaviour can be associated with 'network effects'. There are higher ridership levels associated with high frequency and simple route structures (e.g. grid networks).

The research literature shows there are benefits for multi-destination based networks rather than those associated with radial CBD design. Network effects have been theorised to occur where networks are simple and services run at high frequencies. Theorists have suggested high ridership gains for networks of this design although little evidence supporting this is available. Transfer penalties are measures of the passenger perceived disutility of making a transfer and can range between 1-2 mins and up to 50 mins in equivalent travel time. Research shows transfer penalties are lower when service frequencies are high and network structures are simple (e.g. with rail modes) however good design of interchange facilities is also important.

The results of field surveys show that around half of all travellers on Melbourne buses make transfers mostly to rail services. Overall tram based bus transfer are a low share of total bus travel however where trams operate (only in inner and CBD areas) they dominate bus transfer modes. Younger people, tertiary students, males, commuters and those using periodical and full fare tickets (like commuters) have bus higher transfer rates. Middle and older age groups, off peak travel, shopping trips and concession ticket holders have lower bus transfer rates. Because of high transfer rates for commuters, weekday peaks are the high points for transfer behaviour mainly due to rail based bus transfers. Analysis of bus route types with high and low bus transfer behaviour shows that transfers are higher for higher frequency routes, longer distance routes, those with simpler (straighter) route design, commuter based services and those which operate in networks which require transfers. Schedule coordination with rail was shown to increase bus transfer rates (but not by much) possibly due to traffic delays making coordination difficult to provide in practice.

Analysis demonstrated a modest though significant relationship between the volume of transfer trips and average service frequency of the transfer from and transfer to route pair (R^2= 0.25). Analysis of the best or highest frequency transfer route pair showed that high volume transfers tend to occur where one of the routes has a frequency of 10 minutes or better. This is an important finding because current bus network plans are for a 15 minute grid-based route network. These findings suggest that if major routes in the grid network have 10 minute headways or better then a significantly higher volume of transfers would be made.

Analysis of very high transfer rate sub-networks showed a concentration of transfers around the grid network between high frequency north-south trams and east-west buses in Moreland South to the north of Melbourne CBD. A comparative analysis of this network against two others in Melbourne found that this area has higher service frequency, high network density and high residential density. Armadale, a comparator area with better frequency and density statistics demonstrated lower transfer rates but in this case most routes went directly to the city negating the need for transfers to access this important trip attractor. The analysis concluded that the bus transfer behaviour demonstrated in the Moreland South grid network were highly consistent with the 'network effect' theory since service frequencies are high. However, this cannot act as conclusive proof of the network effect since high transfer rates can also be explained by the particular nature of travel patterns in this area (travel to and from Melbourne University).

Overall this analysis has acted to broaden our understanding of transfer behaviour however the question of the validity of the 'network effect' remains unanswered. To some degree this question, though of great interest, does not matter to practitioners since the planning principles implied by the network effect are robust and supported by this research. The evidence suggests that simple networks, such as grid networks, supported by high frequency services are clearly associated with high transfer rates and are to be encouraged as design principles for new networks. However, the conversion of existing networks such as that at Armadale to a grid is not advisable since much disutility would be caused by forcing transfers on passengers. In simple terms the ‘network effect” though intriguing remains an unsubstantiated theory which informs good practice but should be treated with caution when applied in the real world.

ACKNOWLEDGEMENTS

The authors would like to thank Metlink Victoria for undertaking the Bus O-D Surveys, and the Department of Transport for funding the surveys. We would also like to thank Karen Woo of the University of Toronto whose background research on Melbourne trams highlighted high transfer rates in inner Melbourne. We would also like to thank the papers reviewers for input to the paper. Any omission or errors are the responsibility of the authors.

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